

**NANOFERTILIZERS FOR SUSTAINABLE CROP
PRODUCTION UNDER CHANGING CLIMATE AND
IMPACT OF NITROGEN, PHOSPHOROUS, AND PO-
TASSIUM NANOFERTILIZERS ON GROWTH,
YIELD, AND YIELD COMPONENTS OF MAIZE +
MUNGBEAN AND WHEAT CROPPING SYSTEM.**

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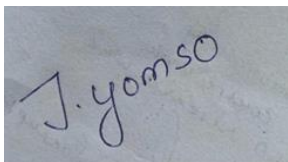


LOVELY PROFESSIONAL UNIVERSITY, PUNJAB

2024

DECLARATION

I hereby declared that the presented work in the thesis entitled “ **Nanofertilizers for sustainable crop production under changing climate and impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean and wheat cropping system**” in fulfillment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of Dr. Sandeep Menon, working as a Head and Associate Professor, in the Department of Agronomy, School of Agriculture of Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of another investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



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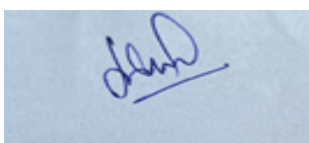
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CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled “Nanofertilizers for sustainable crop production under changing climate and impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean and wheat cropping system” submitted in fulfillment of the requirement for the award of the **degree of Doctor of Philosophy (Ph.D.)** in the Agronomy, School of Agriculture is a research work carried out by Jayanti Yomso, 11916903, is a bonafide record of her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.



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ABSTRACT

Field trials were conducted at the Research Farm of the Department of Agronomy under the School of Agriculture at Lovely Professional University in Phagwara, Punjab, during the *kharif* and *rabi* seasons of 2020–2022, in the semi-arid region of India. The study's goal was to find the best fertilizer combination and cropping system for maize, mungbean, and wheat production, as well as to see what effect the previous crop had on the subsequent crops. The experiment uses a split plot design with 12 treatments and 3 replications. The gross plot size was 25m². In maize + mungbean cropping, the main plot consisted of 3 treatments viz., M₁- maize as sole crop, M₂- Mungbean as sole crop, and M₃- Maize + mungbean intercropping while in subplot consisted of 4 treatments namely., S₁- control, S₂- 100% RDF, S₃- 100% Nano NPK fertilizers, S₄- 50% RDF + 50% Nano NPK fertilizers. The cropping systems were assigned to the main plots, while the fertilizer treatments were assigned to the subplot. When compared to other fertilizer levels during both *kharif* seasons, as well as when the data was mean, the utilization of 50% RDF and 50% Nano NPK fertilizers resulted in superior performance across all growth, phenological, and yield parameters. Intercropping gave better results in the case of maize while in mungbean, sole cropping gave the least results. A significant interaction between fertilizer levels and cropping systems was noted, and this had a significant impact on the yields of maize and mungbean during both seasons. Furthermore, this interaction was also evident in the mean data. Grain yield and every growth and yield components showed strong positive and significant (P=0.05) correlations throughout both seasons. This trend remained consistent even when the data was average. In comparison to other levels of fertilizer application, the NPK uptake in plants was higher in plots that received 50% RDF + 50% Nano NPK fertilizers. In both years and when the data was averaged, the combination of 50% RDF + 50% Nano NPK fertilizers had the greatest economics.

The cropping experiment in wheat included 12 treatments and 3 replications, and it followed a split-plot design. However, instead of using cropping systems, the residual effects of crops were designated to the main plot. Specifically, M₁ was used for the residual effect of maize on wheat, M₂ for the residual effect of mungbean on wheat, and M₃ for the residual effect of maize and mungbean intercropping on wheat. The subplot contained the same treatments as in the previous experiment, which included different levels of fertilizers: S₁ for control, S₂ for 100% RDF, S₃ for 100% Nano NPK fertilizers, and S₄ for 50% RDF and 50% Nano NPK fertilizers. Fertilization had a significant impact on all the growth components. Moreover, fertilization also had a noteworthy effect on phenological parameters like days to 90% maturity, as well as on yield components. The application of 50% RDF and 50% Nano NPK fertilizers showed superior performance in growth, phenological, and yield parameters compared to other fertilizer levels during both *rabi* seasons, as well as when data were average. Additionally, the residual effect of sole mungbean was found to be more effective than other treatments in the main plot. Therefore, the study concludes that the combination of 50% RDF + 50% Nano NPK fertilizers + residual effect of sole mungbean produced the highest yield during both seasons and when data was mean. There was a significant interaction between the residual effect of crops and different levels of fertilizers, observed in wheat yield during both seasons and when data was mean. Positive correlations were found between grain yield and all growth and yield parameters. The NPK uptake in plants was higher in plots that received 50% RDF + 50% Nano NPK fertilizers compared to other levels of fertilizers application. When compared to other treatments, the combination of 50% RDF + 50% Nano NPK fertilizers showed the highest economics. In conclusion, the combination of 50% RDF + 50% Nano NPK fertilizers + intercropping of maize produced the highest yield in both seasons, and it can be recommended for maize production. Similar to maize, the combination of 50% RDF and 50% NPK nanofertilizers with sole mungbean resulted in the highest yield in both 2020 and 2021 seasons, suggesting that this combination could be effective in enhancing mungbean production. Moreover, in both seasons and mean data, the highest yield in wheat was achieved by the combination of 50% RDF and 50% NPK nanofertilizers with the residual effect of sole mungbean.

DEDICATION

This research work is dedicated to my beloved parents, especially my Papa whose foresight and sacrifice laid a solid foundation in my life. Special dedication goes to my Ayi, relatives and friends for their moral support during the study.

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LISTS OF ABBREVIATIONS

Abbreviations	Descriptions	Abbreviations	Descriptions
+	Plus	ha	Hectare
%	Percent	ha ⁻¹	Per hectare
@	At the rate	Hrs.	Hours
*	Significant	hr.	Hour
⁰ C	Degree Celsius	H ₂ SO ₄	Sulphuric acid
⁰ N	Degree north	i.e.,	Which is to say in other words
⁰ E	Degree east	K	Potassium
a.i	Active ingredient	KMNO ₄	Potassium perman-ganate
Ag	Silver	K ₂ cr2O ₇	Potassium dichro-mate
B	Boron	K ₂ SO ₄	Potassium sulphate
B:C	Benefit cost ratio	kg	Kilogram
bn.	billion	Kg/ha	Kilogram per hectare
Calc ₂	Calcium chloride	L	litre
CD	Critical Difference	LA	Leaf area
CGR	Crop growth rate	LAI	Leaf area index
Ch	chelate	m	Meter
cm	Centimeter	m ⁻²	Meter square
Cm ²	Centimeter square	mg	milligram
CO ₂	Carbon dioxide	M ha	Million hectare
Conc.	Concentration	ml	Militre
Cu	Copper	Mt	Million ton
DAS	Days after sowing	Mn	Manganese
dsm ⁻¹	Deci siemens per meter	Mo	Molybdenum
DMA	Dry matter accumula-tion	MOP	Muriate of potash
EC	Electrical conductivity	MS	Morishage and Skooog
etc.	And so, on	N	Nitrogen
<i>et al</i>	And co-worker	Nacl ₂	Sodium chloride
Fig	Figure	NF	Nanofertilizers
FAS	Ferrous Ammonium Sulphate	NFe	Nano Iron
FAO	Food and agriculture organization	nm	nanometer
FFP	Farmer's fertilizing practice	NMs	Nanomaterials
Fe	Iron	No.	Number
g	Gram	NPs	Nanoparticles
g/L	Gram per litre	NS	Non-significant

LISTS OF ABBREVIATIONS

Abbreviations	Descriptions
nSiO ₂	Nano silicon oxide
nTiO ₂	Nano titanium oxide
NUE	Nutrient use efficiency
OC	Organic carbon
P	Phosphorous
pH	Potential Of hydrogen ion concentration
q	Quintal
q/ha	Quintal per hectare
RDF	Recommended dose of fertilizers
Rs	Rupees
Rs/ha	Rupees per hectare
RPM	Revolutions per minute
ROS	Reactive oxygen species
S	Significant
SC	Single cross
SEm	Standard error of Mean
Se	Selenium
SDW	Shoot dry weight
SNF	Symbiotic nitrogen fixation
S. No	Serial number
SNPs	Silver nanoparticles
SOC	Soil organic carbon
SPD	Split plot design
SSP	Single super phosphate
Ti	Titanium
t	tonnes
WHO	World health organization
Zn	Zinc
Zno	Zinc oxide
Viz.	Namely

INTRODUCTION

Maize (*Zea mays* L.), a vital cereal crop originating from Central America, holds a prominent position globally, contributing significantly to food security, particularly in developing countries. Often referred to as the "Queen of Cereals," maize dominates the global trade in coarse grains (Murdia *et al.* 2016; Kumar *et al.* 2013). In India, it stands as the third most important cereal crop after rice and wheat, thriving in diverse agroclimatic conditions during the *kharif* season, covering 82 % of cultivated land and contributing around 10% to the nation's total food grain supply. Apart from being a crucial dietary element and livestock feed, maize serves as a fundamental raw material for various industrial products across 166 countries (Wang *et al.* 2018; Kumar *et al.* 2012a; Chaudhary *et al.* 2012).

Maize is cultivated across more than 170 countries, covering 188 million hectares globally, with China leading in cultivation area and the USA closely following. India secures the 4th position globally with a cultivation area of 9.89 million hectares. Despite year-round production, low freight charges, and strategic advantages, domestic demand limits maize exports. In the 2022-23 period, maize cultivation covered 1.21 lakh hectares, resulting in a production of 5.08 lakh tonnes, with a productivity rate of 4195 kg/ha. India ranks 6th globally in maize production, yielding 31.65 million metric tons annually, slightly exceeding half of the world average productivity (5.6 tons per hectare) (Anonymous, 2023a; FAO, 2023; ICAR-Annual-Report-2022-23).

Top maize-producing states, such as Karnataka, Madhya Pradesh, and Maharashtra, collectively contribute over 40 % to India's maize production, with Karnataka leading at around 15 %. Industry presents opportunities across subsectors, supporting farmers with food and feed security, improved nutrition, and increased profitability. Maize cultivation, known for its profitability and resource efficiency, has a 90% reduction in water consumption and 70% reduction in energy usage compared to paddy cultivation (Kaur *et al.* 2023; Kumar *et al.* 2022).

Maize's C4 crop nature, allowing the production of more dry matter and weed-suppressing properties, makes it highly suitable for various environments. However, continuous cultivation has led to soil fertility decline. Sustainable maize production involves crop diversification and cultivation intensification. Intercropping systems, such as maize with legumes, have proven effective in increasing land productivity, promoting stability, and reducing nutrient depletion (Oyeogbe *et al.* 2021; Raza *et al.* 2022; Zhang *et al.* 2022).

Mungbean (*Vigna radiata* L.), a diploid leguminous crop with a chromosome number of $2x = 2n = 22$, is a crucial pulse crop in India due to its high economic and commercial value. It belongs to the Leguminosae family and is known for its significant protein, mineral, nutrient, and essential amino acid content. Mungbean, also known as green gram or moong, is a key pulse crop in India that is rich in protein, fiber, and iron. Although it is primarily a rainy season crop that is grown during the *kharif* season, it can also be grown in the spring and summer as it requires minimal water and can withstand harsh weather conditions. Mungbean or green gram should only be grown on loamy to sandy-loam soils with good drainage; saline and waterlogged soils are not suited for its growth. This pulse crop contains a good amount of carbohydrates (51%), moisture (10%), minerals (4%) like calcium, zinc, and folate (124, 3, and 549 mg per 100 g, respectively), and vitamins such as vitamin A, vitamin C, riboflavin, and thiamine. The use of early-maturing, high-yielding cultivars has shown significant benefits for crop rotation, soil fertility through nitrogen fixation, and fundamental soil physical characteristics. Pulses are often called "mini fertilizer" elements because they can fix nitrogen biologically from the atmosphere. Their deep taproot structure prevents soil erosion and makes them drought tolerant, earning them the nickname "nature's plow." They possess a distinctive ability to enhance soil quality, sequester carbon, and endure extremely dry or semi-arid conditions (Anonymous, 2013; Singh, 2013; Mehandi *et al.* 2019; Rehman *et al.* 2019).

The mean yield of mungbean is 721 kg/ha, cultivated across approximately 7.3 million hectares globally. A noteworthy 30% of the global production of 5.3 million tonnes is distributed between India and Myanmar. In addition to India and Myanmar, China, Indonesia, Thailand, Kenya, and Tanzania emerge as notable contributors to mungbean production. However, India is the largest

producer of green gram globally, as it is cultivated in nearly every state. The most prominent states in India for green gram farming are Orissa, Maharashtra, A.P, M.P, Gujarat, Rajasthan, and Bihar. It is grown on about 40.38 lakh hectares with a total production of 31.5 lakh tonnes with a productivity of 783 kg/ha and contributes 11 % to the total pulse production in the year 2021-22. In the agricultural season of 2023 in India, green gram cultivation encompassed approximately 30.02 lakh hectares (74.18 lakh acres). States contributing to green gram cultivation included Rajasthan, covering 22.07 lakh hectares (54.54 lakh acres), Karnataka with 1.73 lakh hectares (4.27 lakh acres), Maharashtra with 1.65 lakh hectares (4.08 lakh acres), Odisha with 0.68 lakh hectares (1.68 lakh acres), Madhya Pradesh with 1.66 lakh hectares (4.10 lakh acres), and Telangana with 0.20 lakh hectares (0.49 lakh acres). According to 1st advance estimates during 2022-23, green gram was grown in 0.08 lakh hectares with a production of 0.04 lakh tonnes and productivity was 493 kg/ha. As per the Government's 3rd advance estimates, green gram production for the year 2022-23 was reported to be 3.74 million tonnes. Farmers in marginal areas often cultivate mungbean without using fertilizers if legume crops do not require nutrients. This belief may contribute significantly to the country's low productivity. Enhancing mungbean production can be a crucial achievement in improving farmers' outcomes and enhancing soil fertility, ultimately boosting the production of rice and wheat crops (Anonymous (2023c); Keelery, 2023; Rani, 2023; Bam *et al.* 2022; Anonymous (2022b); Nair and Schreinemachers, 2020; Pataczek *et al.* 2018).

Wheat (*Triticum aestivum* L.) is a vital food source for the northern part of India, serving as the second most significant crop after paddy and a staple diet for millions, especially in the northern and northwest regions. Belonging to the Poaceae family, wheat is an annual plant rich in proteins, vitamins, and carbohydrates, providing a well-balanced diet. Its importance in India's agricultural sector is substantial, ensuring food security and contributing significantly to the economy. India, the second-largest global wheat producer after China, is projected to achieve a record production of 112.74 million tonnes in the 2022-23 period, surpassing the previous year's 106.84 million tonnes. Wheat cultivation in India primarily occurs during the *rabi* season, predominantly in the northern and north-western states. Characterized as predominantly soft to medium hard, Indian wheat

features medium protein content and is classified as white bread wheat. The crop thrives in cool and moist climates, displaying adaptability to various soil types. The significance of wheat production in India extends beyond agriculture to impact food security, economic growth, and rural development. States like Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Rajasthan, and Bihar play crucial roles in meeting the growing demand for this essential crop (EL Sabagh *et al.* 2021; Giraldo *et al.* 2019).

Uttar Pradesh maintains its leading position in wheat production, cultivating 9853 thousand hectares and yielding 33950 thousand tonnes in 2021-22. Madhya Pradesh has witnessed notable expansion, emerging as a prominent wheat-producing state with a production of 22419 thousand tonnes across 6551 thousand hectares. Punjab, renowned as the "Granary of India," consistently produces high quantities, with a cultivation area of 3521 thousand hectares and a production of 14822 thousand tonnes. The Agriculture Ministry projects India's wheat production to reach an unprecedented 112.74 million tonnes in the 2022-23 crop year, part of a record overall foodgrain output of 330.53 million tonnes. Despite unseasonal rains and heat waves affecting previous crop years, the country has consistently exceeded production targets. In the 2023/2024 season, India's wheat cultivation area increased to approximately 31.87 million hectares from the previous season's 30 million hectares (FAO, 2023; Udhayan *et al.* 2023).

On a global scale, the USDA estimates the World Wheat Production for 2023/2024 at 783.43 million metric tons (MMT), a slight decrease from the previous month's projection. The global wheat production during the 2022/2023 marketing year exceeded 781 million metric tons, signaling an increase from the preceding year. The latest forecast predicts a record global wheat production of 800.2 million metric tons, with the European Union leading at 140.5 MMT. China and India, the second and third-largest producers, cater primarily to domestic consumption. China's production is forecasted at 140.0 MMT, and India witnesses a 3.5 MMT increase to 113.5 MMT. Russia and Southern Ukraine experience improved yields, with Russia's forecast rising by 3.5 MMT to 85.0 MMT, though still below last year's record (Shahbandeh, 2023; Sowell, 2023).

In the context of sustainable agricultural practices, intercropping emerges as a promising strategy to maximize productivity and resource utilization. Practices like cereal + legume intercropping, especially maize-bean systems, offer advantages over monoculture systems. This approach aligns with the increasing demand for food in India, where agricultural productivity has faced challenges due to factors like soil nutrient depletion. The adoption of hybrid cultivars and intensive cropping, while boosting production, has led to deficiencies in both macro and micronutrients. Nanofertilizers, a contemporary solution, address these challenges, offering precise nutrient delivery with minimal losses, affordability, and lower environmental impact. The efficient penetration of plant roots and leaves by nanofertilizers results in enhanced nutrient uptake and utilization efficiency, contributing to improved crop quality and yield (Dugassa, 2023; Maitra *et al.* 2023; Hussain *et al.* 2013; Elemike *et al.* 2019; Ain *et al.* 2023).

Nanofertilizers, modified using nanotechnology through chemical, physical, or biological methods, aim to enhance crop productivity. They utilize nanoparticles or incorporate nanotechnology to improve nutrient efficiency. Their physical diameter ranges from 1 to 100 nm. Nanotechnology in agriculture, particularly nanofertilizers, offers precise nutrient delivery with minimal losses, contributing to ecological sustainability (Singh *et al.* 2019; Raliya *et al.* 2017). The use of chemical fertilizers, a staple in modern crop production, poses environmental risks. Nanofertilizers provide a potential solution by offering concentrated nutrient sources with higher absorption rates, utilization efficiency, and minimal losses. They also exhibit antimicrobial properties against certain microorganisms. The adoption of nanofertilizers can lead to higher productivity and improved crop quality (Zulfiqar *et al.* 2019; Raliya *et al.* 2018).

The challenges of food security due to population growth and climate change necessitate sustainable solutions. Nanofertilizers, with their potential to enhance crop production in adverse conditions, offer a promising avenue. Nanotechnology is emerging as a key player in promoting plant growth, development, and productivity. However, challenges in nanofertilizers production, availability, legislation, and risk management remain obstacles to widespread adoption. A shift toward sustainable strategies is essential for more nutritious and enhanced

crop production while minimizing resources and fertilizer use. Nanotechnology's application in agriculture, especially through nanofertilizers, holds promise for addressing global challenges and promoting sustainable agricultural practices (Iqbal, 2019; Janmohammadi *et al.* 2016; Manikandan and Subramanian, 2016).

The selection of wheat, maize, and mung bean crops for the experimental study arises from the existing research gap concerning the impact of nanofertilizers on these crops. The utilization of nanofertilizers in Indian agriculture is still in its early stages, and there is a limited understanding of their effects on these specific crops. The inclusion of maize and mung bean crops in the study serves a dual purpose: firstly, it introduces a break in the conventional wheat-paddy cropping cycle, promoting crop diversity in Punjab; secondly, it addresses the pressing issue of the continuous decline in the water table in the state, aiming to replenish the natural resource base depleted by the traditional cropping pattern.

Nanofertilizers play a pivotal role in this experimental study, strategically employed to mitigate the potential adverse consequences associated with the extensive use of chemical fertilizers. The study focuses on evaluating the impact of environmentally friendly granular and foliar Nano-NPK on the maize + mung bean and wheat cropping systems in Punjab. The overarching goal is to offer farmers a sustainable and economically viable option that not only enhances crop quality and yield but also aligns with environmentally conscious agricultural practices.

It is crucial to note that despite numerous studies conducted to improve the yield of maize, mung bean, and wheat, the utilization of NPK nanofertilizers has been minimally reported in the literature in India, especially in the Punjab region. This study seeks to address this knowledge gap and provide valuable insights into the effectiveness of nanofertilizers in enhancing the productivity of these key crops within the specific agro-climatic conditions of Punjab. The research aims to present practical solutions for farmers, promoting a shift towards more sustainable and technologically advanced agricultural practices in the region.

As India endeavors to enhance its agricultural practices, the integration of nanofertilizers into traditional crops such as wheat becomes increasingly crucial. The application of nanofertilizers in the context of wheat, coupled with intercropping practices, represents an opportunity to improve crop quality, increase yield,

and address challenges in nutrient management. The experimental study, encompassing wheat, maize, and mung bean crops, strives to contribute to sustainable and economically viable options for farmers in Punjab. Emphasizing the need for a diversified cropping pattern to maintain soil health and replenish natural resources, this research aligns with the evolving landscape of Indian agriculture. While wheat remains a cornerstone in India's agricultural framework, innovative approaches like nanofertilizers and intercropping can pave the way for a resilient and productive future.

1.1 Research Gap

After analyzing the literature, several research gaps were identified, which justify the need for the proposed work:

- 1) Nanotechnology and nanoparticles have been the primary focus of research in Punjab and India, with little attention being given to nanofertilizers.
- 2) Limited research has been conducted in Punjab on the use of nanofertilizers for mungbean crops or for intercropping mungbean with maize.
- 3) There is a lack of research on foliar application of nanofertilizers for fertilization in the intercropping of maize and mung bean in Punjab.
- 4) As nanoscience and nanotechnology research in agriculture and horticulture in India is still in its growing phase, there is limited research being conducted on agronomic crops in Punjab.
- 5) There is limited research on the effects of NPK nanofertilizers on wheat, maize, and mungbean cropping system in India, especially in the state of Punjab.
- 6) There is a lack of extensive research in India, particularly in the Punjab region, regarding the combined use of NPK nanofertilizers and conventional NPK fertilizers.

1.2. Hypothesis

The effects of NPK nanofertilizers in combination as compared to conventional fertilizers will be more economical.

1.3. Objectives of the proposed work

The objectives of the proposed work are:

- 1) To study the advantages of nanofertilizers over conventional fertilizers,
- 2) to study the impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean intercropping,
- 3) to study the impact of nitrogen, phosphorus, and potassium nanofertilizers on

the growth, yield, and yield components of wheat and
4)to study the effect of nitrogen, phosphorus, and potassium nanofertilizers on the
economics of maize + mung bean and wheat cropping system.

REVIEW OF LITERATURE

Fertilizers are essential in enhancing food production and improving its quality, especially with the utilization of high-yielding cultivars that respond well to fertilizers. Inorganic inputs are needed in substantial amounts for major crops like wheat and maize. Yet, one of the key causes of soil and environmental degradation is the overuse of fertilizers and pesticides. Disproportionate fertilizer and pesticide use is one of the causes of environmental and soil degradation. Nanofertilizers are a new and advanced technology that provides mineral nutrients to crops. Nanofertilizers, which have a single unit size of 1 to 100 nm in at least one dimension, are known for their ability to provide mineral nutrients to crops in a technologically advanced manner. These fertilizers have a more consistent pattern of nitrogen release that matches the needs of plants while also reducing leaching and improving fertilizer efficiency, as compared to traditional fertilizers (Liu and Lal, 2015). Thus, nanofertilizers can be classified into two categories: those that provide one or more nutrients to crops, leading to improved growth and yield, and those that act as enhancers to conventional fertilizers, without directly providing nutrients to crops. This chapter offers a summary of the pertinent study topic **"Nanofertilizers for sustainable crop production under changing climate and impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean and wheat cropping system."** The discussion is divided into the following sections:

2.1. NANOTECHNOLOGY AND NANO FERTILIZERS IN AGRICULTURE

2.2. IMPACT OF NANO FERTILIZERS

2.2.1. GROWTH COMPONENTS

2.2.2. YIELD COMPONENTS AND YIELD

2.2.3. UPTAKE OF NUTRIENTS

2.2.4. QUALITY PARAMETERS

2.2.5. RELATIVE ECONOMIES

2.1. NANOTECHNOLOGY AND NANOFERTILIZERS IN AGRICULTURE

Modern technology must be used to improve resource efficiency to maximize agricultural productivity while reducing soil damage, especially as arable land and water supplies grow increasingly scarce. Agriculture, environmental engineering, safety and security, water resources, and energy conversion are just a few of the domains which nanotechnology has the potential to transform. In response to environmental cues and biological demands, nano-structured formulations can release their active ingredients with greater precision. According to research, using nanofertilizers can improve fertilizer efficiency, reduce soil toxicity, reduce the negative effects of overdosing, and reduce the frequency of application. Furthermore, nanotechnology holds great promise for boosting sustainable agriculture, particularly in underdeveloped countries.

A study on the potential for nanotechnology to support sustainable agriculture was done by Carmona *et al.* in 2021. They emphasized that climate change, resource depletion, and biodiversity loss are threatening the agricultural industry, and a new agricultural revolution is necessary to increase crop production while maintaining food quality and safety in a sustainable way. The authors propose that nanotechnology can assist in the long-term viability of agriculture, as it is a promising field for utilization in agriculture and has the capacity to increase plant establishment and promote the use of agrochemicals. Moreover, the use of nano-based technology for seed treatment can shift conventional agriculture based on the use of agrochemicals towards a more sustainable form of agriculture. Morab *et al.* (2021) performed research to evaluate the effectiveness of foliar nano fertilization on cereals and pulses compared to traditional methods of nutrient application. They noted that research on nanoscience and nanotechnology in agriculture and horticulture is still in its early stages but is rapidly progressing. Due to the high cost of conventional fertilizers, there is a growing interest in environmentally friendly or "smart" fertilizers, particularly those with high nutrient utilization efficiency. The authors concluded that foliar feeding has become widely accepted in crop production, especially in horticultural crops, and although less common in agronomic crops, the benefits of foliar spraying have been well established. There is a growing effort to obtain consistent responses in agronomic crops as well. According to Thavaseelan and Priyadarshana (2021) study on the use of

nanofertilizers for sustainable agriculture, global agricultural systems will face greater challenges in the years ahead to ensure food security and environmental sustainability for a growing population. As a result, advanced nano-engineering is being utilized to enhance the long-term productivity of crops. Abd El-Azeim *et al.* (2020) indicate that to achieve sustainable agriculture with the greatest output and the fewest threats to the environment, the use of nanofertilizers should be seriously considered. Also, they demonstrated that employing lower rates of nanofertilizers as a foliar application could be a more environmentally friendly, organic, and cost-effective substitute for the suggested rates of chemical fertilizers, with a notable boost in potato yield. Barrios *et al.* (2020) stated that the potential of nanofertilizers as an alternative to traditional fertilizers requires further investigation regarding their environmental impact and various types of materials. They presented a review of the results and prospects of using nanoparticles (NPs) and nanomaterials (NMs) in fruit crop fertilization. The nanofertilizers used in fruit crops can be categorized as direct soil application, irrigation, or foliar application. The use of nanofertilizers has the potential to enhance the availability of nutrients, particularly in poor soils, reduce excessive use of nutrients, especially metals, and mitigate the susceptibility to environmental stress by acting as a bio stimulant. Predoi *et al.* (2020) discussed the potential risks associated with the use of nanoparticles as micronutrients in agriculture. They emphasized the importance of finding safe and effective methods for delivering nanoparticles to soil, water, plants, and ultimately, the human body. To prevent further environmental contamination, they suggest closely monitoring the complex process of utilizing nanoparticles in agriculture and ensuring that appropriate safety measures are in place. Naseem *et al.* (2020) reported that a regulated release of nutrients into the soil can stop the environmental issues brought on by traditional fertilizers. The authors utilized a coprecipitation method to produce a zinc aluminosilicate mesoporous nanocomposite in their research. The results indicate a higher nitrogen recovery efficiency, implying less nitrogen wastage, which is beneficial for the ecosystem by decreasing the amount of nitrogen that leaches into groundwater. Ramirez-Rodriguez *et al.* (2020) concluded that calcium phosphate nanoparticles have been successfully applied in biomedicine due to their high biodegradability and biocompatibility. However, there has been relatively little progress in their application in agriculture, such as for the controlled delivery of active substances

to wheat. The researchers proposed a simple and environmentally friendly synthetic method for doping calcium phosphate nanoparticles with potassium and nitrogen (in the form of nitrate and urea), with adjustments made to the manufacturing conditions. Cota-Ruiz *et al.* (2020), stated that the continual use of copper (Cu) nano-composites in agrosystems has the possibility to enhance the physiological performance and agronomical traits of products. The use of bulk or nano Cu increased the total number of microorganisms involved in organic uptake. Their data indicate that nano copper improved the physiology of *Medicago sativa* and could be a suitable nanofertilizer for crops. So according to Abdel-Aziz *et al.* (2019), the development and usage of novel fertilizers based on nanotechnology are potentially beneficial choices for improving agricultural sustainability. Furthermore, nanofertilizers were found to remain available in the soil and were detected in soybean pods. Adisa *et al.* (2019) conducted a survey to evaluate the existing literature on engineered nanomaterials used as pesticides and fertilizers. The survey identified critical knowledge gaps that must be addressed to ensure sustainable use of nanotechnology in agriculture to achieve global food security. The study found a growing interest in using nanomaterials in agriculture as nanofertilizers, nanopesticides, or nano-enabled sensors to increase crop productivity. Engineered nanoparticles can improve agricultural yield by influencing nutrient availability in the soil and plant uptake. Moreover, they can suppress crop infections by directly acting on microorganisms through a variety of mechanisms, including the generation of Reactive oxygen species. Aziz and colleagues (2019) stated that the spraying of nanofertilizers foliarly enhanced the total carbohydrate content of wheat grains produced on sandy loam, and sandy soils significantly. Moreover, the treatment of wheat plants with nanofertilizers substantially increased the elemental content, particularly potassium and phosphorus, in the wheat grains. The magnitude of the increase was most pronounced in sandy loam soil, followed by sandy soil. Further research is needed to understand the mechanisms by which nanofertilizers enhance the quality of wheat grains. According to Chhipa, (2019) nanotechnology is an emerging technology of the current decade that has shown promising results in reducing excessive agri-inputs and maintaining environmental balance. Controlled and targeted delivery properties of nanofertilizers and nanopesticides have demonstrated great efficacy when compared to standard fertilizers and insecticides. Many nanofertilizers and

nanopesticides, including silver, zinc, iron, titanium, phosphorus, molybdenum, and polymer nanoparticles, have shown significant promise as plant growth and pest control agents. Nanomaterials, nanoformulations, nanocomposites, nanoemulsion, and nanoencapsulation-based agri-tools have all been utilized to provide nutrients to plants and toxins to insects in a regulated manner. Nanosensors have also demonstrated promising applications in smart agribusiness systems and food security. According to Cieschi *et al.* in 2019, the development and utilization of new fertilizers using nanotechnology have the potential to be successful options for enhancing iron humates in sustainable agriculture. Additionally, the ^{57}Fe from the humic nanofertilizers remained available in the soil and was detected in soybean units. The Fe-NFs provide a natural, inexpensive, and organic alternative to traditional iron preparation in calcareous soils. Hussein *et al.* (2019) conducted physical and chemical examinations to characterize an extract of nanofertilizer. Chelated potassium, chelated iron, tryptophan, urea, amino acids, protein, and citrus acid were all present in the nano-fertilizer. The banana peel nanofertilizer was used in the production of two crops: tomato and fenugreek. The findings confirmed that the germination rate of both crops rose with increasing doses of banana peel extract. For the tomato crops, the germination rate increased from 14% (control without nano-fertilizer) to 97% after 7 days of farming. Similarly, the same trend was observed for the fenugreek crop, with the germination rate improving from 25% (control without nano-fertilizer) to 93.14%. According to Mahanta *et al.* (2019), the usage of nanoparticles enables the efficient delivery of specific nutrients to all sections of plants. Plant nutrients in nanoparticles increase the availability of nutrient components, which are then absorbed by crops. According to Merghany and colleagues (2019), the use of fertilizers has resulted in several environmental problems. Therefore, they investigated how nanofertilizers affected the cucumber crop in the winters of 2017–2018 and 2018–2019 and observed that because nano fertilizers significantly enhanced cucumber growth and yield, they can be utilized as a substitute for regular fertilizers. According to Pirzadah *et al.* (2019) findings, nanobiotechnology is being utilized on a global scale to improve crop production. The implementation of nanotechnology is seen as a promising solution to increase crop yields by using fertilizers in a more efficient manner. While the Green Revolution had a significant impact on global crop productivity, the widespread use of synthetic fertilizers, herbicides,

able crop losses over time. The use of nanoparticles for delivering agrochemicals is a valuable tool for precision farming. Both conventional and nonconventional fertilizers can be encapsulated in nanoparticles, leading to their controlled and precise release for sustainable agriculture. Shang *et al.* (2019) emphasized the application of nanotechnology in agriculture to enhance crop production and pesticides, and insecticides has caused a reduction in biodiversity and the development of resistance by microorganisms, resulting in soil degradation and various quality enrichment by optimizing farming systems. The utilization of engineered nanomaterials in sustainable agriculture has significantly transformed the global agricultural landscape through innovation, rapid growth, and scalability, addressing the increasing demand for food worldwide. In the realm of sustainable agriculture, safeguarding the environment from pollution is a paramount objective, and nanomaterials offer a promising avenue for improved management and conservation of inputs in plant production. The potential of nanomaterials holds promise for ushering in a new green revolution, thereby minimizing farming risks. In 2019, a study conducted by Fahmy, and colleagues unveiled that incorporating nanotechnologies in agribusiness could serve as a promising strategy to enhance plant resilience against biotic or abiotic cues referred to as induced resistance. The research entailed evaluating the efficacy of three types of mineral and nano fertilizers as a soil amendment in managing root knot nematodes. The findings demonstrated that the application of nano-fertilizers was superior to their mineral counterparts, with the nano-fertilizer Zn oxide exhibiting the most significant impact among all treatments when administered to tomato plants. According to Zulfiqar *et al.* (2019), nanofertilizers have the potential to enhance nutrient use efficiency in crop management. When applied alone or in combination, these fertilizers are more likely to be adsorbed by nano-sized particles, resulting in a slower release of nutrients than standard manures. Moreover, nanofertilizers can be used to improve biotic stress resistance and to provide extra benefits when combined with microorganisms. Notwithstanding the immense benefits of nanofertilizers in encouraging sustainable agriculture, their limits must be carefully assessed before their commercial introduction. Although nanofertilizers offer great potential for enhancing plant nutrition and stress resistance to achieve higher yields in the face of climate change, not all nanomaterials are equally safe for all applications. The risks associated with nanofertilizers must be thoroughly

examined before their use, and further advances in biotechnology are required for the proper and safe use of nanomaterials in agriculture. According to Abdel-Aziz *and* colleagues (2018), the use of NPK nanofertilizers enhance the expansion of leaves because the nutrients were more readily available, and the formulation of the nano NPK made it easier for air to enter leaf stomata, improving nutrient absorption in wheat. According to Abobatt (2018), nanotechnology is quickly becoming an essential tool for modern agriculture and is expected to overtake other economic forces soon. With the usage of different chemical agents and innovative delivery systems, nanotechnology offers the potential to enhance crop productivity and reduce the dependence on bulk agrochemicals. Nanotechnology improves nutrient use efficiency and reduces the cost of environmental protection, with slow-release fertilizers being an excellent alternative to soluble fertilizers. According to Achari and Kowshik (2018), nanotechnology has the potential to offer workable solutions by substituting conventional bulk fertilizers with their superior-property nanoparticulate equivalents, thereby resolving the issues with mineral bioavailability and uptake, boosting crop yield, lowering fertilizer waste, and safeguarding the environment. The scientists showed that key minerals and trace elements' nanoparticle sizes, structures, concentrations, and modes of administration have an impact on plant growth, physiology, and development. They assert that additional study is required to create sustained-release nanofertilizers that will increase food output and save the environment. El-Ghamry *et al.* (2018) have reported that the utilization of bio-and nano-fertilizers is an essential aspect of current agriculture and agri-food industry, and it is anticipated that it will one day dominate the global economy. Additionally, nano-fertilizers can significantly increase the efficiency of water and land resources and reduce environmental pollution. Therefore, environmentally friendly biotechnological approaches offer alternatives to chemical fertilizers. Biosynthesis of inorganic nanoparticles by microbes, algae, yeast, fungi, actinomycetes, and plants has opened a new field of study for environmentally benign fertilizers. Currently, one of the key purposes of nanotechnology in agriculture and soil sciences is the use of nanofertilizers in plant nutrition. As a result, when compared to traditional farming, the use of biosynthesized nanoparticles in the farming sector can contribute to sustainable growth by using fewer inputs, generating less waste, minimizing nutrient losses, and providing nutrients at a proper rate for plant demand. Guo *et al.*, (2018) stated

that the effectiveness of modern agriculture heavily relies on the use of fertilizers. However, conventional fertilizers are limited by their low nutrient use efficiency (NUE) and high loss in water bodies. To address this issue, one promising approach is the development of nano-enabled fertilizers that can deliver nutrients to crops in a controlled manner. The authors identified six types of nanostructured materials that can act as nutrient carriers, namely nano clays, hydroxyapatite nanoparticles, mesoporous silica, carbon-based nanomaterials, polymeric nanoparticles, and other nanomaterials. They also discussed future directions for the development of standardized and comprehensive evaluation frameworks, the design of multifunctional nanomaterials, and the advancement of improved responsive nanocarriers. He *et al.* (2018) asserted that nanomaterial engineering is a pioneering field of research that supports the development of advanced agricultural practices. It provides a larger specific surface area that is crucial for making sure agricultural systems are long-term sustainable, particularly in high-tech farming. Kah and colleagues (2018) conducted research to determine the differences between nano agrochemicals and traditional products. Their analysis, based on 78 published papers, revealed that the median increase in effectiveness of nano agrochemicals compared to traditional products was approximately 20-30%. Although the fate of agrochemicals can be altered by nanoformulations, changes may not necessarily result in a reduction in environmental impact. Further research will therefore be necessary to make a sound assessment of the benefits and new risks that nano agrochemicals may pose in comparison to existing products. Mijweil and Abboud (2018) noted that nanofertilizers are becoming a popular approach to increase crop production. Nanofertilizers possess the necessary characteristics required for use in agriculture, such as high solubility and efficacy, and can be used in small quantities. This leads to an increase in fertilizer efficiency and reduces costs compared to traditional fertilizers. Raliya *et al.* (2018) noted that the increasing demand for food due to the growing global population has led to the widespread use of fertilizers. However, due to resource limitations and low efficiency in fertilizer use, the cost to farmers has been increasing significantly. Nanotechnology can transform fertilizer production by creating fertilizers with the desired chemical composition, improving nutrient efficiency, and lowering environmental impact while increasing plant yield. Additionally, the controlled and targeted release of active ingredients at the nanoscale can enable sustainable

and precision agriculture. According to El-Ramady *et al.* (2018), nanofertilizers have the potential to improve nutrient usage efficiencies, decrease nutrient loss in agroecosystems, and increase farm profitability and they also emphasized the urgency of sustainable agriculture and the need for the right agri-technical interventions, such as nano-technology. According to Leon-Silva *et al.* (2018), nanofertilizers offer a wide range of promising options to increase the quantity and quality of crops and seeds for consumption, lower production costs, and mitigate negative environmental effects, all of which are essential for the development of a sustainable food supply. Khordadi *et al.* (2018) assessed the impacts of chitosan and magnesium-based nanofertilizers on photosynthetic pigments, protein, proline, and soluble sugar content of sesame under water stress conditions. The study was designed as a split-factorial analysis with three replications, and the results revealed that the absence of nanofertilizers resulted in a drop in chlorophyll content as well as physiological damage. Yata *et al.* (2018) studied the increasing use of nanotechnology in agriculture and food systems to enhance crop production and food security and stated that United States has the highest number of nanotechnology firms at 75.5%, followed by Germany and France with 8.10% and 4.74%, respectively. During 2011-2015, the United States observed approximately 45% growth in nano-food patents, while China experienced a 60.7% increase in nano-agriculture patents during 2012-2015. Dimkpa and Bindraban (2017) found several science-based concerns and evidence needed for the advancement of nanofertilizers in the fertilizer industry. These include potential toxicity associated with nanoscale materials, insufficient research on key yield supplements, lack of field-based studies on nanofertilizers, determination of appropriate nanomaterials to use as fertilizers, effective application methods at the field scale, and economic considerations. They suggest that the development and validation of non-disruptive nanofertilizers for existing mass fertilizer systems will encourage the industry's involvement in nanofertilizers. Despite low nutrient uptake efficiency and substantial losses, the authors conclude that mineral fertilizers are necessary for food production. Yet, nanotechnology can improve crop efficiency and reduce nutrient losses, sparking interest in nanoscale and nano-enabled bulk fertilizers, also known as nanofertilizers. Nonetheless, large-scale industrial production of nanofertilizers requires further research and development. According to their research nanofertilizers are stated as a novel product. Nanotechnology, on the other

hand, has the potential to enhance crop production while also reducing nutrient losses, leading to increased interest in nanoscale and nano-enabled bulk fertilizers. However, the large-scale industrial production of nanofertilizers has yet to be achieved. The study highlights the need for soil- or field-based investigations with nanofertilizers and discusses outstanding concerns and science-based evidence for promoting the fertilizer industry's production of nanofertilizers. According to Duhan *et al.* (2017), nanotechnology has great potential in precision agriculture. According to Perez-de-Luque's (2017) findings, chemicals that have nano coatings and a size exclusion limit greater than 10 nm can improve their ability to penetrate through stomata of plants. Pestovsky and Antonio (2017) examined the possible uses of nanoparticles in agricultural science, such as the usage of nanofertilizers or plant growth stimulants, nano-pesticides, traditional pesticide carriers, and antibacterial agents. The authors suggest that widespread use of nanoparticles can lead to precision agriculture, a significant improvement in agricultural productivity, and reduced costs. According to Prasad *et al.* (2017), nanotechnology acts as a crucial part in the agricultural industry due to its small size. The use of nanotechnology has the possibility of enhancing the safety and quality of food, lower farm inputs costs, enhance soil nutrient absorption at the nanoscale, among other things. The use of nanotechnology in agriculture, including applications like nanofertilizers and nanopesticides to monitor goods and nutrient levels to increase productivity without harming soils, water, and protection against various insect pests and microbial diseases has attracted a lot of interest. Nanotechnology could be used as sensors to keep an eye on the health of crops and the soil quality in agricultural settings. According to Sanivada *et al.* (2017), new fertilizers made with nanotechnology may offer a way to increase agricultural output around the world. They emphasize the importance of developing a reliable and environmentally approachable system for a combination of nanoparticles in the field of agriculture. The authors also review the influence of engineered nanomaterials on soils and propose hazard estimation approaches to address the situation. However, according to Singh (2017), the usage of nano fertilizers is critical in agriculture since they can improve crop growth, yield, and quality while increasing nutrient efficiency and decreasing fertilizers loss and production costs. Precision agriculture can greatly benefit from the effectiveness of nanofertilizers for precise nutrient management, providing nutrients throughout the advance

periods of crop, and adjusting to the nutrient requirements of each growth stage. However, excessive use of nanofertilizers can hinder crop growth due to nutrient toxicity. In addition, nanofertilizers can help protect crops from biotic and abiotic stresses. Belal and Ramady (2016) state that nanotechnology has already made its way into the agricultural and food industries using nanomaterials such as nanofertilizers and nano pesticides. However, these nanoparticles may have adverse environmental impacts in certain conditions. The transportation, mobility, sorption, and bioavailability of nanoparticles are influenced by soil factors such as surface properties, chemical composition, pH, cation exchange capacity, and organic matter. Therefore, the authors review the fate of nanoparticles in agroecosystems. Cheng *et al.* (2016) reported various applications of nanotechnology in soil management, including nanofertilizers, soil covers, water retention aids, and nutrient sensors. Nanotechnology techniques have also been used in plants to deliver DNA to plant cells, enhance nutrient absorption, detect plant pathogens, regulate plant hormones, and other applications. In animal farming, nanocapsules have been developed for vaccine delivery and nutrient delivery. Additionally, numerous post-harvest applications have been reported, including the production of nanocellulose from agricultural waste, nanocomposites, silk, biochar, and nano silver, among others. Most of the reported work in agricultural nanotechnology is still in the developmental stage and not yet commercially available. As per Chen *et al.* (2016), the use of nanosensors in precision agriculture has resulted in a considerable improvement in monitoring and measuring numerous elements such as crop growth, soil conditions, pesticide usage and penetration, environmental pollution, and illnesses. This has led to a better management system for soil and plant health, quality control, and safety assurance. Nanosensors have played a crucial role in establishing sustainable agricultural and environmental systems. Chhipa and Joshi (2016) stated that nanotechnology has the capability to enhance agriculture. They talked about how agriculture uses nanopesticides, nanofertilizers, and nanosensors. Fe, Mn, Zn, Cu, Mo, Ti, and carbon nanotubes are examples of nanofertilizers that enhance plant development and are more cost-effective than traditional fertilizers. Nano sensors are useful in precision farming because they can quickly and precisely apply pesticides by detecting weeds and pests in real-time. Davarpanah *et al.* (2016) assess the impact of foliar applied nano-fertilizers of Zn and boron (B) on natural product yield and quality in pomegranate (*Punica*

granatum). A sole foliar application with generally low measures of B or Zn nano-fertilizers (34 mg B tree⁻¹ or 636 mg Zn tree⁻¹, separately) prompted increments in pomegranate natural product yield, and this was fundamental because of increments in the number of organic products per tree. Dubey and Mailapalli (2016) reviewed the potential applications of nanotechnology in farming, such as plant production, protection, and microbe detection, while also addressing the environmental risks associated with nanotechnology. Although nanotechnology has the potential to boost agricultural output, there is little known about its long-term consequences on soil, plants, and human health. A prudent application of nanotechnology may help to achieve food security while preserving a quality and sustainable environment. Iavicoli *et al.* (2016) stated that nanotechnology has the potential to positively impact various challenges in agriculture, forestry, and the environment, such as urbanization, energy limitations, and sustainable resource use. However, nano-enhanced applications may also introduce new ecological and human health risks. This raises concerns for agricultural workers who may become significantly exposed to such xenobiotics during their work activities. Nano-fertilizers could offer targeted/controlled release of agrochemicals, designed to maximize their full organic efficacy without overdosing. Manikandan and Subramanian (2016) have discussed the potential of nano-fertilizer technology to deliver nutrients in a controlled manner, improving NUE without associating any negative consequences. They have explored the use of nano-zeolite and proposed that its high surface area, along with its coating or blending with conventional nitrogen fertilizers, can control the release of nitrogen, making it an excellent slow-release fertilizer that promotes sustained nitrogen release proportional to crop growth without causing environmental harm. The newly developed intercalated N nano-fertilizer formulations were tested using maize as a model system. The fate of nitrogen in the soil system was analyzed to gain insights into the use of nano-fertilizer in promoting crop productivity with higher nitrogen use efficiency. The response of maize plants to synthetic fertilizer was tested in two greenhouse experiments using two different soil surfaces and they observed that the treatment with nano-zeo-urea consistently outperformed the treatment with urea in terms of growth, yield, quality, and nutrient uptake. Nanotechnology, according to Manjunatha *et al.* (2016), has the potential to revolutionize a variety of fields, including agriculture, biomedicine, health and safety, water resources,

energy conversion, and more. By working with the smallest possible particles, nanotechnology offers hope for addressing longstanding challenges in agriculture. In 2016, Subramanian conducted research on the application of nano-zeolite in the production of nano-fertilizer, specifically nano-zeo-urea which delivers nitrogen. As a result of his studies, he learned how useful different characterization techniques for nanomaterials were for improving the field of nanoscience and technology in agricultural applications. Amine groups of urea interacted with nano-zeolite and created vibrations, while the hydrogen and oxygen bonding altered the practical groups' peak of nano-zeo urea. According to Valizadeh and Milic (2016), nanotechnology has significant potential to improve plant productivity in modern agriculture and is predicted to become a dominant economic force in the near future. It can aid agricultural production through the development of nano-designed Agro-chemicals and nano-fertilizers. Nano-formulated fertilizers possess unique physical-chemical properties that allow them to meet plant root requirements more effectively than conventional fertilizers. Nanoparticles can also be used to increase the supply of elements to plant shoots and foliage. Benzon *et al.* (2015) found that the utilization of nanofertilizers enhanced the antioxidant capacity of rice. Antioxidants are secondary compounds that plants produce as a response to unfavorable conditions. In addition, the application of these fertilizers was supplementary, as its greater absorption through plant cells seemingly provided sufficient nutrients to enhance antioxidant activities. Dasgupta and colleagues (2015) stated that agriculture has a vast scope of potential applications for nanotechnology, which has led to extensive research conducted by both academic and corporate institutions. According to Deepa *et al.* (2015), nanofertilizers provide a productive and proficient method for delivering nutrients to specific areas of plants. Dixit *et al.* (2015) suggested that agricultural bioremediation can contribute to sustainable soil restoration techniques. By exploring the interaction between nanoparticles and agricultural soil, it may be possible to remove toxic components and improve soil sustainability. Jampilek and Kralova (2015) reported that nano agrochemicals, such as nano pesticides, nanofertilizers, or plant growth stimulating nano systems, were primarily designed to enhance solubility, improve bioavailability, target delivery, controlled release, as well as protection against degradation resulting in a reduced amount of applied active ingredients and ultimately in a reduction of dose-dependent

toxicity/harm. Their study centered on the creation and biological activity of nano formulations that allow for the regulated delivery of plant-available nutrients and the regular release of active chemicals into weeds and pests. According to Liu and Lal (2015), nanotechnology can significantly boost global productivity to fulfil the expanding population's future needs. Innovative nanotechnology-based fertilizers can enhance plant growth and increase agronomic yields while reducing environmental pollution. They reviewed the available literature and found that certain engineered nanomaterials can be used as nanofertilizers in agriculture. They also examined the importance, research directions, and prerequisites for achieving sustainable agriculture using each class of nanofertilizers. Finally, the authors recommended that the development of nanofertilizers containing macronutrients like nitrogen and phosphorus should be a high priority for achieving sustainable food production and environmental conservation. According to Kah (2015), there has been increasing interest in utilizing nanotechnology in agribusiness, especially in the development of innovative nano agrochemicals, such as "nano pesticides" and "nanofertilizers." Their viewpoint critically assesses the advancements made over the last ten years while taking into account scientific, regulatory, public, and commercial viewpoints. Numerous nano agrochemicals resemble commonly used products, which begs the question of whether formulation effects have been sufficiently considered when evaluating agrochemicals. Kah's analysis points to future directions for evaluation and regulatory requirements to support the development of more environmentally friendly and sustainable agrochemicals. According to Mishra and Singh (2015), nanoparticles have the potential to improve pesticide efficacy by boosting solubility, increasing resistance to hydrolysis and photodecomposition, and delivering pesticides to target species in a more precise and regulated manner. El- Ramady *et al.* (2015) suggest that nanofertilizers have the potential to provide nutrients to plants for an extended period without posing environmental risks. Although research in this area is relatively new, the available literature has demonstrated that nano-fertilizers can control nutrient release in a more sustainable and controlled manner than traditional fertilizers. The authors reviewed the research on nano-fertilizers and provided insights into the processes involved in slow-release fertilizers and their potential role in enhancing farm productivity without harming the environment. Nano-fertilizer research is crucial to support sustainable agriculture by reducing fertilizer

response ratios and addressing concerns about imbalanced treatment and its detrimental effects on soil fertility. According to Rameshaiah *et al.* (2015), nanotechnology is an innovative discovery that is being explored in almost all fields and has numerous benefits. It has the potential to provide faster solutions to current issues in the field of agriculture. By applying concepts of nanotechnology, farmers can better understand the effects of various inputs and provide better solutions. Controlled use of this technology can enhance sustainability and benefit both the ecosystem and farmers by overcoming local myths and moral barriers. Nanocarriers can deliver nutrients to plants at the right time and place, reducing the amount of active chemicals required and increasing the effectiveness of nutrient uptake. Solanki *et al.* (2015) stated that in ongoing years, nanotechnology has broadened its significance in plant science and Agriculture. Nanostructures fertilizer can expand the supplement use effectiveness through instruments, for example, directed conveyance, slow or controlled delivery and improve crop profitability. Nanotechnology, according to Siddiqui *et al.* (2015), is a rapidly expanding and intriguing field of study that allows for the discovery of nanotechnological findings with potential microbiological and agricultural applications. It is often known as "magic bullets," and can carry herbicides, fertilizers, nano-pesticides, or genes that are directed at certain cellular organelles in plants to release their contents. The mode of application, nanoparticle concentration, and size can all influence the plant's response differently. In 2015, Veronica and her colleagues conducted a study on the impact of nanofertilizers on agricultural farming. Their findings show that nanofertilizers can help boost food production, particularly in underdeveloped nations where high-yielding, fertilizer-responsive crop varieties have been introduced. The potential for nanofertilizers to revolutionize the field of biology, specifically in agriculture, raises optimism for future innovations. The study conducted by Amirnia *et al.* 2014 emphasized the critical function of nanofertilizers in improving saffron yield, and specifically highlighted the impact of Fe, P, and K nanofertilizers on saffron flowering. However, the study revealed that environmental factors and farm management approaches had a significant impact on saffron flowering features. As a result, choosing the right saffron ecotypes, nanofertilizers, and maternal corm weight are key elements in farm management and effective saffron production. Manik and Subramanian did a study in 2014 to improve urea nitrogen consumption efficiency by employing

microporous natural zeolite and nanoporous zeolite as substrates. Their findings suggest that the use of nanoporous zeolite, supplemented with N fertilizer, can be a viable alternative approach for improving nitrogen use productivity in crop production systems. In 2014, Mukhopadhyay noted that nanotechnology has the potential to significantly enhance productivity through the regulation of nutrients. In 2014, Sabir and colleagues discussed the characteristics and applications of zinc oxide nanoparticles. According to them, these nanoparticles have gained significant importance compared to their bulk counterparts and among various metal nanoparticles, zinc oxide nanoparticles are particularly significant due to their utility in gas and biosensors, cosmetics, drug delivery systems, and more. Zinc oxide nanoparticles (ZnO NPs) also possess strong optical, physical, and antimicrobial properties, making them a valuable addition to agriculture. Prasad *et al.* (2014) stated that the many features and applications of nanoparticles make a full assessment of their health and environmental implications impossible. However, nanoparticles can play a significant role in monitoring pesticides and water quality, which is critical for agriculture's long-term sustainability. The FAO and WHO recommended in 2013 that the use of nanotechnologies and nanomaterials in agriculture has the potential to greatly contribute to addressing sustainability concerns, particularly in light of rising global population and climate change. The usage of nanoscale transporters and compounds can enhance fertilizer and pesticide efficiency, while maintaining productivity by reducing the amount required to be sprayed. In addition, nano sensor technology can enable precision agriculture, promoting more effective management of resources, especially energy. According to Hong *et al.* (2013), the advancement of nanotechnology has the potential to change agribusiness by providing novel disease treatment and diagnostic tools, smart delivery systems, sensors, and improved management devices. However, the rapid advancement of nanotechnology could also result in many engineered nanoparticles that may have adverse effects on edible plants. They conducted a review of the latest literature on the use of nanotechnology in agribusiness, covering topics such as nanofertilizers, nano sensors, crop protection, pollution control, waste management, and pesticide detection. The study also discusses the negative impacts of nanoparticles on cucumber plants. As per Naderi and Danesh (2013), nanostructured design can distribute active ingredients with more accuracy by using targeted delivery, slow/controlled release mechanisms,

and conditional delivery in response to environmental stimuli and biological demands. The use of nanofertilizers has been shown to boost nutrient use efficiency, reduce soil toxicity, minimize potential negative consequences of overdosing, and reduce application frequency. As a result, nanotechnology has enormous potential for attaining sustainable agriculture, particularly in underdeveloped countries. Nanotechnology, according to Fakhruddin *et al.* (2012), is a special scientific method that makes use of a substance's chemical and physical properties and equipment at the cellular level to explore the biological and material worlds at the nanoscale level. It has numerous applications, including agriculture and medicine. According to Khin *et al.* (2012), environmental contaminants have been absorbed by both organic and inorganic nanomaterials, improving soil remedy capability, and lowering treatment time and costs. A field study, according to Milani *et al.* (2012), supported the hypothesis that nano nitrogen fertilizers could increase rice productivity. They concluded that nano nitrogen fertilizers have the potential to replace mineral urea and reduce environmental pollution caused by leaching, denitrification, and volatilization of chemical fertilizers. Singh (2012) states that nanofertilizers are currently being developed for their ability to gradually release and provide effective dosages for plants.

2.2. IMPACT OF NANO FERTILIZERS

2.2.1. GROWTH COMPONENTS

Amin and colleagues (2020) researched the influence of nano fertilizers on lime at various concentration levels (0, 0.5, 1, and 1.5 ml/litre) and potassium chelate (0, 2, 3, and 4 ml/litre) on plant growth indicators. The results uncovered that all the growth indicators were significantly manipulated by the treatment of 1.5 ml/litre of nano fertilizer and 4 ml/litre of potassium chelate. The greatest values for each of the investigated parameters were produced by the interaction between these treatments. In a study conducted by Irum *et al.* (2020), biosynthesized iron oxide nanoparticles (IONPs) were investigated for their potential to mediate in-vitro callus induction and shoot regeneration in chickpea crops. Chickpea is an economically important crop, and its regeneration potential is promising for maintaining seedling health and promoting growth. The use of green synthesized IONPs showed improved chickpea plant growth parameters, suggesting their potential application in agronomic crops to enhance the ecosystem. However, further molecular research is needed for the effective implementation of

IONPs to increase crop productivity and resistance to abiotic and biotic stress. In their research, Mohamed *et al.* (2019) studied the use of nanofertilizers to enhance the growth and yield of sweet pepper. They found that all treatments, including levels of potassium fertilizer and their interaction with other factors, led to an increase in all vegetative growth parameters. Shebl and colleagues (2019) studied the impact of foliarly applied of zinc, iron, and manganese micronutrient oxide nanoparticles, as well as their combinations, on the growth, production, and quality of squash plants across two growing seasons in Egypt in 2017 and 2018. Spraying manganese oxide nanoparticles on the plants resulted in the best vegetative growth characteristics, fruit characteristics, yield, and photosynthetic pigment content. Meanwhile, the squash fruits treated with iron oxide nanoparticles had the highest levels of protein, lipids, and energy. El- Henawy *et al.* (2018) performed research to examine the impact of diverse types of fertilizers on the growth and productivity of red cabbage and broccoli under salinity and waterlogging stresses. The fertilizers used in the study were mineral fertilizer (recommended NPK fertilizer), organic fertilizer (compost tea), and nano-fertilizer (copper nanoparticles as nano-Cu and selenium nanoparticles as nano-Se). The results showed that the vegetative growth of red cabbage and broccoli was dependent on the type of fertilizer used. The incorporation of nano-fertilizers with organic fertilizer showed promise in modern and non-conventional agriculture. However, further readings are required to determine the efficacy and hypothetical risks of using these nanoparticles. Rajonee and colleagues (2017) explored the impact of nano fertilizers on the expansion of *Ipomoea aquatica* (Kalmi). When compared to traditional fertilizer and nano fertilizer treatments, Kalmi grew faster with the nanofertilizers treatment. Abdel-Aziz *et al.* (2016), emphasized the growing significance of nanofertilizers in modern agricultural research. They studied the foliar uptake of chitosan nanoparticles containing NPK on wheat plants. The life cycle of nano-treated wheat plants was 23.5% shorter than that of traditionally produced wheat plants (130 days compared to 170 days for yield production from the planting date). The findings show that employing nanofertilizers to accelerate plant growth and productivity can open new avenues for agricultural operations. Gerdini (2016) investigated the impacts of nano potassium fertilizer on the morphologic and physiological features of medicinal plant pumpkin seeds using an RBD design experiment with 3 replications. The experiment included 3 distinct

degree of drought stress (1, 3, and 6 days) and four different nano potassium fertilizer concentrations (0, 0.5, 1.5, and 2.5 thousand /ml). The usage of nano fertilizers is thought to be a potential strategy to attaining sustainable agriculture since it allows more exact nutrient release. When compared to all other fertilizer treatments, the administration of nano potassium fertilizer at a concentration of 2.5 thousand/ ml resulted in the largest stem diameter. Additionally, the greatest no. of branches and leaves were examined. The authors also observed that all growth indices, including shoot length, fresh weight, dried weight, and leaf area, were improved significantly. Furthermore, the time required for wheat plants to achieve 50% ear head stage, days to physiological maturity, and days to harvesting were all vividly shortened, demonstrating the potential of nanofertilizers in accelerating plant growth and enhancing productivity. Manikandan and Subramanian (2016) researched the effects of nitrogen nano-fertilizers on zeolite and conventional fertilizers on maize plants and observed that the response was more pronounced in alfisols than in inceptisols. They found a significant increase in the growth components of maize. However, when nano-zeolite urea was applied foliarly, the increase in accumulation of dry matter was shown to be comparable to that of normal urea applications. In 2016, Saedpanah and colleagues conducted a study to investigate the impact of salicylic acid, ascorbic acid, and nano-fertilizers on the agronomic features of fodder maize and stated that utilization of nano chelate iron fertilizer resulted in a substantial growth components of fodder maize. Ajirloo *et al.* (2015) carried out a two-year study to examine how Nano-K fertilizer and N bio-fertilizers affected tomato (*Lycopersicon esculentum* L.) yield and yield components. The application of Nano-K fertilizer and nitrogen fertilizer significantly enhanced various crop growth factors, including PH, stem diameter and LA, as indicated by the results. Asadzade and colleagues (2015) reviewed the influence of foliarly applied conventional and nano-fertilizers (ZnO and SiO₂) on sunflowers and stated that the usage of ZnO nano-fertilizer considerably increased the growth characteristics of sunflowers. In South Korea, Benzon *et al.* (2015) conducted research experiment to probe the effect of nano-fertilizers on rice. The researchers discovered that, except for the treatment that used only nano-fertilizer, all combination treatments significantly improved agronomic parameters such as plant height and tiller numbers. Furthermore, when compared to the control and other treatments, the full recommended rate of both conventional

and nano fertilizers significantly increased plant height and tiller no. Bakhtiari *et al.* (2015) examined the influence of several concentrations of Fe nano oxide solution on wheat at five distinct levels (0, 0.01, 0.02, 0.03, and 0.04%) in their study. All the growth characteristics in wheat were significantly greater in plants treated with 0.04% Fe nano-oxide. Farnia *et al.* (2015) reported that the application of nano-biofertilizer and nano-Zn led to a substantial boost in the 100-grain weight, no. of rows/cob, no. of grain/ cob, grain produce, and harvest index of red bean compared to the control and other treatments. Hafeez *et al.* (2015) conducted several experiments in Pakistan to assess the efficacy of copper nanoparticles in promoting wheat cultivar growth and yield at various concentrations. The results showed that administering Cu-NPs at doses ranging from 0.2 to 1.0 ppm in solution culture considerably increased plant development when compared to control plants. Similarly, soil application of Cu-NPs at concentrations of 10, 20, 30, 40, and 50 ppm in pots resulted in a substantial boost in chlorophyll and leaf area. In their study, Hassani *et al.* (2015) assessed the influence of zinc and potassium nano-fertilizers compared to traditional chemical fertilizers on the yield of peppermint (medicinal plant). The study included nine treatments, which were fertilizers, Fe, Zn and K nanofertilizers, a mix of nano and traditional fertilizers, and a control group. The results showed that using nano-fertilizers substantially improved the height of plant, no. of branches, leaves, and nodes, wet and SDW of the plant. In 2015, Hiyasmin and colleagues revealed that using nanofertilizers promoted the growth, development, and antioxidant activity in rice, highlighting their potential to enhance crop production and plant nutrition. In 2015, Hussain and colleagues conducted a pot experiment to examine how potassium fertilizer affects maize production. The researchers applied potassium fertilizer in 5 treatments with doses of 0, 70, 100, 130, and 160 kilogram per hectare, respectively. Nitrogen and phosphorus were also applied at recommended levels to all pots, along with the control. Results showed that the T₃ treatment led to the most significant improvement in maize growth and physiological parameters. This treatment increased water use efficiency and nutrient uptake, resulting in higher yields and reduced root-to-shoot dry weight ratios. They determined that administering 100 kg/ha of K considerably improved all growth-related parameters, such as shoot length, root length, and fresh root weight, when compared to the control. Jhanzab *et al.* (2015) used a chemical approach to create silver nanoparticles and

tested their impact on wheat growth and yield in a pot experiment. Their results indicated that the application of 25 ppm concentration of Ag nanoparticles significantly enhanced root growth, no. of harvested grains/pot, yield/pot. As a result, silver nanoparticles stimulate and hinder wheat growth and output. Liu and Lal (2015) stated that nano-fertilizers can improve plant growth and yields by supplying one or more nutrients. In contrast, nanomaterial-enhanced fertilizers enhance the effectiveness of conventional fertilizers without providing nutrients directly to the crops. It is expected that nano-fertilizers will significantly increase crop growth and production when compared to traditional fertilizers. According to Marimuthu and Surendran (2015), nanofertilizers improve metabolic processes and stimulate meristematic activities, resulting in increased apical growth and photosynthetic area. They conducted an experiment where black gram plants were sprayed with nano formulations containing an NPK and micronutrient mixture and observed a substantial rise in PH and no. of branches. Mir *et al.* (2015) found that the usage of nanofertilizers resulted in the enhancement of growth traits in sorghum plants. Mohamed (2015) revealed that the application of titanium nanoparticles leads to the boost in coriander yield, height of plant, no. of branches, total sugars, total indoles, total phenols, and amino acid content. Mossanna and Behrozyar (2015) examined the effect of Zn nano-chelate spraying on morpho-physiological characteristics of maize by foliar and soil treatments. When compared to the control plot and other treatments, the results revealed a significant influence of nano-chelate Zn application on the morpho-physiological characteristics of maize. In Iran, Nargesi *et al.* (2015) performed an experimentation to compare the consequences of ordinary chelate and nano-iron chelate fertilizers on wheat genotypes in nutrient solutions. The outcomes indicated that the use of nano-iron chelate fertilizer decreased the average yield of shoots, leaf area, and root volume by 14.1%, 9.5%, and 8.9%, respectively, and increased root shoot ratio by 13.7% for certain wheat varieties compared to the regular iron chelate. Vafa *et al.* (2015) revealed that using Nano Zn increased a variety of growth parameters of savory plants. Asgari *et al.* (2014) did a trial to explore the effects of nano potassium fertilizer on the physiological and morphological responses of *Narcissus tazetta*. Two components of benzyl adenine hormone and nano potassium fertilizer were used in the experiment. Four distinct quantities of adenine and three different amounts of nano potassium were tested. The findings

demonstrated that 2.5 g/l nano potassium fertilizers had the highest water absorption rate while producing the largest stem. Therefore, the study suggests that the usage of nano potash enhances floral quality. In Kolkata, Bala, and colleagues (2014) performed research to investigate the influence of engineered hydroxyapatite nano-rods on the growth of chickpea (*Cicer arietinum*) plants. The usage of following treatments by the researchers resulted in an increase in both germination rate and plant height. Dolatabadi and colleagues (2014) conducted a trial to evaluate the impact of exogenous nano-TiO₂ treatment on annual medic (*Medicago scutellar* L.) using 6 concentrations of nano-TiO₂ (Control, 0.01, 0.02, 0.03, 0.04, and 0.06%) and applied it in 2 stages namely, pod stage and 10% blooming stage. Their results suggested that the usage of nano-TiO₂ considerably boosted the dry forage produce of the crop. Furthermore, the seed production of annual medic was significantly higher when the nano-fertilizer was administered at the seed stage as compared to the 10% blooming stage. In their 2014 study, Ghahremani *et al.* investigated the effects of fertilizers containing nano-calcium and nano-potassium chelates at concentrations of 0.1%, 0.2%, 0.4%, and 0.6% on the quantitative and qualitative traits of basil. The report found that the use of nano-calcium and nano-potassium significantly increased basil dry matter and leaf area. Kumar *et al.* (2014) conducted research in Pant Nagar to evaluate the impact of gypsum and rock phosphate nano-fertilizers mixed with urea on wheat growth. The use of nano-fertilizers and traditional fertilizers significantly improved tiller number/meter, dry matter accumulation, and days to 50% blooming, physiological maturity. In an experiment conducted by Rezaei and Abbasi (2014) in Iran, the effects of mineral fertilizer of zinc (Mi), chelate of zinc (Ch), and nano-chelate of zinc (N Ch) on the growth, physiological, and some biochemical processes of the cotton plant were compared. When compared to the mineral fertilizer treatment, treatments with nano-chelate and zinc chelate exhibited considerably greater maximum height, fresh weight, and dry weight. Using a randomized full block design, Tavan and colleagues (2014) conducted an experiment on wheat plants that were grown in the field. Foliar application of nano K fertilizer was carried out at different rates during the early reproductive stages. The study found that spraying wheat plants with nano K fertilizer at a concentration of 0.3% significantly increased the no. of leaves, while a concentration of 0.15% enhanced the length of roots and shoots. However, no effect was observed on node no. or

root dry weight. In addition, different amounts of nano K fertilizer considerably raised the levels of chlorophyll a, b, and soluble sugars of wheat plants as contrasted to the control. Dhoke *and* colleagues (2013) undertook an experiment to assess the influence of nanoparticles on mung. When mung seedlings were treated with suspensions of nanoparticles, the researchers noticed a substantial increase in growth components. Ghafari and Razmjoo (2013) studied the effect of foliar iron oxide, iron chelate, iron sulphate, and control on durum wheat grain yield, quality, and yield characteristics. The use of nano-iron oxide fertilizers significantly increased harvest index, yield and, and yield components. Jafarzadeh *et al.* (2013) from Iran evaluated the impact of potassium soil treatment at three levels (no application, one fifty kg/ha K₂SO₄, and ten kg/ ha nano K) and foliar nano-K at four levels in a field experiment on wheat crop (no application, application at tillering, application at stem elongation, and application at tillering and stem elongation). The research reveals that adding nano-K to the soil enhanced plant height and tillers per plant considerably. In a research done by Mahmoodzadeh and colleagues (2013) in Iran, an experiment was carried out to examine how TiO₂ influenced the physiological characteristics of wheat. Their findings demonstrated that spraying nano-TiO₂ had no substantial impact on the length of the wheat shoot and root. Van and colleagues (2013) conducted a study to examine how chitosan nanoparticles affect the growth of coffee seedlings. The results showed that at appropriate concentrations, these nanoparticles led to an increase in growth parameters. Feizi *et al.* (2012) did a research in Iran to investigate how nano-sized TiO₂ influences on wheat. Their study's findings revealed that both bulk and nano-sized TiO₂ concentrations influenced growth components in wheat. When examining the impact of nano-sized titanium on wheat seedlings, low concentrations of this substance were found to stimulate both shoot length and seedling length. In contrast, higher concentrations of nano-sized titanium dioxide had a neutral effect, while bulk titanium dioxide inhibited the growth of the wheat seedlings. In a study conducted in China in 2012, Liu *et al.* investigated the effects of nitrogen fertilizer and nano-carbon use in combination on soil nitrogen uptake and rice yield. According to the study's findings, using nitrogen fertilizer and nano-carbon together increased DMA significantly compared to using inorganic standard fertilizers. According to Moghadam *et al.* (2012), the Fe chelates nano-fertilizer had a favourable impact on *Spinacia oleracea* L. spinach's wet weight,

as it enhanced growth metrics such as LAI, CGR, and leaf numbers of treated plants compared to both the control and other treatments. In Chennai, Prasad *et al.* (2012) carried out a study to look into the effects of nano-scale ZnO particles on peanuts. The study found that the application of these particles led to an increase in germination percentage, seedling vigor, plant height, chlorophyll content, and flowering initiation in peanut plants. Suriyaprabha *et al.* (2012) did a trial to investigate the impact of various treatments of silica nanoparticles on maize crops. The study found that a silica nanoparticle dose of 15 kg/ha had a substantial favorable influence on growth parameters.

2.2.2 YIELD COMPONENTS AND YIELD

Panda *et al.* (2022) investigated the effects of nano fertilizer use on millets' development and productivity. The experimental findings indicated that treatment T₁₂, which involved the application of 75 percent RDF, seed treatment with nano fertilizer, and spraying of nano fertilizer at the active tillering stage and seven to ten days before flowering, outperformed the other treatments. Additionally, all of millet's production and yield characteristics were substantially enhanced as a result. Kumaraswamy *et al.* (2021) studied chitosan-silicon nano fertilizer (CS-Si NF), a new type of nano fertilizer aimed to improve plant development and yield in maize. The study revealed that the release of silicon from the CS-Si NF led to physiological and biochemical responses in maize that ultimately resulted in increased growth and yield. According to Genaidy and colleagues (2020), the most effective treatment for achieving the largest final olive fruit set and highest olive (*Olea europaea*) fruit production, as well as a lower acidity and higher seed oil percentage, in both the first and second seasons was spraying with a combination of nano-boron at 20 ppm and nano-zinc at 200 ppm, which was labeled as T₈. Kumar *et al.* (2020) examined the impact of nanofertilizers on nutrient utilization efficiency, wheat yield, and economic returns. The findings demonstrated that applying 50% less nitrogen and two sprays of Nano-N on standing crops resulted in higher crop yields than the traditional farmer's fertilizing practice (FFP) for most crops. The effectiveness of nanofertilizers was dependent on the level of a specific nutrient deficiency such as zinc (Zn) or copper (Cu) and the type of crop since micronutrient deficiencies are not uniform. To examine the effects of various commercially available nanofertilizers on cotton growth and yield, Kanjana conducted field experiments in 2020. Cotton (variety:

Suraj) was sprayed with macro and micronutrient nanofertilizers (NF 1, NF 2, NF 3, and NF 4) in combination and compared with a recommended dose of normal micronutrient fertilizers at thirty and ninety days after sowing. The outcomes disclose that foliar application of NF 3 and NF 4 nanofertilizers at recommended doses led to a 16.0% and 14.4% increase in seed cotton yield, respectively, compared to standard recommended doses of micronutrients, with NF 2 (9.5%) and NF 1 (9.2%) nanofertilizers closely following. However, the application of commercial fertilizer did not significantly impact fiber efficiency parameters. Mishra and colleagues conducted an experiment in a farmer's field in Odisha's Krishi Vigyan Kendra in 2020 in conjunction with IFFCO to examine the economic effects and effects of nano fertilizers on tomato yield. The findings indicated that by applying 50% N + 100% PK + 50% Zn to the soil inorganically and supplementing it with Nano N, Nano Zn, and Nano Cu sprays, higher plant height, more branches, longer and wider fruits, greater fruit weight, and increased yield in tomatoes could be achieved. Babubhai and colleagues conducted a pot culture experiment in 2019 and stated that soil treated with nanofertilizers had the highest growth parameters and yield characteristics when compared to soil treated with chemical fertilizer. Their findings demonstrated that incorporating nanofertilizers into maize cultivation can reduce the recommended potassium fertilizer dose by up to 40%. In 2019, Juthery and colleagues studied the impact of nanofertilizers and amino acids foliar nutrition on wheat yield. They found that foliar spraying of a tri nano combination resulted in maximum grain production and agronomic productivity. Merghany and colleagues carried out an experiment in 2019 to assess the effects of nano-fertilizers on cucumber plant growth, fruit yield, and quality. They saw that the usage of mineral fertilizers had caused severe environmental difficulties. Furthermore, their outcome also showed that the nanofertilizers considerably improved cucumber growth and yield. All types of nanofertilizers increased yield components. In conclusion, nanofertilizers were discovered to improve cucumber yield and could be utilized as an alternative for traditional fertilizers. According to Zahedi *et al.* (2019), using nano-fertilizers can boost flower vegetative development, pollination, and fertility and can lead to higher yields and better-quality produce for fruit crops. According to Rezaei-Chiyaneh and colleague (2018), foliar micronutrient administration had a significant impact on many features, resulting in improved yield parts and essential oil yield compared

to the control group. The foliar application also led to enhancements in yield parts, seed yield, essential oil rate, and essential oil yield. Furthermore, combining the use of Nano-Fe, Nano-Zn, and Nano-Mn micronutrients showed a greater increase in the examined characteristics than their individual use. Overall, the findings suggest that foliar spraying with Nano-micronutrients has a worthy part in increasing the quantitative and qualitative productivity of black cumin. According to El-Metwally *et al.* (2018), the use of nFe, manganese, and zinc fertilizers at 30 ppm resulted in the maximum yield and diverse features in peanuts. Mijweil and colleagues conducted a study in 2018 on the impact of nano-fertilizers and different planting dates on potato yield and development (*Solanum tuberosum* L.). Because of its great solubility and efficacy, as well as its ability to be applied in small quantities, they discovered that the usage of nano-fertilizers is gaining popularity as a promising strategy to enhance crop yield. As a result, it enhances fertilizer effectiveness and reduces costs compared to traditional fertilizers. In their study of rice crop production. According to Sohair and colleagues' study in 2018, the use of nanofertilizers had a more pronounced influence on cotton crop yield while also reducing fertilizer expenses and mitigating the risks of pollution. El-Sharkawy and colleagues conducted a greenhouse experiment in 2017 to investigate the impact of varied K₂SO₄ nanoparticle rates on the development and physiological response of alfalfa (*Medicago sativa* L.) under salt stress. Two genotypes of lucerne were chosen and planted in pots with 2 kg of sand, one of which was salt-tolerant (Me-sa-Sirsa) and the other salt-sensitive (Bulldog 505). Using a Hoagland solution with a CaCl₂:2H₂O: NaCl (2:1) ratio, the genotypes were exposed to varying salt concentrations. In three separate applications, K₂SO₄ nanoparticle concentrations of 1/4, 1/8, and 10% of the potassium (K) level in full-strength Hoagland solution (235 mg/L) were used. According to the results, utilizing K nanoparticles rather than conventional K fertilizers may be more efficient at providing the right plant nutrition and reducing the negative effects of salt stress on lucerne. During the summers of 2016 and 2017, Gomaa and colleagues conducted two field investigations at Alexandria University and demonstrated that foliar application of nano fertilizer led to the largest average values of all the yield parameters of hybrid maize. Jyothi and Hebsur (2017) observed how certain cereal yield components were affected by nanofertilizers. They found that nanofertilizers have the potential to reduce costs in

agriculture and aid in environmental remediation efforts. Lemraski *et al.* (2017), revealed that the highest rice yield was attained by utilizing nitroxin and nano-silicon. Hence, the application of nano particles led to an improved yield in both rice cultivars. According to Mekkdad (2017), the improved nutrient usage efficiency of nano-fertilizers led to an enhance in pigment production, dry matter, and photosynthetic rate. As a result, the use of nano-fertilizers may result in increased yield of the peanut. According to Rostami and colleagues (2017), the use of N nanofertilizers led to the rise in the dry weight of peppermint leaves. According to Singh *et al.* (2017), using K nanofertilizers increased yield by roughly 8% in comparison to MOP using at the similar amount of 20 kg K₂O/ha. However, there is limited understanding about the impact of controlled-release K fertilizer on cotton leaf photosynthesis and K usage efficiency (KUE). Three different kinds of K fertilizer, KC1, and polymer-coated nano KC1 (CRX) were used in a 2-year pot research by Tian and colleagues (2017) in the years 2014 and 2015 at four application rates. The study found that CRX application significantly increased plant-available K contents from blooming to maturity, resulting in an increase in lint cotton yields and a rise in KUE respectively, compared to KC1 and K₂SO₄ treatments at the same K rate. The study recommends the use of CRK instead of traditional K fertilizers, particularly in the production of cotton. Furthermore, Anon, 2016 revealed that the usage of nano-fertilizers resulted in higher cotton product quality, increase the number of bolls, raise boll weight, and improve seed yield as compared to conventional fertilizers. Abdel-Aziz and colleagues (2016) stated that the usage of nano chitosan-NPK fertilizers through foliar spraying on wheat plants resulted in significant improvements in spike length, 1000-grain weight, no. of grains/spike, grain produce, stover yield, and HI compared to control plants that were either not fertilized or fertilized with normal NPK. They also examined potential benefit of nanofertilizers on crop cycle. Their study found that nanoparticles loaded with NPK resulted in a reduction of up to 40 days in the crop cycle of wheat. Additionally, grain yield was increased compared to mineral fertilizers applied at recommended rates. Davarpanah *et al.* (2016) found that applying foliar fertilizers containing nanoscale zinc led to an increase in the yield and no. of fruits per tree in pomegranates. Drostkar and associates (2016) determined that applying NPK nano fertilizers on chickpea boosted both the yield and its constituent parts. This was attributed to the higher

activity of growth hormones and improved metabolic processes, which stimulated flowering and grain formation. They prove that seed weight, biological produce, and seed yield could all be improved by foliarly applying Zn nanofertilizer. Overall, the study demonstrated that the usage of Zn, Fe, and NPK nanofertilizers as growth promoters can increase plant growth and seed yield in chickpea. According to Janmohammadi and colleagues (2016), using nano-fertilizers substantially enhanced wheat production in all its forms. They also contend that introducing nanotechnology into fertilizer products can improve fertilizer usage efficiency and substantially raise grain production. In two greenhouse studies, Janmohammadi *et al.* (2016) examined the impact of applying titanium dioxide nanoparticles and nano macronutrient fertilizers on the parameters of barley output under supplemental irrigation and stated that nano fertilizers were more effective and environmentally friendly than conventional chemical fertilizers. Manikandan and Subramanian (2016) examined the effects of chemical fertilizers and N nanofertilizers on maize. The results showed that the maize grain produce was considerably higher when treated with nano-zeolite urea compared to conventional urea treatment. Ajirloo and associates conducted an experiment in 2015 to look at how nano- and biofertilizers affected tomato crop yield and yield components. The findings show that using 300 kg/ha of K nano fertilizer led to the highest no. of fruits per plant, fruit weight, fruit diameter, and fruit output. The researchers concluded that using K nano fertilizer enhanced both tomato production and yield components. In a study conducted by Benzon and colleagues (2015), a nursery test was performed to assess the outcomes of nanofertilizers application on the produce, total phenolic content (TPC), and antioxidant activity of rice. Except for the use of nanofertilizers alone, all combination treatments considerably increased yield characteristics, suggesting the potential to increase rice crop productivity. According to a study by Jhanzab and colleagues in 2015, applying silver nanoparticles to wheat resulted in increased yield when a concentration of 25 ppm was used. Rameshaiah and associates carried out a study in 2015 to look at the effect of nano K fertilizer on rice production in Sri Lanka and India. When compared to muriate of potash, the researchers discovered that employing nano K caused more grains and panicle formation. They also looked into the impact of slow-release fertilizer with nano-coating on wheat and other crops. The study's findings revealed that using nano-sized potash in fertilizers led to increased crop

yield rates and improved fertilizer recovery. In 2014, Afshar and colleagues hypothesized that nanofertilizers could increase grain Zn content without altering the yield of grain, the no. of spikelets on each spike, or the weight of a thousand kernels of wheat. The researchers suggested that this effect was due to improved enzyme activity and carbohydrate metabolism, which resulted in increased yield. In 2014, Armin and colleagues performed research to examine the effects of different concentrations and application times of Nano-Fe fertilizer on wheat crops. They observed that increasing the concentration of nano-fertilizers and the duration of application had a significant impact on the tillers no., the no. of seeds/spike, the grain produce, the biological produce, and the weight of one thousand grains. Their findings indicated that foliar applications of Fe at tillering and stem elongation resulted in higher grain yields, which were 9.17% and 5.19% higher, respectively, compared to foliar applications of Fe at stem elongation alone. In a factorial experiment conducted in 2014 by Azarpour and colleagues, the first factor, K fertilizer, was examined at four levels: application of no fertilizer (control), application of potassium sulphate, application of nano powder fertilizer, and application of both potassium sulphate and nano powder fertilizer. The second factor, amino acid, was examined on three different levels: not applied (control), applied falsely, and applied with water-soluble amino acid. The results showed that the amino acid solution, in conjunction with potassium sulphate and nano K fertilizer, had the highest impact on grain production of quinoa. Delfani and colleagues carried out a trial in 2014 in which they sprayed black-eyed pea plants with nano Fe at a dosage of 0.5 g/l. In comparison to using conventional Fe fertilizers, the results revealed an increase in the no. of pods per plant, the weight of a thousand seeds, yield, and chlorophyll content. Additionally, the application of nano-Fe fertilizer during tillering and stem elongation stages in wheat increased the number of seeds per spike, while early application of Fe fertilizer reduced the same. To determine how the use of nano- and bio-fertilizers affects red bean yield and yield-related characteristics, Farnia and Ghorbani conducted a trial in 2014. Their results showed that the production of red beans and other attributes were significantly increased when N-based bio- and nanofertilizers were used. In 2014, Ghahremami and colleagues conducted a greenhouse experiment in which they applied nano-calcium and nano-potassium chelate fertilizers. When compared to the control and other treatments, these fertilizers considerably

boosted all yield and yield components of basil. Harsini and colleagues (2014) investigated the effects of foliar spraying iron nano-chelated fertilizer on wheat yield and yield components. The results showed that using nano iron chelate as a foliar application on wheat cultivars considerably improved all yield and yield components when compared to both the control and other treatments. Manjili, *et al.* (2014) noticed that if nano chelate molybdenum are foliarly applied they led to substantial impact on components and production of peanuts. Kumar *et al.* (2014) studied the impact of nano-fertilizers consisting of gypsum and rock phosphate, applied at a dose of 3 kg/ha, on wheat yield. Their findings revealed that produce obtained with the use of nanomaterials at 50% RDF were statistically like those attained without nanomaterials at 100% RDF. Rezaei and Abbasi (2014) assert that employing zinc nano chelate increases cotton production as well as the production of cotton's component parts. According to Tarafdar and colleagues (2014), spraying pearl millet with zinc nanofertilizers on the leaves significantly increased grain yield and the number of grains per spike. The usage of metal nanoparticles to wheat led to a considerable rise yield of up to 20-25% (Batsmanova *et al.*, 2013). According to Ghafariyan *et al.* (2013), spraying *Vigna radiata* (L.) with manganese nanoparticles resulted in a greater advancement in soyabean yield and yield components contrasted to manganese sulfate. Jaberzadeh *et al.* (2013) found that foliar spraying 2% Nano-Fe increased grain production by 23.3% in comparison to the control. In a field experiment, Maqsood *et al.* (2013) investigated the effects of different potassium dosages (0, 90, 120, and 150 kg/ha) on maize grown under various furrow irrigation schemes. The study found that characteristics including cob length, grains per grain row, and 100-grain weight were significantly yielded by alternate-furrow irrigation (AFI), fixed-furrow irrigation (FFI), and conventional-furrow irrigation (CFI). In research performed by Morteza and colleagues (2013), the effects of TiO₂ spray treatments on corn (*Zea mays* L.) were investigated. Results showed that nano TiO₂ sprays significantly increased crop production compared to the control and other treatments. In 2013, Nadi and associates assessed the effects of various nano Fe concentrations on the faba bean yield components. Their findings indicate that higher concentrations of nano-iron had a positive and significant impact on grain yield. Specifically, application of nano-iron at a conc. of six gram per litre water during the flowering phase resulted in the highest grain yield, while spraying

during the vegetation phase had the least effect on grain output. Wu, (2013) found that the application of slow-release fertilizers, such as nano fertilizer, improved the blending of maize fat and protein content: total amino acid and free sugar content in maize grain. Similarly, slow-released nano fertilizer increased rice crop grain production by 11.3 percent as compared to standard fertilizers. In order to examine the effects of applying mixed N fertilizer and nano-carbon on wheat, Fan *et al.* (2012) carried out a study in China. The data revealed that foliar spraying of nano potassium had a substantial impact on all yield metrics, except for 100-seed weight.

2.2.3 UPTAKE OF NUTRIENTS

Adisa *et al.* (2019) Engineered nanoparticles can improve agricultural yield by influencing nutrient availability in the soil and plant uptake. Researchers Sadique *et al.* (2017) examined how growth hormones and nanofertilizers effects on various plants and concluded that using nanofertilizers increases nutrient usage efficiency, reduces soil toxicity, minimizes the possibility of side effects from overdosing, and decreases the frequency of application. According to Jamadar (2016) research, the application of nanoparticles through foliar spraying resulted in a 48% improvement in zinc uptake and a 53% increase in enzyme activity in upland rice compared to the control group. According to Manikandan and Subramanian's (2016) research, the uptake of nutrients was significantly greater with the use of nano-zeolite urea treatment compared to conventional urea. According to Rameshaiah *et al.* (2015), nanocarriers can deliver nutrients to plants at the right time and place, reducing the amount of active chemicals required and increasing the effectiveness of nutrient uptake. According to Shashidara *et al.* (2015), the nano fertilizer's ability to easily penetrate the plant's pores is due to their small size. These chemically produced fertilizers, which are ground into a powder from granules, effectively provide nutrients to agricultural plants(cereals), improving uptake and decreasing loss through the provision of balanced and necessary nutrients in nano size. Using maize as a test crop, Adhikari and colleagues (2014) undertook an investigation at the Indian Institute of Soil Science (IISS) in Bhopal to assess the efficacy of several nano Rock Phosphate (RP) treatments. A control group, NK (100%), NPK (100%), NK (100% + 60 kg P₂O₅), and nano rock phosphate (Nano RP) through Udaipur Nano RP (34% P₂O₅) and Udaipur Nano RP (31% P₂O₅) were the five treatments that were investigated. The

findings showed that SSP-treated plants had the highest total phosphorus (P) content and absorption (0.65% and 40.29 kg/ha, respectively), closely followed by Udaipur nano RP 34% (0.63% and 38.2 kg/ha). The SSP-treated plants showed the highest apparent P recovery (47.98%), which was comparable to Udaipur nano RP (34% P_{2O_5}), whereas Udaipur nano RP showed the lowest apparent P recovery (31% P_{2O_5}). The application of P sources also increased N and K uptake in maize under different P treatments. Kumar *et al.*, (2014) stated a noteworthy rise in nutrient uptake of wheat at 50% RDF with nanomaterials, which was found to be comparable to 100% RDF without nanomaterials, based on experiments conducted at Pant Nagar. Ashrafi and colleagues (2013) performed a research to determine the impact of nano-silver application, the findings showed that integrated usage of composts, farmyard manure, nano-silver fertilizers, and chemical fertilizers considerably boosted soyabean uptake of NPK compared to other combination. The effects of CNPS on tobacco cultivar Zhongyang 100 were explored in a pot experiment conducted by Liang and colleagues (2013). CNP concentrations ranging from 0 to 125 mg per pot were tested, and it was found that CNPs boosted nitrogen and potassium levels in several regions of the tobacco plant. The potassium content of tobacco leaves increased by 21.05%, 25.26%, and 36.84% at maturity, contributing to an improvement in tobacco quality. The use of CNPs boosted tobacco plant growth, facilitated nutrient absorption and accumulation, and increased fertilizer efficiency, all of which resulted in higher tobacco quality. Fan and colleagues conducted a study in 2012 to examine the impact of combining nitrogen fertilizer and nano-carbon fertilizers on rice. They found that combining these two fertilizers considerably increased plant nitrogen uptake. According to Suriyaprabha and colleagues, in 2012 adding nano SiO_2 to maize seeds improves germination by enhancing nutrient availability, pH, and conductivity in the growing medium.

2.2.4 QUALITY PARAMETERS

According to Jubeir and Ahmed findings in 2019, the use of nano-fertilizer and NPK can enhance the overall quality of date palm fruits. El-Metwally and colleagues reported in 2018 that using nanofertilizers substantially enhanced the percentages of total carbs, total soluble sugars, protein, and oil in peanut seeds. According to Taran and colleagues' research in 2017, exposure of plants to nano-particles during drought conditions led to increased activity of catalase and

SOD, which suggests a boost in the plant's antioxidative status. Cu and Zn nanoparticles were also used, which changed the ratio of chlorophyll a to b and increased the number of carotenoids in the wheat leaves. In 2017, a study was done by Hasaneen and colleagues to compare the positive impacts of carbon nanotube-coated NPK and chitosan nanoparticle-coated NPK on French bean growth. They found that, either alone or in combination, nanomaterials significantly increased plant growth and biomass compared to the control after approximately 30 days after planting under experimental settings through combined morphological and anatomical study. As a result of their investigation, they concluded that low doses of nano fertilizers had beneficial effects, including improved water absorption and nutrient uptake, as well as enhanced plant development. Singh and Kumar (2017) found that higher concentrations of nano ZnS (500 ppm) in sunflower seed oil increased seed oil content. In 2017, Sham reported that a foliar spray of ZnO nanoparticles resulted in improved quality indicators, including sunflower oil content. According to Anon (2016), using metal oxide nanoparticles improved cotton fibre strength and homogeneity ratio compared to control. According to Janmohammadi and colleagues' research in 2016, the use of nanosized TiO₂ particles as a foliar spray had a positive impact on some morphophysiological traits of barley, including the number of days until anthesis and the amount of chlorophyll present. nTiO₂ has been shown to alter the structure of chlorophyll, which can enhance solar absorption, facilitate pigment production, stimulate rubisco activity, and increase photosynthesis. In two greenhouse experiments with different soil textures (Inceptisols - Periyannayakkan palayam soil series - clay loam and Alfisols - Iregur soil series - sandy loam), In 2016, Manikandan and Subramanian tested zeolite-based nitrogen nano-fertilizers on maize and found that the crude protein content of the maize crop was much superior for the nano-zeolite urea treatment when compared to conventional urea. Sharifi and colleagues' 2016 study stated that the treatment of titanium dioxide nano-particles had a substantial impact on the levels of amino acids, total sugars, total phenols, total idols, and pigments in coriander. Mir and colleagues (2015) investigated the effect of biological and nano-fertilizers on forage sorghum quality measures such as carbohydrate and chlorophyll content. The study showed that the application of bio-fertilizers combined with chelated nano-fertilizers led to the highest levels of chlorophyll a (1.59 mg/g), chlorophyll b (5.31 mg/g), carotenoid (2.24 mg/g), and

carbohydrate (3.24 mg/g). Yasmeeen *et al.* (2015) found that nanoparticles of Ag, Cu, and Fe influence wheat germination. Delfani *et al.* (2014) showed that using nano-Fe reduced seed protein concentration by 2% when compared to common Fe in pea. According to Pirvulescu and colleagues (2014), the application of nanofertilizers increased crop physiological and biochemical parameters significantly. The use of a biocompatible magnetic nanofluid increased the overall chlorophyll content (both a and b) in sunflower leaves. However, when the magnetic nanofluid concentration exceeded 0.75%, the chlorophyll content decreased. Ramesh *et al.* (2014), on the other hand, discovered that low-concentration nano-ZnO treatment led to a considerable rise in chlorophyll and protein content in wheat crops. Raskar and Laware (2014) investigated the impact of ZnO nanoparticles on onion seed. Germination of seeds increased at lower zinc nanoparticle concentrations but decreased at higher quantities, according to the study. According to Rezaei and Abbasi (2014), using nano-chelate zinc fertilizer increased the activity of peroxidase, catalase, and polyphenol oxidase enzymes in cotton and soybean crops, resulting in improved shoot and root growth. Similarly, Tarafdar and colleagues (2014) noticed that foliar zinc nano-fertilizer treatment increased chlorophyll content, total soluble leaf protein, and plant dry biomass in pearl millet crops. By incorporating nano-TiO₂ into maize leaves, Morteza and colleagues (2013) found that nitrogen absorption, photo-reduction activities of photosystem II and the electron transport chain, and reactive oxygen species scavenging were all enhanced. In 2012, Prasad and colleagues revealed that groundnut seeds treated with nano-sized zinc oxide at a concentration of 1000 ppm exhibited notably higher rates of germination, as well as longer shoot and root length, and greater vigour index compared to the control. According to Rezvani and colleagues (2012), the use of silver nanoparticles inhibited ethylene signaling, resulting in the development of *Crocus sativus* roots. Safyan *et al.* (2012) performed research which revealed that the addition of zinc had a substantial impact on protein synthesis in plants, resulting in increased protein content of corn. Soleymani and Hesam (2012) observed that the use of zinc fertilizers improved the soluble carbohydrates content in sorghum, likely due to the involvement of zinc in the production of chlorophyll, starch, and carbonic anhydrase enzyme, which together accelerate the generation of carbohydrates.

2.2.5. RELATIVE ECONOMICS

Panda *et al.* (2022) assessed the influence of nano fertilizers on the economic features of tiny millets produced under rain-fed conditions in an experiment. The application of T₅, which consisted of FP (50% N + 100% PK + 50% Zn) + 1st Nano N + 2nd Nano Z + 3rd Nano Cu spray, resulted in superior economics, according to the study. Su *et al.* (2022) performed research to reveal the influence of nanofertilizers on greenhouse gas emissions and the possible economic advantages or losses connected with their use. The study aimed to identify practical applications and important challenges related to the use of nanofertilizers. The cost-benefit analysis indicated that although current nanofertilizers formulations show promise in increasing corn net revenue and reducing environmental impact, further improvements in their efficiency are necessary for widespread use. Developing novel nano formulations for targeted delivery, reducing greenhouse gas emissions associated with nanomaterials, and limiting the nanomaterial content in generated nanofertilizers or pesticides could significantly enhance both economic and environmental benefits. In 2020, Kumar and colleagues conducted an experiment on the winter season crop in Uttar Pradesh to evaluate the effectiveness of nanofertilizers in enhancing yield, nutrient use efficiency, and economic returns. The study found that administering farmers' fertilizing practice (FFP) with 50% N and one application of nano N, Zn, and Cu resulted in the highest economic returns (Rs/ha). However, the efficacy of nanofertilizers varies depending on the extent of a specific nutrient deficiency, such as Zn or Cu, and the crop type, despite micronutrient deficiencies being uncommon. Mishra and colleagues conducted an experiment on a farmer's field in Odisha in 2020, in collaboration with IFFCO and Krishi Vigyan Kendra, to investigate the impact of nanofertilizers on tomato economics. The findings revealed that applying 50% N + 100% PK + 50% Zn as an inorganic fertilizer to the soil resulted in increased yield and economic returns. However, there was no significant change in the outcome when the first foliar spray of Nano N, the second spray of Nano Zn, and the third spray of Nano Cu were applied. Khan and colleagues conducted an experiment on apples in 2019 to assess the economic impact of nano-fertilizers combining N, P, and K with humic and fulvic acid. According to the economic analysis, using P nano-fertilizer at 50 ppm led to the utmost economics and B:C ratio. The results of the experiments suggested that using humic and fulvic acid in

organic systems can improve yield and returns, whereas using nano-fertilizers in traditional systems can improve yield and returns. Jyothi and Hebsur (2017) evaluated the impact of nanofertilizers on crop(cereal) economics. They concluded that nanofertilizers have the potential to lower agricultural costs while also aiding in environmental rehabilitation initiatives. In another study, Kumar and colleagues (2014) conducted a study in Pant Nagar on wheat crop and observed that the B:C ratio obtained at 50% RDF (recommended dose of fertilizer) with nanomaterials was statistically comparable to 100% RDF without nanomaterials.

MATERIALS AND METHODS

The study, titled "**Nanofertilizers for Sustainable Crop Production under Changing Climate and Impact of Nitrogen, Phosphorus, and Potassium Nanofertilizers on Growth, Yield, and Yield Components of Maize + Mung Bean and Wheat Cropping System**" was conducted at Lovely Professional University's Research Farm in Phagwara for 2 years, during the *kharif* and *rabi* seasons of 2020-2021 and 2021-2022. This chapter presents an overview of the experimental site, climate, soil characteristics, experimental design, and cultural and agronomic practices adopted in the study.

3.1. EXPERIMENTAL SITE:

The current study's trials focused on growth and yield-related parameters, which were observed and recorded on the School of Agriculture's Farm. In addition, the soil and chemical analysis necessary for the investigation was conducted in the Department of Agronomy's laboratory at Lovely Professional University in Punjab.

3.2. LOCATION AND CLIMATIC CONDITIONS:

The experimental site was 249 metres above sea level, with latitude and longitude coordinates of 31.25° N and 75.71° E, respectively. The weather of Phagwara is humid subtropical, with hot summers and cool winters. It is situated in the central plain region of Punjab, one of the state's 6 agro-climatic regions. The land in the district is made up of alluvial deposits. Summer temperature can range from 45 to 48 °C, while winter temperatures can range from 1 to 19 °C.



(Source: www.mapsofindia.com, 2021)

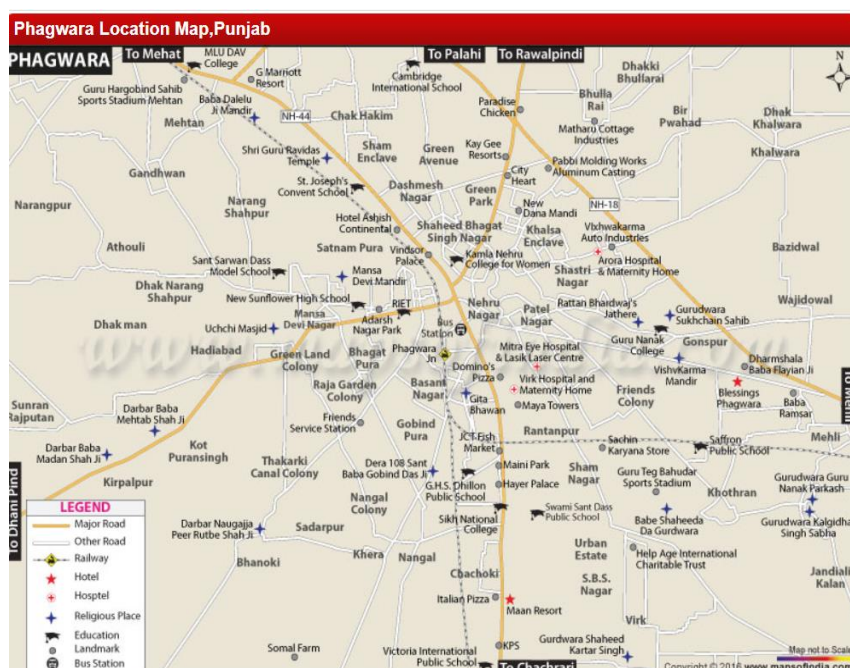


Fig.3.1 and 3.2: Location map and experimental site

Source: www.mapsofindia.com, 2021

3.3. PHYSICO-CHEMICAL PROPERTIES OF EXPERIMENTAL FIELD

To assess the Physico-chemical properties of the study area, soil samples were collected from various locations within the field at a depth of 0-15 cm. These soil samples were combined, dried, sieved, and subsequently analyzed in the laboratory to assess their physicochemical properties. The detailed results of this analysis are presented in Table 3.1. The comprehensive analysis adhered to standard protocols outlined below. The soil analysis outcomes indicated that the experimental soil possessed a sandy loam texture and exhibited a slightly alkaline pH. The soil exhibited a low level of organic carbon. Additionally, the soil analysis

revealed medium levels of available nitrogen, available phosphorus, and available potassium. The electrical conductivity was determined to be within the normal range as detailed in Table 3.1.

3.3.1. Physical analysis

3.3.1.1. Soil textural class:

The soil textural class of the experimental site was identified using the Hydrometer method as proposed by Bouyoucos (1962), and the classification was further determined through the triangular textural diagram for soil classification as outlined by Kanwar and Chopra (1967).

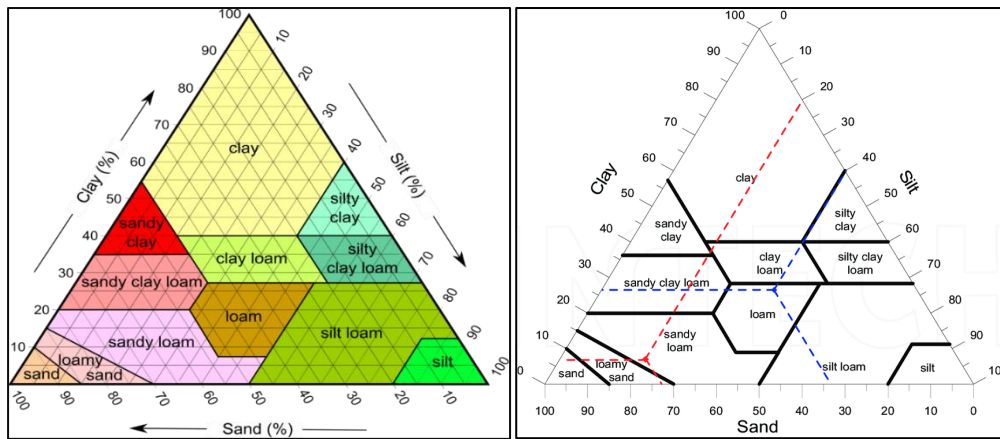


Fig.3.3.: Textural system of soil classification
(Source: Dream Civil, 2023)

3.3.2. Chemical analysis

3.3.2.1. Soil pH

The pH measurement was conducted using a glass electrode pH meter in a 1:2.5 soil-to-water suspension method both before and after the harvest of the crops, following the methodology outlined by Piper (1966).

3.3.2.2. Electrical Conductivity (EC)

The electrical conductivity (EC) was determined using a glass electrode and an EC meter in a 1:2.5 soil-to-water suspension method, both before and after the harvest of the crops, following the methodology outlined by Jackson (1967).

3.3.2.3. Organic carbon (%):

The estimation of soil organic carbon was conducted using the Walkley and Black method (1934).

3.3.3.4. Available Nitrogen (kg/ha):

The estimation of available nitrogen was conducted using the alkaline potassium permanganate (KMnO₄) method, wherein the organic matter in the soil underwent oxidation with a hot alkaline KMnO₄ solution. The ammonia released during oxidation was distilled and captured in an indicator solution mixed with boric acid. The quantity of NH₃ trapped was then estimated by titrating with standard acid, following the procedure outlined by Subbaiah and Asija (1956).

3.3.3.5. Available Phosphorous (kg/ha):

The determination of the available phosphorus content in the soil was carried out using the Olsen method, as described by Olsen *et al.* (1954). A 2.5 g sample of dried soil, containing a pinch of Darco G-60, was extracted with 50 ml of 0.5M NaHCO₃ (pH 8.5) for 30 minutes. Five milliliters of the filtrate were transferred to a 25 ml volumetric flask, and 2-3 drops of p-nitrophenol indicator were added, resulting in the development of a yellow color. Subsequently, 5N H₂SO₄ was added drop by drop until the yellow color disappeared, acidifying the solution to a pH of 5. To this, 4 ml of ascorbic acid solution was added, and the volume was adjusted. The resulting blue color, proportional to phosphate content, was measured on a spectrophotometer at a wavelength of 730 nm. A blank was prepared by adding all the chemicals except soil. The calculation for available phosphorus (kg/ha) was performed as follows: ppm of P calculated from the standard curve × dilution factor × 2.24.

3.3.3.6. Available Potassium (kg/ha):

The determination of available potassium content in the soil was conducted using the method outlined by Jackson (1973). In this process, 5.0 g of prepared soil was placed in a 100 ml conical flask and extracted with 25 ml of neutral normal ammonium acetate solution. The resulting filtrate was aspirated into the atomizer of a calibrated flame photometer, and the corresponding reading was recorded.

Table 3.1: Physico-chemical properties of soil.

S.N .	Properties	Before sowing (2020)	Method employed
1.	Physical analysis		
(i)	Sand (%)	56.4	Hydrometer method (Bouy-oucos,1962)
(ii)	Silt (%)	33	
(iii)	Clay (%)	10.6	
	Soil textural class	Sandy loam	Triangular Textural diagram (Kanwar and Chopra,1967)
2.	Chemical analysis		
(a)	Organic carbon (%)	0.52	Walkey and Black,1934
(b)	Soil pH	8.12	Piper,1966
(c)	Electrical conductivity (dSm ⁻¹).	0.47	Jackson,1967
(d)	Available nitrogen (kg/ha)	240.12	Subbaiah and Asija,1956
(e)	Available phosphorous (kg/ha)	18.12	By Olsen's method (Muhr <i>et al.</i> 1963)
(f)	Available potassium (kg/ha)	190.80	Muhr <i>et al.</i> 1963

3.4. CROPPING HISTORY

Table 3.2 provides information on the crops and cropping systems that were used on the experimental field in the years leading up to the experiment's start.

Table 3.2: Crop cultivation record of the experiment site

Year	<i>Kharif</i>	<i>Rabi</i>
2017-2018	Sugarcane	Sugarcane
2018-2019	Sugarcane	Sugarcane
2019-2020	Sugarcane	Sugarcane
2020-2021	Maize and Mungbean (Experimental crop)	Wheat (Experimental crop)

3.5. METEOROLOGICAL DATA

Weather conditions such as temperatures, relative humidity and rainfall were monitored throughout the study and the record was obtained from the meteorological unit of Lovely Professional University, Punjab. The monthly average temperature, relative humidity, wind speed and rainfall of the *kharif* season are presented below: -

SMW*	Period	Mean Temperature ($^{\circ}$ C)	Relative Humidity (%)	Wind speed (km/hr.)	Rainfall (mm)
27	01-05 Jul 2020	41.60	26.60	15.00	0.04
28	06-12 Jul 2020	36.71	42.43	11.00	5.23
29	13-19 Jul 2020	38.43	38.00	9.86	1.63
30	20-26 Jul 2020	34.43	50.00	8.43	4.87
31	27Jul-02Aug 2020	35.57	54.43	9.71	8.16
32	03-09Aug 2020	35.86	53.14	10.14	2.10
33	10-16Aug 2020	32.57	73.00	11.43	15.61
34	17-23Aug 2020	31.57	71.14	10.29	10.40
35	24-30Aug 2020	31.29	70.14	9.14	14.06
36	31Aug-06Sep 2020	31.29	69.57	10.14	6.53
37	07-13Sep 2020	33.14	52.86	6.86	0.03
38	14-20Sep 2020	33.57	43.71	8.14	0.00
39	21-27Sep 2020	32.71	42.71	9.57	0.00
40	28Sep-04Oct 2020	31.57	25.07	6.43	0.00
41	05-11Oct 2020	30.07	22.29	6.71	0.00
42	12-18 Oct 2020	28.8	27.70	6.10	0.0
43	19-25 Oct 2020	26.57	48.50	3.71	2.29
44	26Oct-01 Nov 2020	24.43	51.79	4.71	2.00
45	02-08Nov 2020	23.71	47.00	3.14	0.00
46	09-15 Nov 2020	21.64	54.00	4.29	0.00
47	16-22 Nov 2020	20.00	59.00	4.43	0.29
48	23-29 Nov 2020	17.79	61.50	4.29	0.00
49	30Nov-06 Dec 2020	16.93	60.21	2.86	0.00
50	07-13 Dec 2020	16.79	65.14	5.71	0.00
51	14-20 Dec 2020	13.43	37.79	11.29	0.00
52	21-27 Dec 2020	11.64	60.14	3.57	0.00
53	28 Dec 2020-03 Jan 2021	11.29	67.50	1.29	0.00
01	04-10 Jan 2021	10.57	70.93	1.71	0.00
02	11-17Jan 2021	10.07	74.50	1.29	0.00
03	18-24 Jan 2021	10.43	79.79	4.29	0.00
04	25-31Jan 2021	11.57	67.50	6.29	0.00
05	01-07Feb 2021	15.93	46.43	9.57	0.00
06	08-14 Feb 2021	15.86	70.86	3.57	0.00
07	15-21Feb 2021	16.71	81.71	3.14	0.00
08	22-28 Feb 2021	21.79	64.93	3.14	0.00
09	01-07 Mar 2021	22.43	52.79	3.43	0.00
10	08-14Mar 2021	24.79	51.29	4.57	0.00
11	15-21 Mar 2021	24.57	51.29	2.29	0.00
12	22-28Mar 2021	21.86	47.57	2.29	0.60
13	29Mar-04 Apr 2021	23.36	38.57	6.00	0.00
14	05-11 Apr 2021	22.64	35.50	2.57	0.71
15	12-18 Apr 2021	24.79	33.57	2.00	0.03
16	19-25Apr 2021	23.43	37.86	3.71	2.63
17	26Apr-2May2021	24.00	35.00	2.00	0.00

Table 3.3: Mean weekly meteorological weather parameters and rainfall during crop season 2020-21. SMW*= Standard Meteorological Week.

Source: Lovely Professional University, Punjab

SMW*	Period	Mean Temperature (°C)	Relative Humidity (%)	Wind speed (km/hr.)	Rainfall (mm)
26	01-04Jul 2021	36.00	49.50	5.00	6.00
27	05-11 Jul 2021	36.43	48.00	5.43	4.86
28	12-18Jul 2021	36.29	52.64	4.00	4.00
29	19-25 Jul 2021	34.50	70.71	3.14	6.86
30	26Jul-01Aug 2021	31.14	67.29	4.00	4.39
31	02-08 Aug 2021	35.36	72.36	4.00	0.00
32	09-15 Aug 2021	34.93	69.86	6.29	1.37
33	16-22 Aug 2021	35.07	69.07	3.71	0.00
34	23-29Aug 2021	35.07	68.57	5.67	8.57
35	30Aug-05 Sep 2021	34.75	69.58	3.33	4.67
36	06-12 Sep 2021	34.36	69.29	4.00	3.23
37	13-19 Sep 2021	34.00	68.14	3.60	1.71
38	20-26 Sep 2021	34.21	66.00	4.29	7.86
39	27Sep-03Oct 2021	32.86	60.79	4.86	0.00
40	04-10 Oct 2021	32.14	49.93	3.00	0.00
41	11-17 Oct 2021	28.43	49.21	3.33	0.00
42	18-24 Oct 2021	25.29	49.00	2.00	0.00
43	25-31 Oct 2021	23.71	48.07	3.00	0.00
44	01-07 Nov 2021	23.21	49.50	2.86	0.00
45	08-14 Nov 2021	20.64	49.21	2.00	0.00
46	15-21 Nov 2021	19.79	52.79	2.29	0.00
47	22-28Nov 2021	17.64	50.36	0.57	0.00
48	29 Nov-05Dec 2021	16.36	55.86	1.43	0.00
49	06-12 Dec 2021	15.71	60.36	1.43	0.00
50	13-19 Dec 2021	14.50	59.29	1.43	0.00
52	20-26Dec 2021	14.57	59.14	0.57	0.00
53	27Dec 2021-02 Jan 2022	12.64	62.14	0.86	0.07
01	03-09 Jan 2022	11.57	69.07	1.71	13.79
02	10-16 Jan 2022	14.00	69.14	3.14	1.29
03	17-23 Jan 2022	14.00	66.86	2.00	0.29
04	24-30 Jan 2022	13.21	71.86	2.29	0.00
05	31Jan-06 Feb 2022	12.14	70.07	3.20	0.07
06	07-13 Feb 2022	10.79	71.14	3.20	0.00
07	14-20Feb 2022	12.86	66.07	3.50	0.00
08	21-27 Feb 2022	14.93	57.93	3.20	2.29
09	28 Feb-06 Mar 2022	14.07	53.21	2.00	0.00
10	07-13 Mar 2022	18.86	49.00	1.43	0.00
11	14-20Mar 2022	25.00	48.64	3.14	0.00
12	21-27Mar 2022	26.93	46.43	2.86	0.00
13	28Mar-03 Apr 2022	26.79	47.50	3.71	0.00
14	04-10 Apr 2022	30.21	40.50	4.86	0.00
16	11-17 Apr 2022	34.43	39.71	1.71	0.07
17	18-24Apr 2022	34.29	33.29	15.43	0.00
18	25-01May2022	36.42	27.50	8.33	0.00

Table 3.4: Mean weekly meteorological weather parameters and rainfall during crop season 2021-22. SMW*= Standard Meteorological Week.

Source: Lovely Professional University, Punjab

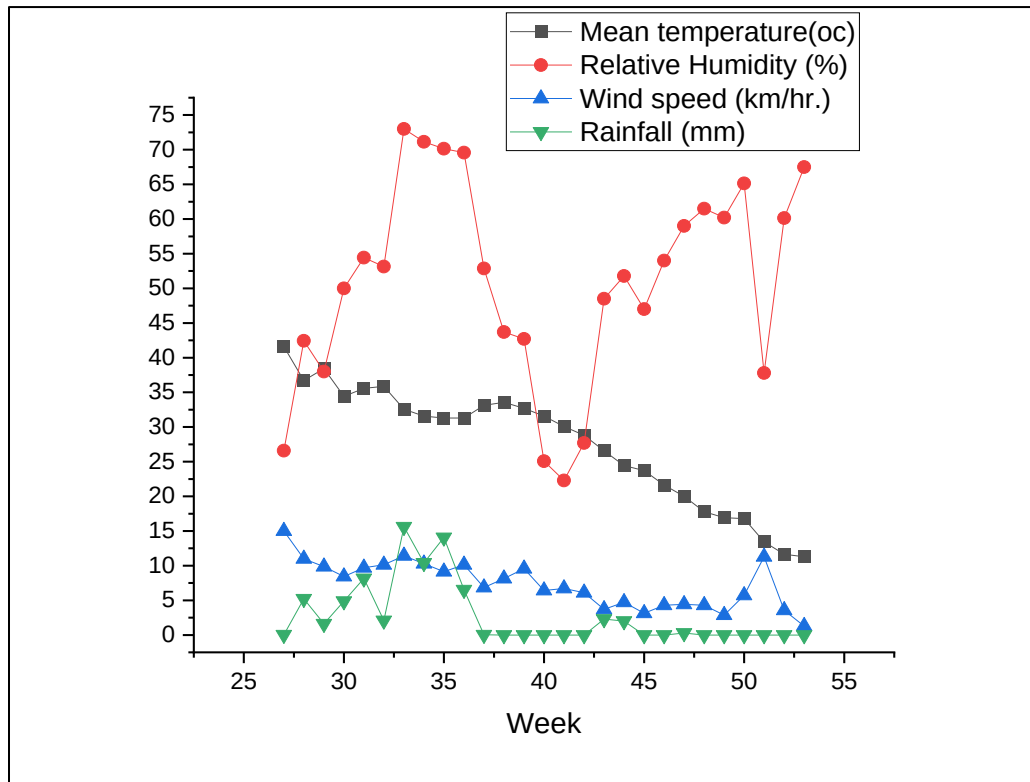


Fig. 3.4: Mean weekly meteorological weather and rainfall during crop season (2020-21).

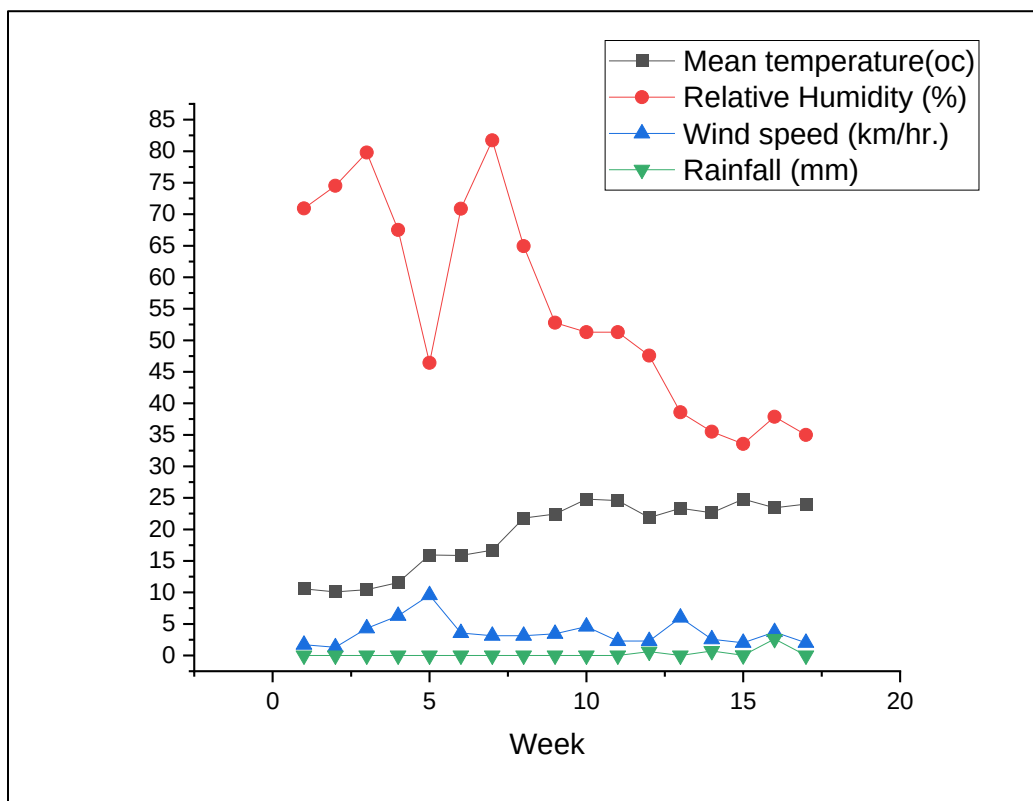


Fig. 3.5: Mean weekly meteorological weather and rainfall during crop season (2021).

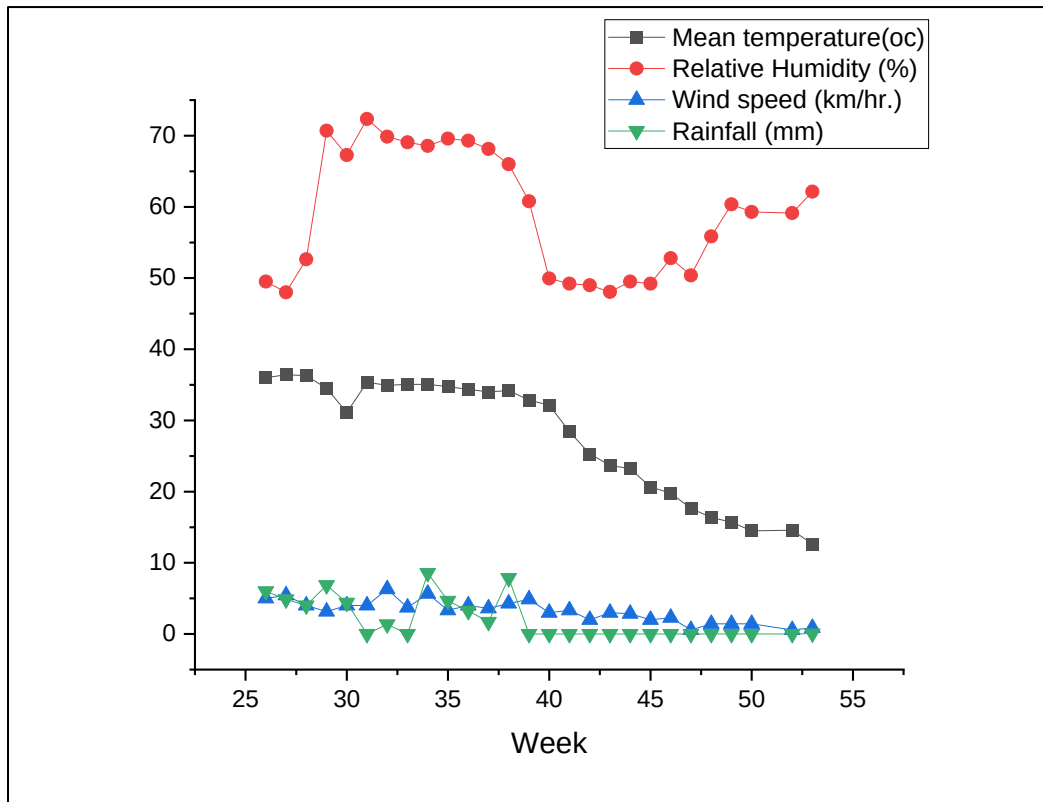


Fig. 3.6: Mean weekly meteorological weather and rainfall during crop season (2021-22).

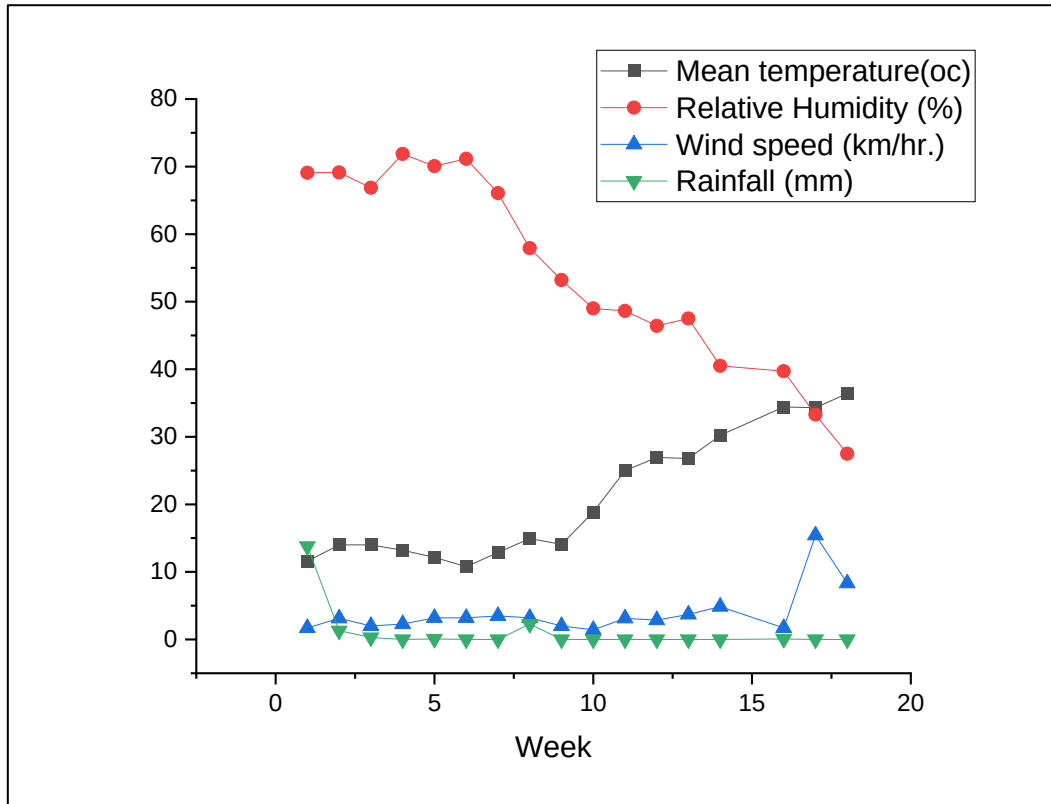


Fig. 3.7: Mean weekly meteorological weather and rainfall during crop season (2022).

3.6. EXPERIMENTAL DETAILS AND DESIGN

The experiment consisted of a total of 12 treatments, and each treatment was replicated three times. The field trials were conducted in both *kharif* and *rabi* seasons of 2020-22. The split plot design was employed for the field experiments, particularly during the *kharif* season in the first main factor, the cropping system was considered, consisting of three sub-factors: M₁) maize sole cropping, M₂) mungbean sole cropping, and M₃) maize + mungbean intercropping. Additionally, the second main factor involved different levels of fertilizers, with four subplots designated as S₁ (control), S₂ (100% RDF), S₃ (100% Nano NPK fertilizers), and S₄ (50% RDF + 50% Nano NPK fertilizers).

Similarly, for the *rabi* season focusing on wheat, two main factors were considered. The first main factor involved the residual effect of the previous crop, with M₁ representing the residual effect of maize on wheat, M₂ for the residual effect of mungbean on wheat, and M₃ for the residual effect of maize and mungbean on wheat. In the second main factor, different levels of fertilizers were applied across four subplots: S₁ (control), S₂ (100% RDF), S₃ (100% Nano NPK fertilizers), and S₄ (50% RDF + 50% Nano NPK fertilizers). The table detailing the specifics of the experiment is given below (table 3.10 and 3.11).

Table 3.5: Experiment detail followed for *kharif* season (2020 and 2021).

Crop	Maize and mungbean (2020)	Maize and mungbean (2021)
Treatments	12	12
Replication	3	3
Design	Split plot design	Split plot design
Gross Plot size	5m x5m=25m ²	5m X 5m=25m ²
Net plot size	4.5m x 4.5=20.25m ²	4.5m x 4.5=20.25m ²
Total experimental plot	62x18=1116m ²	62x18=1116m ²
Spacing	Maize=60cmx20cm Mungbean =30cmx10cm	Maize=60cmx20cm Mungbean =30cmx10cm
Sowing depth	Maize=4-6cm Mungbean =3-5cm	Maize= 4-6cm Mungbean =3-5cm
Date of sowing	13 July 2020	1 July 2021
Harvesting of crop	Maize= 9 November 2020 Mungbean= 30 Sep 2020	Maize= 28 October 2021 Mungbean= 18 September 2021
Spacing between the main plot	1m	1m
Spacing between replication	1.5m	1.5m

Table 3.6:Experiment detail followed for *rabi* season (2020-21 and 2021-22).

Crop	Wheat (2020-2021)	Wheat (2021-2022)
Treatments	12	12
Replication	3	3
Design	Split plot design	Split plot design
Gross Plot size	5m x5m=25m ²	5m X5m=25m ²
Net plot size	4.5m x 4.5=20.25m ²	4.5m x 4.5=20.25m ²
Total experimental plot	62x18=1116m ²	62x18=1116m ²
Spacing	22.5cm	22.5cm
Sowing depth	4-6 cm	4-6 cm
Date of sowing	28 December 2020	13 December 2021
Harvesting of crop	25 May 2021	10 May 2022
Spacing between the main plot	1m	1m
Spacing between replication	1.5m	1.5m

3.6.1. VARIETAL CHARACTERISTICS OF CROPS

The seed of maize, variety- Kaveri-50 (hybrid), mungbean (variety- ML-818) and wheat (variety -PBW-550) and were procured from Lovely Professional University, Phagwara, Punjab and were used for the present study. Uniform seeds were screened and used freshly for the experiment to minimize errors in seed germination.

Table 3.7.: Varietal characteristic of maize crop

S.No.	Character	Kaveri 50 (Hybrid corn)
1	Type of seed	Truthful seed
3	Germination	90
4	Purity (%)	95
5	Grain Yield (q/acre)	16-25
7	Days to maturity	110-120
9	Seed rate (kg/ha)	25-30

Table 3.8: Varietal characteristics of mungbean crop.

S.No.	Character	ML- 818
1	Type of seed	Certified seed
2	Year of release	2003
3	Germination	86
4	Purity (%)	98
5	Seed Yield (q/acre)	4.9

6	Tolerance to disease	Yellow vein mosaic, cercospora and bacterial leaf spot
7	Days to maturity	80
8	Suitable for area	Punjab
9	Seed rate (kg/ha)	20

Table 3.9: Varietal characteristics of wheat crop

S.No.	Character	PBW-550
1	Type of seed	Certified seed
2	Year of release	2017
3	Germination	89
4	Purity (%)	98
5	Grain Yield (q/acre)	23
6	Resistant to disease	Yellow and brown rust
7	Days to maturity	145
8	Suitable for area	Punjab
9	Seed rate (kg/ha)	125-150

3.7. TREATMENTS

Table 3.10: Treatments of *kharif* season.

Treatments	Experiment-I (Maize and Mungbean)
Main plot	Cropping system
M ₁	Maize (sole cropping)
M ₂	Mungbean (sole cropping)
M ₃	Maize + Mungbean (Intercropping)
Subplots	Different levels of fertilizers
S ₁	Control (No fertilizers)
S ₂	100 % Recommended dose of fertilizers (RDF)
S ₃	100 % Nano NPK fertilizers
S ₄	50 % RDF +50% Nano NPK fertilizers

Table 3.11: Treatments of *rabi* season.

Treatments	Experiment-II (wheat)
Main plot	Residual effect of crops
M ₁	Residual effect of maize on wheat
M ₂	Residual effect of mungbean on wheat
M ₃	Residual effect of Maize + Mungbean Intercropping on wheat
Subplots	Different levels of fertilizers
S ₁	Control (No fertilizers)
S ₂	100 % Recommended dose of fertilizers (RDF)
S ₃	100 % Nano NPK fertilizers
S ₄	50 % RDF +50% Nano NPK fertilizers

3.8. EXPERIMENTAL LAYOUT

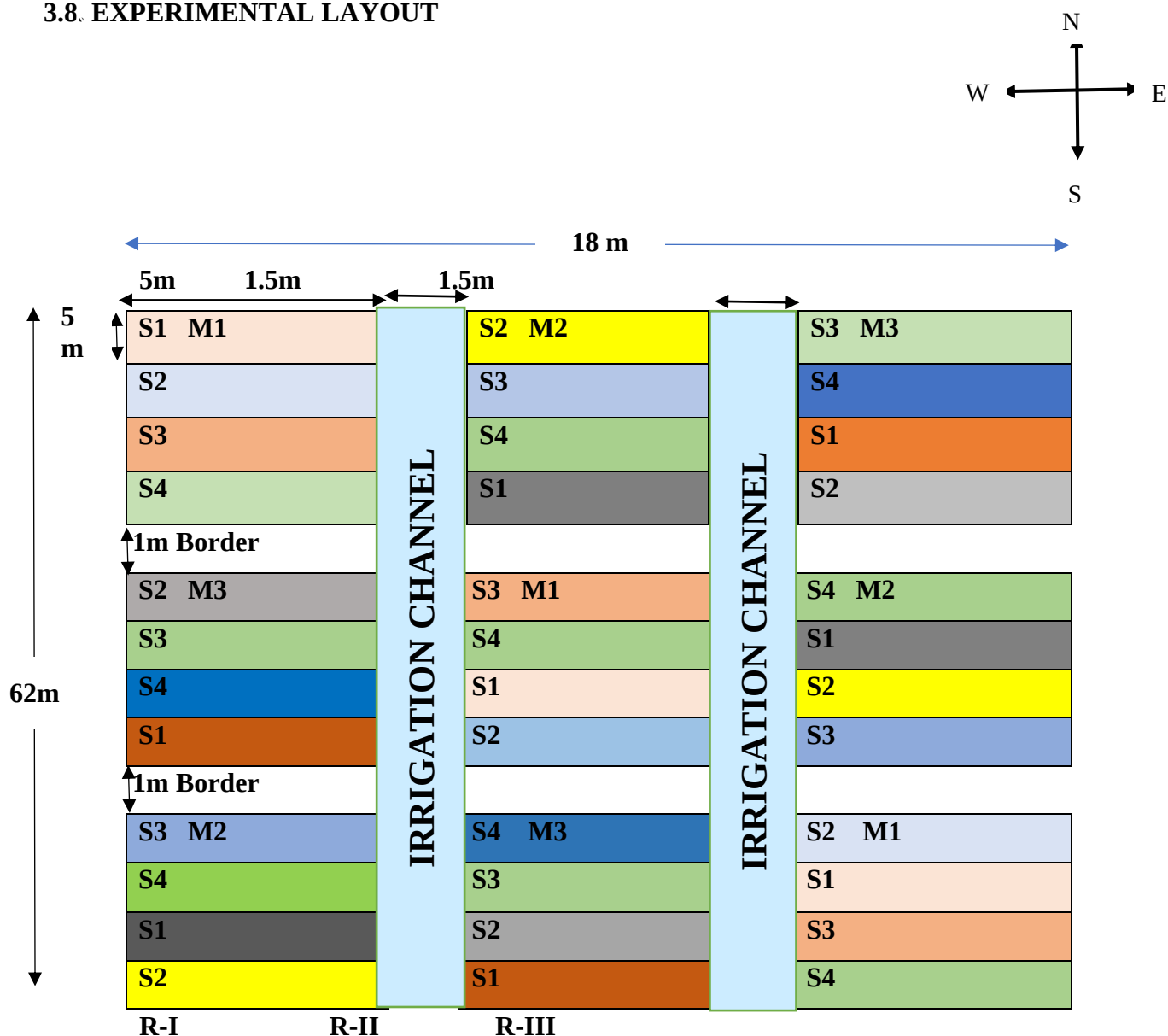


Fig.3.8: Experimental layout (both *kharif* and *rabi* season)

3.8. CULTURAL PRACTICES

3.8.1. Pre sowing Irrigation.

One week prior to field preparation, pre-sowing irrigation was performed to ensure that the soil had enough moisture for the seeds to germinate properly as well as to control weed and remove chemicals used in the cultivation of previous crops.

3.8.2. Field Preparation

The trial field was methodically ready by first cultivating it using a tractor-attached cultivator, then harrowing it, and finally planking it to make sure it

was level. After the field had been prepared, plots were set up in accordance with the layout's specific instructions. Table 3.12, 3.13 and 3.14 contains a list of the precise actions taken throughout the field investigation.

Table 3.12: Schedule of cultural operations in maize (*kharif*).

S.No.	Cultural operation	Implement/method used (2020)	Implement/method used (2021)	Date (2020)	Date (2021)
1	Pre sowing irrigation	Flooding	Flooding	01-07-20	18-06-21
2	Ploughing and harrowing	Tractor-drawn cultivator and disc harrow	Manual	10-07-20	28-06-21
3	Soil sampling	Soil auger	Soil auger	10-07-20	29-06-21
4	Planking	Tractor drawn planker	Manual	11-07-20	30-06-21
5	Layout preparation	Manual	-	11-07-20	01-07-21
6	Fertilizer application and sowing	Manual	Manual	13-07-20	01-07-21
8	Gap filling	Manual	Manual	20-07-20	12-07-21
7	Nanofertilizers application	Knapsack sprayer	Knapsack sprayer	07-08-20 04-09-20 19-09-20	26-07-21 17-08-21 02-09-21
9	Hand weeding	Khurpi	Khurpi	03-08-20 28-08-20	21-07-21 09-08-21
10	Irrigation	Controlled flow	Controlled flow	01-08-20 17-08-20 02-09-20 17-09-20 22-09-20	19-07-21 16-08-21 01-09-21 06-09-21 20-09-21
11	Plant protection	Knapsack sprayer	Knapsack sprayer	04-08-20 21-08-20	22-07-21 21-08-21
12	Harvesting	Manual	Manual	09-11-20	28-10-21
13	Threshing and winnowing	Manual	Manual	10-11-20	30-10-21

Table 3.13: Schedule of cultural operations in mungbean (*kharif*).

S.No.	Cultural operation	Implement/method used (2020)	Implement/method used (2021)	Date (2020)	Date (2021)
1	Pre sowing irrigation	Flooding	Flooding	01-07-20	18-06-21
2	Ploughing and harrowing	Tractor-drawn cultivator and disc harrow	Manual	10-07-20	28-06-21

3	Soil sampling	Soil auger	Soil auger	10-07-20	29-06-21
4	Planking	Tractor drawn planker	Manual	11-07-20	30-06-21
5	Layout preparation	Manual	-	11-07-20	01-07-21
6	Fertilizer application and sowing	Manual	Manual	13-07-20	01-07-21
7	Nanofertilizers application	Manual	Manual	07-08-20 17-08-20 28-19-20	26-07-21 18-08-21 01-09-21
8	Gap filling	Manual	Manual	24-07-20	12-07-21
9	Hand weeding	Khurpi	Khurpi	28-07-20 05-08-20	15-07-21 30-07-21
10	Irrigation	Controlled flow	Controlled flow	03-08-20 18-08-20 02-09-20 17-09-20	10-07-21 26-07-21 10-08-21 25-08-21
11	Harvesting	Manual	Manual	30-09-20	18-09-21
13	Threshing and winnowing	Manual	Manual	01-10-20	19-09-21

Table 3.14: Schedule of cultural operations in wheat (*rabi*).

S.No.	Cultural operation	Implement/method used	Date (2020-21)	Date (2021-22)
1	Pre sowing irrigation	Flooding	21-12-20	30-11-21
2	Ploughing and harrowing	Manual	27-12-20	10-12-21
3	Soil sampling	Soil auger	27-12-20	11-12-21
4	Planking	Manual	27-12-20	11-12-21
5	Layout preparation	Manual	27-12-20	13-21-21
6	Fertilizer application and sowing	Manual	28-12-20	13-12-21
7	Nanofertilizers application	Knapsack sprayer	22-01-21 11-02-21 24-03-21	03-01-22 24-01-22 07-03-22
8	Gap filling	Manual	09-01-21	23-12-21
9	Hand weeding	Khurpi	18-01-21 04-02-21	03-01-22 18-01-22
10	Irrigation	Controlled flow	19-01-21 13-02-21 09-03-21 01-04-21 26-04-21	04-01-22 27-01-22 23-02-22 15-03-22 28-03-22
11	Harvesting	Manual	25-05-21	10-05-22
13	Threshing and winnowing	Manual	27-05-21	12-05-22

3.8.3. Manure incorporation.

Farmyard manure was incorporated across the entire field before the crop

was sown.

3.8.4. Fertilizer application

Urea, single super phosphate, and muriate of potash were among the chemical fertilizer sources. During the experiment, nanofertilizers treatments included Nano NPK in granular form (G).

3.8.4.1 Maize

During the sowing process, full doses of phosphorus and potassium were administered. Whereas nitrogen was provided in three doses: the first at sowing, the second at knee height, and the last dose at the pre-tasseling stage.

3.8.4.2 Mungbean

In mungbean, the complete dose of N and P was drilled at the time of sowing.

3.8.4.3 Wheat

Phosphorus and potassium were given full doses at the time of sowing, while nitrogen was supplied in three different doses. The initial dose of nitrogen was given during sowing, followed by the second and third doses at the time of irrigation.

Table 3.15: Recommended dose of fertilizers.

S.No.	Crops	Recommended dose of fertilizers(kg/acre)
1	Maize	50:24:12 N: P ₂ O ₅ : K ₂ O (110 kg urea,150kg SSP and 20 kg of MOP)
2	Mungbean	5:16:0 N: P ₂ O ₅ : K ₂ O (11 kg urea and 100 kg SSP)
3	Wheat	50:25:12 N: P ₂ O ₅ : K ₂ O (110kg urea,155kg SSP and 20kg MOP)

3.8.5. Nanofertilizers application

Nitrogen, phosphorous and potassium nanofertilizers were obtained from authorized sources and were applied as foliar application at the rate of 2g/litre. The Nano NPK (G) contains 19 % each of N, P and K respectively.

3.8.5.1. Specification

The Nano NPK contains, 1.5 % of moisture by weight, 4.0 % of nitrate nitrogen by weight,4.5 % of ammoniacal nitrogen percent by weight, water soluble phosphate (as P₂O₅) (19%), water soluble potassium (as K₂O) percent by weight, sodium as NaCl percent by weight on dry basis (0.5%), maximum and matter insoluble in water percent by weight (0.5%).

3.8.5.2. Maize

NPK Nanofertilizers in maize were used as foliar applications, with three sprays given in maize crop, the first at knee height stage (25 DAS), the second at tasseling (50 DAS), and the third at silking stage (65 DAS).

3.8.5.3. Mungbean

In mungbean NPK nanofertilizers were sprayed in three equal split dosages, first at 25 DAS, then at 34 DAS (Pre-flowering stage), and finally at 60 DAS.

3.8.5.4. Wheat

In wheat, NPK nanofertilizers were sprayed three times: at crown root initiation (25 DAS), tillering (45 DAS), and pre-flowering (86 DAS).

3.8.6. Sowing

The maize, mungbean, and wheat seeds are sown manually at a recommended spacing and depth as mentioned in Table 3.5 and 3.6.

3.8.7. Gap filling and thinning

To maintain an optimal plant population, gaps were filled 10 days after seeding in each plot. Filling in the gaps in areas where germination does not occur was done to ensure adequate space and the best crop stand. Wheat and mungbean plants were thinned.

3.8.8. Irrigation

Maize crop being very sensitive to moisture stress; moisture availability to the crop throughout the growth period was maintained. A total of five irrigations were given during the entire crop period.

For optimal development and growth, the mungbean crop requires the least amount of moisture. In the instance of the mungbean crop, four irrigations were given.

Irrigation was applied to the wheat crop based on the amount of soil moisture present. A total of 5 irrigation was given to the wheat crop given during the entire crop period.

3.8.9. Weeding

To maintain a weed-free experimental field, continuous efforts were made throughout the agricultural season. In both the *kharif* and *rabi* crop growth cycles, two hand weeding sessions were carried out for all crops, including maize, wheat,

and mungbean.

3.8.10. Plant protection

In maize, the incidence of pest infestation (fall army worm) was controlled by spraying emamectin benzoate (5 SG) at 0.4g/litre with 120 litres of water per acre for crop up to 20 days old. Following that, the amount of water utilized per acre increased to 200 litres, with a corresponding increase in insecticide dosage. The nozzle was pointed towards the whorl for effective control.

3.8.11. Harvesting, threshing, and winnowing

3.8.11.1. Maize

Harvesting was done by removing the ear manually when the plants had attained physiological maturity as the cobs turn yellowish-brown and grains have hardened. The cobs were then sundried, weighed and later threshed and winnowed to obtain clean grain.

3.8.11.2. Mungbean

A sickle was used to harvest the crop once 80% of the pods were fully mature. Each net plot's harvested crop was wrapped into bundles and kept in the sun for two days for drying. The bundles were then threshed and winnowed before being weighed individually with a weighing balance (Mettler Toledo SB 16001 model).

3.8.11.3. Wheat

The crop was manually harvested with a sickle once it had reached full maturity. The crop from individually net plot was bundled in bundles and left to dry in the sun for two days. The bundles were collected after two days and brought to the threshing floor where they were threshed and winnowed before being weighed individually on a weighing balance (model-Mettler Toledo SB 16001).

3.9. OBSERVATION RECORDED ON CROPS

3.9.1. MAIZE

3.9.1.1. Growth Parameters

At 30, 60, and 90 days after sowing (DAS), as well as at harvest, measurement of all growth parameters was done.

3.9.1.1.1. Plant height (cm)

The height of each plant was measured using a measuring tape from the ground up to the tips of the flag leaf and tassels. Each net plot contained five sample plants, and measurements were made at the 30, 60, 90, and harvest stages.

Next, calculation and recording of the average value for each plot was made.

3.9.1.1.2. Number of leaves

From top to bottom, each plant's leaves were counted to determine the no. of leaves on each individual plant. The no. of leaves per plant was then used to express the average value for the chosen plants in each treatment.

3.9.1.1.3. Leaf area (cm²)

Destructive sampling was utilized to measure leaf area through a leaf area meter (model No-211).

3.9.1.1.3.1. Working principle of Leaf Area Meter

The Leaf Area Meter (Model no. 211) is made of a diffuser plate whose four sides are marked with a mask plate to leave a circle of definite area in the center. The circular portion is illuminated from underneath within fluorescent lamps to achieve good uniformity. This illuminated circle is imaged on a photocell by a lens. The output of the photocell is proportional to the intensity of illumination which is a measure of the area of the circle. A leaf plate on the carriers covers certain areas of the luminous rectangle and the resulting decrease in the output of the photocell is proportional to the covered area by the sample leaf.

3.9.1.1.4. Leaf Area Index (LAI)

The leaf area index was calculated by dividing the total leaf area measured by the leaf area metre by the area of the ground.

Total leaf area (cm²)

Leaf area index=-----

Total ground area (cm²)

3.9.1.1.5. Days to 50% tasseling.

The no. of days from when the seeds were planted until roughly half of them had reached tasseling was counted and recorded.

3.9.1.1.6. Days to 50% silking

At the time the seeds were sown until roughly half of them reached tasseling, the number of days was counted and recorded.

3.9.1.1.7. Days to 90% physiological maturity

For each plot, the no. of days from the date of seeding till the plant reached physiological maturity was determined and recorded in accordance.

3.9.1.1.8. Crop growth rate (g/m²/day)

Using the formula provided by Watson (1958), the crop growth rate was determined as follows:

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{A} \text{ g m}^{-2} \text{ day}^{-1}$$

Whereas,

W_1 and W_2 = the total dry weight of plant at T_1 and T_2 stages in grams.

T_1 and T_2 = the time interval between two stages in days.

A represents the ground area in m².

3.9.1.1.9. Relative growth rate (g/g/day)

Using the formula provided by Blackman (1919), the relative growth rate was determined as follows.

$$\text{RGR} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1 \text{ (g/g/day)}}{t_2 - t_1}$$

Whereas,

W_1 and W_2 = the total dry weight of plant at t_1 and t_2 stages in grams.

t_1 and t_2 = the time interval between two stages in days.

3.9.1.1.10. Shoot dry weight (g)

To determine the shoot dry weight per plant, five plants were chosen from each plot and dried in a hot air oven at 70°C until a consistent weight was achieved. The dried plants were weighed using a weighing balance, and the average weight was recorded as g/plant.

3.9.1.2. Yield components and yield

3.9.1.2.1. Cobs per plant

The average no. of cobs from each net plot was determined by randomly selecting five plants and counting them. The mean value was then calculated accordingly.

3.9.1.2.2. Cob diameter (cm)

From five randomly chosen plants, the diameter of the cobs was measured at the center, and the mean value was represented in centimeters.

3.9.1.2.3. Cob length(cm)

Five randomly chosen dehusked cobs from each net plot were used to measure the length of the cobs, and the mean value was then noted.

3.9.1.2.4. Cob weight(g)

The weight of five randomly chosen cobs was recorded using a weighing scale, and the mean was represented as cob weight in grams.

3.9.1.2.5. Number of grains/row

For each of the five sampled cobs, the no. of grains per row were recorded. For each plot, the average value was recorded.

3.9.1.2.6. No. of grain rows/cob

For each of the five plants, the no. of grain rows was counted. The values obtained were put together, then divided by the sample size of the corn (5). For each plot, the average value was recorded.

3.9.1.2.7. No. of grains/cob

No of grains/cob was recorded from each 5 selected cobs and mean was computed.

3.9.1.2.8. Test weight (g)

One thousand grains were randomly chosen from each treatment's cobs, washed, dried, and weighed in grams.

3.9.1.2.9. Straw yield (kg/ha)

The maize straw yield from each net plot, comprising that of five plants and the shank after shelling, was measured and reported as kg/ha after the produce was sun dried until it reached a consistent weight.

3.9.1.2.10. Grain yield(kg/ha)

Each net plot's cobs were threshed, cleaned, and weighed using a weighing balance. The weight was then represented in kg/ha.

3.9.1.2.11. Biological yield (kg/ha)

Each net plot's biological yield was separately recorded and then converted into biological yield by using the mean value.

BY = (Grain yield + straw yield)

3.9.1.2.12. Harvest Index (%)

It was estimated using Donald and Hamblin's (1976) method.

$$\text{HI (\%)} = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

3.9.1.3. Maize equivalent yield (kg/ha)

It was determined by using the formulation given below: -

$$\text{MEY (kg/ha)} = \text{Maize yield (kg/ha)} + \frac{\text{Intercrop yield (kg/ha)} \times \text{Intercrop price (Rs/ha)}}{\text{Maize price (Rs/ha)}}$$

3.9.1.4. Fall armyworm (*Spodoptera frugiperda*) on maize.

Observation of fall armyworm was recorded at weekly intervals on five randomly selected plants starting from sowing to harvesting of the crop. The fall armyworm infestation because of various levels of fertilizer and cropping systems was recorded at the phonological stage of plants on a different basis. A numerical scale (1-9) also known as the Davis scale, was used to evaluate leaf damage maize ear, and kernel damage (As per Davis and Willams,1992).

Table 3.16: Indicating maize leaf rating scale.

Explanation/definition of damage	Rating
1. No visible damage.	0
2. Only pin-hole damage.	1
3. Pinhole and small circular hole damage to leaves	2
4. Pinhole, small circular lesions, and a few small elongated (rectangular shaped) lesions of up to 1.3 cm length present on whorl and furl leaves.	3
5. Several small to mid-sized 1.3 to 2.5 cm in length elongated lesions present on a few whorls and furl leaves and or a few small to mid-sized, uniform to irregular shaped holes (basement membrane consumed) eaten from whorl leaves.	4
6. Several large, elongated lesions present on several whorl and furl leaves and or several large uniform to irregular shaped holes eaten from furl and whorl leaves.	5
7. Many elongated lesions of all size present on several whorl and furl leaves and or several large uniform to irregular shaped holes eaten from the whorl and furl leaves.	6

8. Many elongated lesions of all sizes present on several whorl and furl leaves and or several large uniform to irregular shaped holes eaten from the whorl and furl leaves.	7
9. Many elongated lesions of all sizes present on most whorl and furl leaves plus many mid to large sized uniform to irregular shaped holes eaten from the whorl and furl leaves.	8
10. Whorl and furl leaves almost destroyed.	9

Table 3.17: Indicating leaf damaging rating scale/classification.

Explanation/definition of damage	Rating
Minimal visible leaf damage;(Least susceptible)	1-4
Marginal leaf damage;(Moderately susceptible)	>4-7
Extensive leaf damage;(Highly susceptible)	>7-9

Table 3.18: Indicating maize ear and kernel rating scale.

Explanation/definition of damage	Rating
1.No damage to any ears;	1
2.Tip(<3cm) damage to 1-3 ears	2
3. Tip damage to 4-7 ears	3
4. Tip damage to 7 and more ears and damage to 1-3 kernels below ear tips on 1 to 3 ears	4
5. Tip damage to 7 and more ears and damage to 1-3 kernels below tips of 7 to 8 ears	5
6. Ear tip damage 7-10 ears and damage to 1-4 kernels below tips of 7-10 ears.	6
7. Ear tip damage to 7-10 ears and damage to 4-6 kernels destroyed on 7-8 ears.	7
8. Ear tip damage to all ears and 4-6 kernels destroyed on 7-8 ears	8
9. Ear tip damage to all ears and 5 or more kernels destroyed below tips of 9-10 ears.	9

Table 3.19: Indicating maize ear and kernel rating scale.

Explanation/definition of damage	Rating
1. Minimal damage to any ears (Least susceptible)	1-4
2. Kernels and ears damaged (Moderately susceptible)	>4-7
3. Ear and kernels extensively destroyed (Highly susceptible)	>7-9

3.9.1.5. Nutrient uptake (kg/ha) in grain and straw

This was established after crop harvest, when grain and straw samples from each plot were collected and examined for a variety of factors (NPK). Using a modified version of the Kjeldahl technique, the nitrogen content of maize grain and straw was assessed on a dry weight basis (Jackson,1967). The P content in both grain and straw of maize was determined using the Vando-molybdo phosphate yellow color method (Jackson,1967). The standard neutral ammonium acetate method was used to determine the potassium content in both maize grain and straw, utilizing a flame photometer (Jackson, 1967). The results were used to

determine nutrient uptake.

$$\text{Nutrient uptake} = \frac{\text{Nutrient content in grain/straw (\%)} \times \text{dry weight of grain/straw (kg/ha)}}{100}$$

3.9.2. MUNGBEAN

3.9.2.1. Growth parameters

The growth characteristics were observed at 20, 40, and 60 days after sowing (DAS), as well as at harvest.

3.9.2.1.1. Plant height (cm)

The height of five randomly selected plants in each plot was measured from the ground to the tip of the main stem and then the mean was calculated.

3.9.2.1.2. Number of leaves /plant

Counting the leaves of five randomly selected, tagged plants in each net plot yielded the no. of leaves per plant. The no. of leaves per plant was then calculated using the mean value of the number of leaves per plant.

3.9.2.1.3. Number of branches/plant

The no. of branches per plant was determined by counting 5 randomly tagged plants from each net plot. Each plot's average value was recorded and expressed as the no. of branches/plant.

3.9.2.1.4. Leaf area (cm²)

Same as maize

3.9.2.1.5. Leaf Area Index (LAI)

Same as maize

3.9.2.1.6. Days to 50% flowering

The plots were checked on a regular basis and the exact day that 50% of the crops in the experimental plot started flowering was noted. The 35 days after seeding were computed from the date of sowing.

3.9.2.1.7. Days to 90% maturity

The days between when the seeds were planted and when approximately half of them reached physiological maturity were tallied and recorded.

3.9.2.1.8. Crop growth rate (g/m²/day)

Same as maize.

3.9.2.1.9. Relative growth rate (g/g/day)

Same as maize.

3.9.2.1.10. Shoot dry weight (g)

Five plants were randomly picked from each plot and dried in a hot air oven at 70°C until they attained a consistent weight before being weighed on a weighing balance to determine the shoot dry weight. The average value was afterwards expressed in grams.

3.9.2.2. Yield components and yield

3.9.2.2.1. Number of pods/plant

The no. of pods on each net plot's 5 randomly selected tagged plants was counted, and the mean was calculated by dividing the total number of pods by the number of plants chosen (5), expressed as the no. of pods per plant.

3.9.2.2.2. Number of seeds/ pod

Five ripened pods were harvested from each plot from five randomly selected tagged plants, and the number of seeds in each pod was tallied. The no. of seeds per pod on average was calculated and expressed.

3.9.2.2.3. Pod length (cm)

Each net plot's five randomly selected pods had their lengths measured, with the average value being given in centimeters.

3.9.2.2.4. Test weight (g)

A random sample of grains was obtained from each net plot after the crops were harvested and threshed, and the average weight was determined by weighing 1000 seeds, expressed in grams.

3.9.2.2.5. Straw yield (kg/ha)

The yield from each net plot was harvested and sun-dried in separate bundles. The dried bundles were then weighed using a Mettler Toledo SB 16001 weighing balance and the results were expressed in kg per hectare.

3.9.2.2.6. Seed yield (kg/ha)

Using a weighing scale, the seed yield of each net plot was calculated after threshing, winnowing, and drying procedures and was calculated as kg per hectare.

3.9.2.2.7. Biological yield (kg/ha)

Biological yield was recorded from each net plot separately and then converted into biological weight by taking the mean value.

BY = Seed yield + straw yield

3.9.2.2.8. Harvest Index (%)

Same as maize

3.9.2.3. Nutrient uptake (kg/ha) in seed and straw

Same as maize

3.12.3. WHEAT

3.12.3.1. Growth components

All growth indicators were recorded at 30, 60, 90, and 120 days after sowing (DAS), as well as at harvest.

3.9.3.1.1. Plant Population

By counting the plants within a 1-meter square area of each net plot, the number of plants per unit area was calculated.

3.9.3.1.2. Plant height (cm)

The average value of each net plot was calculated after measuring the height of each plant in centimeters from the base of the plant, or from the soil's surface to the top of the spike at maturity.

3.9.3.1.3. Number of leaves

The no. of leaves on the plant from top to bottom and the mean value of the plants chosen for each treatment were counted and recorded.

3.9.3.1.3. Leaf area (cm²)

Same as maize

3.9.3.1.4. Leaf area index (LAI)

Same as maize

3.9.3.1.5. Days to 50% flowering

For each net plot, the no. of days the plants needed to reach 50% blooming from the day of seeding was recorded and statistically examined.

3.9.3.1.6. Days to 90% physiological maturity

For each plot, the no. of days from planting to physiological maturity was noted and recorded.

3.9.3.1.7. Crop growth rate (g/m²/day)

Same as maize

3.9.3.1.8. Relative growth rate (g/g/day)

Same as maize

3.12.3.1.9. Shoot dry weight (g/m²)

Five plants were picked at random from each plot. The samples were then

dried in a hot air oven at 70°C until they reached a consistent weight. Dried samples were weighed using a balancing scale. The average weight was recorded and represented in gram per square meter (g/m²).

3.9.3.2. Yield components and yield.

3.9.3.2.1. Number of effective tillers/m²

The no. of tillers with ear heads was carefully counted from one square area of each net plot. The average value of each plot was obtained and expressed as the number of effective tillers/square metre.

3.9.3.2.2. Number of grains/ spike

Each plot's 5 randomly selected spikelets were manually threshed. Each spike's no. of grains was counted, and the average value was computed.

3.9.3.2.3. Spike length (cm)

From the base of the spike to the tip of the last spikelet awns, the length of each spike on the main culm of five randomly selected plants from each net plot was measured. The average measurement was taken and represented in centimeters.

3.9.3.2.4. Test weight (g)

After the crop was harvested and threshed, a random sample of 1000 seeds were picked from each net plot, and the average weight was estimated and computed in grams.

3.9.3.2.5. Grain yield (kg/ha)

The yield was represented in kilograms per hectare and the amount of grain produced in each net plot was measured after threshing, winnowing, and drying.

3.9.3.2.6. Straw yield (kg/ha)

Each net plot's crop was divided into individual bundles for sun-drying, and the weight of each bundle was recorded using a weighing balance. After taking the seed yields from each individual plot into account, the weight of the straw from each net plot was calculated. Straw yield was specified as kg per hectare.

3.9.3.2.7. Biological yield (kg/ha)

Each net plot's biological yield was recorded independently, and biological weight was calculated by using the mean value.

BY = grain yield + straw yield

3.9.3.2.8. Harvest Index (%)

Same as maize

3.9.3.3. Nutrient uptake (kg/ha) in grain and straw

Same as maize

3.9.4. Incorporation of crop residues into the soil

Incorporating 100 % crop residues of mungbean into the soil is a beneficial approach since it improves the fertility of the soil, adds organic matter, and enhances the nutrient content. The procedure for how mungbean and maize crop residues were incorporated into the soil is given below: -

Procedures

Mungbean and maize plants were allowed to reach maturity and harvested. The mungbean residues were cut and chopped into smaller pieces using chop residue chopping machines. By chopping the residues, the surface area was increased by facilitating faster decomposition. Before incorporating the residues, the soil was prepared by removing the weeds and unwanted debris to create a suitable environment for the incorporation process. The chopped mungbean and maize residues are spread evenly over the soil surface. This ensures the uniform distribution of the residues decompose at a similar rate throughout the field. Once the residues were spread, then it was incorporated into the soil by using a tiller, disc harrow, using small tractor without mixing the treatments of the plot. The goal of mixing the residues into the top layer of soil (around 4-6 inches deep) was done to facilitate decomposition and nutrient release. Irrigation of the whole field was done to ensure that the field receives adequate moisture. Moist conditions help in breaking down the crop residues faster and promote microbial activity, which aids in decomposition. The mungbean and maize residues decompose in the soil over a certain period. Once the mungbean residues have sufficiently decomposed and integrated into the soil, the planting of the next crop was done.

3.9.5. Economic analysis

Economics for both the experiments (*kharif and rabi*) was worked with the prevailing costs during the experimentation.

3.9.5.1 Cost of cultivation

The cost of input at the time of usage was used to calculate the cost of cultivation. The cultivation cost was determined by factoring in the costs of inputs such as seeds, manure, fertilizers, plant protection, manpower, and so on.

3.9.5.2. Gross returns (Rs/ha)

The prevailing market prices and main and components at the time of harvest were obtained and was used for the calculation of gross returns and expressed in Rs/ha.

3.9.5.3. Net returns (Rs/ha)

The cultivation costs were subtracted from the gross returns to determine the net return, which was then expressed in rupees per hectare.

3.9.5.4. Benefit-cost ratio

It was calculated by applying the information below: -

Gross returns (Rs/ha)

B:C= -----

Cost of cultivation (Rs/ha)

3.9.6. Data Analysis

To assess the significant differences between treatments and draw reliable conclusions, the data collected from diverse observations underwent statistical analysis using the appropriate method of Analysis of Variance (ANOVA) as delineated by the STAR (Statistical Tools for Agriculture Research) Software Package. The standard error was calculated for each factor, and the significance of differences among treatment effects was evaluated using the "F" test. In instances where differences were identified at 5% of significance, the Critical Difference (CD) was determined. The Analysis of Variance table is presented below.

Table 3.20: Analysis of Variance for maize and mungbean

ANOVA						
Source of Variation	DF	SS	MSS	F Cal	F Tab (5%)	F Tab (1%)
Replication	(r-1) = 2					
Main-plot	(a-1) = 1					
Error (a)	(r-1) (a-1) = 2					
Sub-plot	(b-1) = 3					
Main-plot X Sub-plot	(a-1) (b-1) = 3					
Error (b)	a(r-1) (b-1) = 12					
Total	rab-1= 23					

Table 3.21: Analysis of Variance for wheat

ANOVA						
Source of Variation	DF	SS	MSS	F Cal	F Tab (5%)	F Tab (1%)
Replication	(r-1) =2					
Main-plot	(a-1) =2					
Error (a)	(r-1) (a-1) = 4					
Sub-plot	(b-1) =3					
Main-plot X Sub-plot	(a-1) (b-1) = 6					
Error (b)	a(r-1) (b-1) =18					
Total	rab-1= 35					

SS= Sum of square

MSS= Mean sum of Square ($\frac{SS}{d.f}$)

CD=Critical difference

$$CD = \sqrt{\frac{2x \text{ Error sum of square}}{N}} \times t (\text{error d.f. 5\%})$$

t (at 5%) =Tabular Value for error degree of freedom at 5% level of significance.

$$F \text{ table} = \frac{Ms \text{ treat}}{Ms \text{ error}}$$

$$i) \quad a = \frac{Ms \text{ treat a}}{Ms \text{ error b}}$$

$$ii) \quad b = \frac{Ms \text{ treat b}}{Ms \text{ error b}}$$

$$iii) \quad a \times b \text{ (Interaction)} = \frac{Ms \text{ axb}}{Ms \text{ error b}}$$

RESULTS AND DISCUSSION

The results of the present experiment “ **Nanofertilizers for sustainable crop production under changing climate and impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean and wheat cropping system**” conducted at the Research Farm of Lovely Professional University, Phagwara, Punjab during the *kharif* and *rabi* seasons (2020 -2022) have been described in detail in this chapter. The study's goal was to evaluate the amount of variation in various metrics brought on by treatment variables. At the proper locations in the tables, the data has been statistically assimilated. Graphs for yield data are used to further illustrate it. The major impacts have been discussed first, followed by a description of any significant interactions. The significant experimental findings obtained during the course of experimentation are discussed below with possible explanations and evidence wherever necessary to determine the significant relationship among the treatments concerning numerous growth and yield components studied and to sort the information of practical value.

4.1.1. Maize

4.1.1.1. Growth components

4.1.1.1.1. Plant height (cm)

The current study emphasizes the impact of cropping system and different levels of fertilizer on sole maize and intercrop maize plant height during the 2020 and 2021 *kharif* seasons and the mean data. Data in Table 4.1.1 depicted that the height of the plant gradually rose to the end of the study period at 30, 60, and 90 DAS as the plant approaches maturity in both the season 2020 and 2021. The cropping system had a significant impact on the sole and intercrop maize plants' height. During all sample intervals in both the seasons 2020 and 2021, the maximum maize plant height was measured with maize as the intercrop and the minimum plant height was measured when maize was planted as a sole crop. When the results were mean, a comparable pattern was seen (Table 4.1.1). Taller plant

height was observed in intercrop maize than the sole maize in all the sampling periods (30 DAS, 60 DAS, 90 DAS, and at harvest) and growing years (2020 and 2021) and in mean statistics. This could possibly be because of the fact that, in the context of maize-mungbean intercropping, the maize crop must compete with the mungbean crop for light to grow more effectively. Moreover, the mungbean crop improved the accessibility of nitrogen to the maize and generated a favorable microclimate, both of which increased the height of the intercropped maize. The outcome approves with (Ginwal and colleagues. 2019), they described that cereal intercrops with leguminous plant had a significant influence on plant height, with the highest values obtained in a 1:1 intercropping ratio and the lowest in their sole cereal crop. Belsti *et al.* (2016) also reported a similar result that intercropped maize was considerably taller than mono-cropped maize in maize/haricot bean intercropping. Likewise, Lin *et al.* (2018) observed that the intercropping of corn with peanuts resulted in elevated plant height, expanded leaf area, and an increased relative growth rate for corn, indicating that this intercropping practice is particularly advantageous for enhancing corn yield. These results also align with the observations of Oskoi *et al.* (2015), who reported increased plant height in sole crop conditions compared to maize intercropped with faba bean, where plant height was minimized.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the tallest plants among all fertilizer applications at all sampling periods, in both 2020 and 2021 in addition to when the results were average, while it was statistically comparable to the 100% RDF at 60 DAS, 90 DAS, and at harvest in the year 2020 and 2021 but considerably superior to the other treatments. The plot treated with 100 % RDF was statistically comparable to 100 % Nano NPK fertilizers application at 60 DAS, 90 DAS, and at harvest in 2020 and 2021 growing years. Nonetheless, in both the years 2020 and 2021, the control exhibited the lowest plant height across all sampling periods. When the data were combined, similar data to those obtained in 2020 and 2021 were noted (Table 4.1.1). The increased height of plants resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers can be ascribed to various potential factors. Nanofertilizers due to their nanoscale dimensions, may enhance nutrient availability and uptake efficiency. When integrated with conventional NPK fertilizers, they might have offered a more readily accessible nutrient source, fostering overall plant growth,

including an increase in height. Additionally, nanofertilizers might have improved nutrient use efficiency by facilitating optimal absorption and utilization by plant roots, contributing to the increased plant height. The synergy between NPK fertilizer and nanofertilizers may have yielded cooperative effects, with the two types of fertilizers complementing each other in promoting plant growth, resulting in more robust and taller plants. Furthermore, nanofertilizers may have influenced plant hormone levels and signaling pathways, stimulating cell division and elongation, key factors in determining plant height. Interactions between nanofertilizers, soil microbes, and plant roots may also have enhanced nutrient availability and uptake, potentially contributing to taller plant growth. Reddy *et al.* (2022) obtained comparable findings, establishing that the joint application of 50% nitrogen through urea and 50% nitrogen through nano urea significantly enhances plant height of maize. In addition, Benzon *et al.* (2015) also reported that the integrated usage of nano fertilizer with traditional fertilizers significantly increased the height of the maize plants due to nano fertilizer's ability to provide nutrients or aid in the transportation and absorption of available nutrients, leading to better crop growth. Suriyaprabha *et al.* (2012) observed an increase in the plant height of maize plants and suggested that this could be attributed to the foliar application of nano NPK fertilizers and stated that this application potentially increased bioavailability through roots and stomata, leading to overall growth in plants.

The cropping system and different fertilizer levels interacted significantly ($P=0.05$) in 2020, 2021 and in the mean data at all sampling periods, except 30 DAS. In the year 2020 and 2021, the intercropped maize combined with 50% RDF +50% Nano NPK fertilizers had the highest plant height during the sampling periods, followed by the intercropped maize combined with 100% RDF, intercropped maize combined with 100% Nano NPK fertilizers followed by sole maize combined with 50% RDF +50% Nano NPK fertilizers, sole maize combined with 100% RDF, sole maize combined with 100% Nano NPK fertilizers. However, when sole maize was combined with control, plant height was the lowest. Similarly, when the data were mean, a similar trend was seen (Table 4.1.1.a, Table 4.1.1.b, and Table 4.1.1.c).

Table 4.1.1.:Effect of cropping systems and different levels of fertilizers on the plant height (cm) of sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A –Cropping system												
M₁	32.13 ^b	144.64 ^b	199.42 ^b	201.79 ^b	34.56 ^b	158.03 ^b	211.33 ^b	213.74 ^b	33.35 ^b	151.34 ^b	205.38 ^b	207.77 ^b
M₃	52.86 ^a	176.87 ^a	226.57 ^a	230.12 ^a	57.01 ^a	195.56 ^a	239.64 ^a	243.63 ^a	54.93 ^a	186.22 ^a	233.11 ^a	236.88 ^a
SEm (±)	0.79	3.98	3.47	3.43	1.93	5.20	3.36	3.69	1.36	4.59	3.41	3.56
CD (P=0.05)	4.79	24.20	21.11	20.85	11.72	31.61	20.42	22.46	8.25	27.90	20.77	21.66
B-Different levels of fertilizer												
S₁	31.79 ^b	99.65 ^c	167.37 ^c	169.54 ^c	32.10 ^c	100.48 ^c	169.17 ^c	171.30 ^c	31.95 ^c	100.07 ^c	168.27 ^c	170.42 ^c
S₂	50.72 ^a	182.03 ^{ab}	225.94 ^{ab}	229.19 ^{ab}	55.35 ^a	203.25 ^a	242.00 ^{ab}	245.41 ^{ab}	53.04 ^a	192.64 ^a	233.97 ^b	234.77 ^{ab}
S₃	33.30 ^b	168.05 ^b	221.63 ^b	224.66 ^b	37.37 ^b	187.67 ^b	237.05 ^b	240.56 ^b	35.33 ^b	177.86 ^b	229.34 ^b	230.12 ^b
S₄	54.16 ^a	193.28 ^a	237.05 ^a	240.44 ^a	58.33 ^a	215.75 ^a	253.72 ^a	257.47 ^a	56.24 ^a	204.52 ^a	245.39 ^a	246.23 ^a
SEm (±)	2.32	4.96	5.25	5.40	1.85	4.59	5.45	4.57	2.08	4.77	5.35	4.98
CD (P=0.05)	7.13	15.27	16.16	16.64	5.70	14.15	16.78	14.07	6.42	14.71	16.47	15.35
Interaction (Ax B)	NS	S	S	S	NS	S	S	S	NS	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.1a: Interaction between cropping systems and different fertilizers levels on plant height(cm) of sole and intercrop maize at 60DAS.

60DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	90.87 ^e	161.47 ^{cd}	144.64 ^d	181.59 ^{bc}	90.91 ^e	179.17 ^{cd}	160.50 ^d	201.50 ^b	90.89 ^e	170.32 ^{cd}	152.57 ^d	191.55 ^b
M ₃	108.43 ^e	202.60 ^a	191.46 ^{ab}	204.98 ^a	110.06 ^e	227.33 ^a	214.83 ^{ab}	230.00 ^a	109.24 ^e	214.97 ^a	203.15 ^{ab}	217.49 ^a
SEm (±)	7.01				6.49				6.75			
CD(P=0.05)	21.60				20.01				20.80			

Table 4.1.1b: Interaction between cropping systems and different fertilizers levels on the plant height of sole and intercrop maize at 90DAS.

90DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	130.96 ^c	222.23 ^{ab}	216.49 ^b	229.65 ^a	131.10 ^d	237.67 ^b	231.53 ^b	246.01 ^a	131.03 ^d	229.95 ^b	224.01 ^{bc}	237.83 ^a
M ₃	203.77 ^b	230.65 ^a	227.43 ^a	244.45 ^a	207.23 ^c	246.68 ^a	243.23 ^{ab}	261.43 ^a	205.50 ^c	238.66 ^a	235.33 ^{ab}	252.94 ^a
SEm (±)	7.42				7.70				7.56			
CD(P=0.05)	22.86				23.73				23.30			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.1c: Interaction between cropping systems and different fertilizers levels on the plant height of sole and intercrop maize at harvest.

At harvest	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	132.12 ^c	224.11 ^{ab}	218.33 ^b	232.61 ^a	132.30 ^d	239.90 ^b	233.71 ^b	243.04 ^{ab}	132.21 ^d	239.90 ^{ab}	226.02 ^b	240.80 ^a
M₃	206.96 ^b	234.26 ^a	230.99 ^a	248.28 ^a	210.25 ^c	250.93 ^a	247.42 ^a	260.45 ^a	208.60 ^c	242.60 ^a	239.20 ^a	257.11 ^a
SEm (±)	7.64				6.46				7.05			
CD(P=0.05)	23.53				19.90				21.71			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.1.2. Number of leaves

Table 4.1.2 shows the impact of cropping systems and different fertilizers levels on sole and intercrop maize no. of leaves during the 2020 and 2021 *kharif* seasons and mean data. The no. of leaves on sole and intercrop maize was significantly impacted by the cropping system. The maize grown as intercrop with mungbean produced the maximum leaves per plant during all sampling periods, while the sole maize produced the minimum leaves per plant in both the growing seasons. A similar trend was observed when data were mean. The no. of leaves was higher in intercropped maize, which may be related to both better crop canopy development and effective solar energy utilization as a result of the intercropping with mungbean throughout the growing seasons. These results are consistent with the ones reported by Hamd Alla *et al.* (2014), who observed that when maize and cowpea crops were intercropped together, more leaves and plants were recorded in the intercropped maize than in the pure stand. Similarly, Fu *et al.* (2023) reported that the intercropping of sweet corn with peanuts, potentially enhancing nitrogen supply to sweet corn, was associated with an observed increase in the no. of leaves.

Application of 50% RDF + 50% Nano NPK fertilizers to maize has produced the most no. of leaves at all sampling periods in both the years (2020 and 2021) followed by plot treated with 100 % RDF and 100 % Nano NPK fertilizers while the lowest no. of leaves was observed in control plot at all sampling periods as well as when the data were mean. The elevated no. of leaves in the presence of a combination of 50% NPK fertilizers and 50% Nano NPK fertilizers can be attributed to improved nutrient availability and uptake efficiency. Nanofertilizers, with their nanoscale size, enhance nutrient absorption, stimulating photosynthesis and supporting cell division. The synergy between NPK and nanofertilizers promotes overall plant growth, fostering the development of a greater leaf count. Yadav *et al.* (2023); Nongbet *et al.* 2022, provided a comparable explanation regarding nanofertilizers and their delivery. Rashmi and Prakash (2023) provided a similar explanation, indicating foliar application of nano phosphorous fertilizer resulted in a higher no. of leaves per plant in maize.

At all sample intervals, in both the growing years (2020 and 2021), and when statistics data were mean, it was determined that there was no significant interaction between the cropping system and various levels of fertilizers.

Table 4.1.2.: Effect of cropping system and different levels of fertilizers on the number of leaves of the sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A - Cropping system												
M₁	4.41 ^b	10.71 ^b	11.11 ^b	9.76 ^b	4.86 ^b	10.92 ^b	11.77 ^b	10.08 ^b	4.63 ^b	10.82 ^b	11.44 ^b	9.92 ^b
M₃	5.54 ^a	11.58 ^a	12.30 ^a	10.61 ^a	6.06 ^a	11.94 ^a	12.84 ^a	10.86 ^a	5.80 ^a	11.76 ^a	12.57 ^a	10.74 ^a
SEm (±)	0.17	0.15	0.18	0.13	0.11	0.14	0.16	0.12	0.14	0.15	0.17	0.13
CD (P=0.05)	1.01	0.93	1.12	0.79	0.67	0.88	1.00	0.73	0.84	0.91	1.06	0.76
B- Different levels of fertilizer												
S₁	4.12 ^c	9.05 ^c	10.48 ^c	9.07 ^d	4.65 ^c	9.31 ^c	11.04 ^d	9.12 ^d	4.38 ^d	9.18 ^c	10.76 ^c	9.09 ^d
S₂	5.52 ^b	12.06 ^b	12.28 ^a	10.54 ^b	5.85 ^b	12.59 ^a	12.87 ^b	10.88 ^b	5.68 ^b	12.33 ^a	12.57 ^a	10.71 ^b
S₃	4.25 ^c	10.87 ^c	11.40 ^b	9.44 ^c	4.92 ^c	11.13 ^b	11.94 ^c	9.82 ^c	4.58 ^c	11.00 ^b	11.67 ^b	9.63 ^c
S₄	6.01 ^a	12.59 ^a	12.67 ^a	11.69 ^a	6.42 ^a	12.69 ^a	13.36 ^a	12.07 ^a	6.21 ^a	12.64 ^a	13.02 ^a	11.88 ^a
SEm (±)	0.17	0.32	0.27	0.21	0.13	0.24	0.25	0.26	0.15	0.28	0.26	0.24
CD (P=0.05)	0.51	0.98	0.84	0.65	0.42	0.75	0.78	0.80	0.46	0.87	0.81	0.72
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize(sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.1.3. Leaf area (cm²)

The cropping system demonstrated no significant influence on the leaf area of sole maize and intercropped maize across both the 2020 and 2021 growing seasons, as well as in the mean data (Table 4.1.3).

In terms of different fertilizer treatments, the application of 50% RDF + 50% Nano NPK fertilizers produced the maximum leaf area at 30 DAS in 2020, which was comparable to 100% RDF but significantly superior to all other treatments. However, in 2021, 50% RDF + 50% Nano NPK had the maximum leaf area, compared to all other treatments. At sampling periods of 60 DAS, 90 DAS, and harvest, the plot treated with 50% RDF + 50% Nano-NPK fertilizers produced the maximum leaf area which was comparable to both 100% RDF and 100% Nano-NPK fertilizers but significantly higher than the control in both seasons (2020 and 2021). The control consistently recorded the lowest at every sampling periods. A similar trend was observed when data were mean. The enhanced leaf area due to the combined application of both 50% NPK fertilizers and 50% Nano NPK fertilizers may be attributed to the nanofertilizers which might have enhanced the availability of nutrients, stimulated photosynthesis, and promoted cellular expansion, contributing to larger leaf surfaces. The combined application of NPK and nanofertilizers synergistically may have fostered optimal plant growth, resulting in increased leaf area. The increase in leaf area can be linked to the heightened plant height. This leads to a larger presence of functional leaves and, consequently, an expanded leaf area. These findings align with the studies conducted by Prasanna *et al.* (2020) and Jadhav *et al.* (2020). Gowtham *et al.* (2023) reported a comparable outcome, affirming that the nano foliar application had a positive effect, resulting in an increase in the leaf area of sweet corn. Likewise, Yomso *et al.* (2022) reported akin results in maize leaf area through the combined application of nano-NPK and chemical fertilizers. Additionally, studies conducted by Tarafdar *et al.* (2014), Manikandan and Subramanian (2016), Gomaa *et al.* (2017), Kandil *et al.* (2017), and Burhan *et al.* (2019) have supported a notable enhancement in the vegetative growth parameters when using nano fertilizers.

During all sample intervals, in both the years (2020 and 2021), and when statistics were mean, it was determined that the interaction between the cropping system and different levels of fertilizers was not significant.

Table 4.1.3.: Effect of cropping system and different levels of fertilizers on the leaf area (cm²) of the sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At har-vest	30DAS	60DAS	90DAS	At har-vest	30DAS	60DAS	90DAS	At har-vest
A - Cropping system												
M₁	257.34	398.17	469.01	425.21	278.66	436.58	493.53	450.76	268.00	417.37	481.27	442.57
M₃	278.36	404.73	478.46	432.09	303.13	443.85	503.42	458.01	290.75	424.29	490.94	449.74
SEm (±)	4.17	8.07	9.22	4.40	4.35	8.17	9.26	4.65	4.26	8.12	9.24	4.53
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B- Different levels of fertilizer												
S₁	222.07 ^b	377.79 ^b	408.62 ^b	336.73 ^b	241.17 ^c	414.17 ^b	429.91 ^b	356.84 ^b	231.62 ^c	395.98 ^b	419.27 ^b	350.41 ^b
S₂	301.59 ^a	408.70 ^a	496.43 ^a	460.64 ^a	327.35 ^b	448.22 ^a	522.45 ^a	488.20 ^a	314.47 ^b	428.46 ^a	509.44 ^a	479.37 ^a
S₃	225.93 ^b	404.12 ^a	490.95 ^a	454.37 ^a	245.60 ^c	443.15 ^a	516.72 ^a	481.78 ^a	235.77 ^c	423.64 ^a	503.83 ^a	473.02 ^a
S₄	321.80 ^a	415.18 ^a	498.93 ^a	462.85 ^a	349.47 ^a	455.32 ^a	524.82 ^a	490.72 ^a	335.64 ^a	435.25 ^a	511.87 ^a	481.83 ^a
SEm (±)	4.19	8.06	9.18	8.18	7.30	8.21	9.30	8.42	4.65	8.14	9.24	8.30
CD (P=0.05)	12.14	23.26	29.21	24.11	22.50	23.41	30.42	24.62	12.32	23.34	29.82	24.37
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize(sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.1.4 Leaf Area Index (LAI)

Table 4.1.4 displays the impact of the cropping system and various fertilizer levels on the leaf area index of sole and intercrop maize during the 2020 and 2021 *kharif* seasons, along with mean data. The cropping system significantly affected maize across all sampling periods. The maximum LAI was obtained when maize was planted as an intercrop with mungbean, but the minimum leaf area was recorded when maize was cultivated as sole crop in both seasons, i.e., 2020 and 2021, and when data were mean. In both the growing seasons and when the data was average, the intercropped maize with mungbean exhibited a higher LAI compared to the sole maize. This may be attributed to a robust surge in crop growth, which also contributed to an expansion in the length and width of the intercropped maize leaves. Comparable conclusions were obtained by Ginwal *et al.* (2019) in maize and legume intercropping. Fan *et al.* (2020) observed similar results and concluded that the advantages of intercropping encouraged greater root density and leaf area, encouraging maize to use more soil water and solar radiation when intercropped with pea. Borghi *et al.* (2013) also found a considerable boost in leaf area index in maize-legume intercrop due to the complementary effect between base crop and intercrop. Naher and Hossain (2021) also found higher LAI when maize was cultivated with mungbean. According to Yang *et al.* (2018), the leaf area index of intercropped maize within the pea/maize intercropping system was higher than that of sole maize.

Concerning, different levels of fertilizer treatments, at all sampling periods (30 DAS, 60 DAS, and harvest), the application of 50% RDF + 50% Nano NPK fertilizers produced the highest leaf area index while in the 90 DAS, it was comparable with 100% RDF which was also comparable with 100% Nano NPK fertilizers but significantly higher than control in the year 2020. 100% Nano NPK fertilizers were comparable to the control in 2020 at 30 DAS but was significantly superior than the control. In 2021, 50% RDF + 50% Nano NPK had the highest leaf area at all sample intervals, which was substantially greater than all other levels of fertilizers. When data of 30 DAS and at harvest are average, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest mean value of leaf area index, followed by 100% RDF and 100% Nano NPK nanofertilizers. However, at 60 DAS and 90 DAS, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest mean value and was comparable with the plot

treated with 100% RDF followed by 100% Nano NPK fertilizers. The control plot had the lowest leaf area index during both seasons of 2020 and 2021, and when the data were mean. The increased leaf area index in maize with the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers can be attributed to enhanced nutrient uptake and utilization. Nanofertilizers improve the efficiency of nutrient absorption, leading to optimized nutrient utilization by plants. This improved nutrient availability stimulates robust growth, resulting in larger and more abundant leaves, thereby contributing to a higher leaf area index. Additionally, the synergistic effects of NPK fertilizer and nanofertilizers promote overall plant development, including leaf expansion, further influencing the leaf area index in maize. Reddy *et al.* (2022) reported analogous findings, suggesting that the simultaneous use of conventional and nanofertilizers led to an augmentation in the leaf area index of maize. This enhancement was attributed to the application of nano fertilizers as foliar sprays, enhancing absorption rates, and contributing to the development of a higher leaf area index. Meena *et al.* (2023) noticed analogous results in the case of combined application of nitrogen and nano-nitrogen, in the maize leaf area index. Likewise, Ajithkumar *et al.* (2021) observed comparable outcomes and indicated that the highest leaf area was achieved through the combined application of NPK, along with two sprays of nano nitrogen. A considerable rise in wheat leaf area index was observed when nano fertilizers were applied to maize via foliar spray [Abdel-Aziz *et al.* 2016].

At all sampling intervals during both the years (2020 and 2021) and when data were mean, the interaction between the cropping system and different fertilizer levels was not statistically significant.

Table 4.1.4.: Effect of cropping system and different levels of fertilizers on the leaf area index of the sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A - Cropping system												
M₁	0.98 ^b	3.57 ^b	4.38 ^b	3.48 ^b	1.16 ^b	3.99 ^b	4.87 ^b	3.82 ^b	1.07 ^b	3.78 ^b	4.63 ^b	3.65 ^b
M₃	1.32 ^a	3.92 ^a	4.92 ^a	3.86 ^a	1.57 ^a	4.44 ^a	5.41 ^a	4.19 ^a	1.45 ^a	4.18 ^a	5.16 ^a	4.02 ^a
SEm (±)	0.045	0.050	0.084	0.037	0.029	0.064	0.086	0.059	0.037	0.057	0.085	0.048
CD (P=0.05)	0.274	0.301	0.513	0.227	0.175	0.389	0.520	0.361	0.225	0.345	0.517	0.294
B- Different levels of fertilizer												
S₁	0.77 ^c	2.85 ^d	3.58 ^c	2.55 ^d	0.94 ^c	3.22 ^c	3.97 ^c	2.71 ^c	0.86 ^d	3.03 ^c	3.77 ^c	2.63 ^d
S₂	1.41 ^b	4.11 ^b	5.08 ^{ab}	4.05 ^b	1.62 ^b	4.71 ^a	5.61 ^a	4.43 ^a	1.51 ^b	4.41 ^a	5.34 ^a	4.24 ^b
S₃	0.81 ^c	3.66 ^c	4.67 ^b	3.58 ^c	1.02 ^c	4.12 ^b	5.15 ^b	3.94 ^b	0.91 ^c	3.89 ^b	4.91 ^b	3.76 ^c
S₄	1.63 ^a	4.36 ^a	5.27 ^a	4.51 ^a	1.88 ^a	4.82 ^a	5.85 ^a	4.94 ^a	1.75 ^a	4.59 ^a	5.56 ^a	4.72 ^a
SEm (±)	0.093	0.091	0.130	0.131	0.099	0.102	0.128	0.105	0.096	0.097	0.129	0.118
CD (P=0.05)	0.285	0.281	0.399	0.402	0.306	0.316	0.393	0.323	0.296	0.298	0.396	0.363
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize(sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.1.5 Days to 50% tasseling.

Table 4.1.5 shows the impact of the cropping system and different fertilizer levels on the days to 50% tasseling of sole and intercrop maize during the 2020 and 2021 *kharif* seasons, as well as the mean data. The days to 50 % tasseling were recorded less when maize was grown as the intercrop with mungbean, while longer days were recorded when maize was cultivated as the monocrop in both seasons i.e., 2020 and 2021, and when data were mean. The possible reason for longer days to 50% tasseling in sole maize may be due to the higher availability of nitrogen as higher availability of nitrogen delayed tasseling in maize. The obtained outcome aligns with the conclusions drawn by Moges (2015), who observed a consistent increase in the days to tasseling with higher levels of nitrogen. Similarly, Takele *et al.* (2017) also documented that elevated nitrogen fertilizer levels led to a delay in maize tasseling.

Application of different levels of fertilizer to maize significantly affected the days to 50% tasseling in both seasons (2020 and 2021) as well as when the data were mean. Plots treated with 50 % RDF + 50 % Nano NPK fertilizers took most days to attain 50% tasseling followed by 100 % NPK fertilizers and 100 % Nano NPK fertilizers in both seasons and when data was average. In both seasons and when data were mean, the control plot took the lesser days to reach 50% tasseling. The extended duration for maize to reach 50% tasseling when utilizing a combination of 50% NPK fertilizers and 50% Nano NPK fertilizers may have arisen from the optimized nutrient uptake associated with the combined fertilization. The synergy between NPK fertilizers and Nano NPK formulations may have enhanced the nutrient availability to the plants, ensuring a sustained and balanced nutrient supply over an extended period. Moreover, the gradual growth observed could be a consequence of the improved efficiency in nutrient absorption facilitated by the Nano NPK fertilizers. Nano-sized particles often exhibit increased surface area, allowing for more efficient nutrient absorption by plant roots. This enhanced nutrient absorption efficiency might lead to a slower yet more sustained growth pattern, contributing to the extended duration for tasseling. Delayed physiological responses in the form of prolonged vegetative growth before transitioning to the reproductive stage might be influenced by the intricate interactions between the applied fertilizers and the plant's internal signaling pathways. This delay could manifest as an extended duration before reaching the critical stage of

50% tasseling. Furthermore, the combined fertilization approach might have interacted differently with the environmental factors (temperature, humidity, and soil conditions) further contributing to the observed extended duration for tasseling. Similarly, Amrutha and colleagues (2021) also observed that the simultaneous foliar administration of organic nano NPK at a concentration of 0.5% along with NPK fertilizer resulted in the minimum number of days required for 50% flowering in chili plants. Comparable findings were observed by Gilbert (2012) in wheat who stated that applying nano fertilizer heightened physiological and metabolic activities, inducing alterations in gene expression. This, in turn, facilitated the transition from vegetative to floral characteristics. Likewise, Sarwar and colleagues (2021) observed that the application of nano nitrogen fertilizer in maize significantly minimized the days required for 50% tasseling. Jinnur *et al.* (2023) also reported that the foliar application of nanofertilizers documented the minimum number of days needed to achieve 50 percent tasseling and silking in maize.

The interaction between the cropping system and different levels of fertilizers in both the years (2020 and 2021) and mean data was significant. In 2020 and 2021 and mean data, the highest mean value of 50% tasseling was recorded in sole maize combined with 50% RDF + 50% Nano NPK fertilizers which was comparable with sole maize coupled with 100% RDF, followed by sole maize combined with 100 % Nano NPK fertilizers which was at par with sole maize coupled with control, intercrop maize coupled with 100% Nano NPK fertilizers, intercrop maize couple with 100% RDF and intercrop maize coupled with control. Whereas the lowest mean value was recorded when intercrop maize was combined with control (Table 4.1.5a).

4.1.1.1.6 Days to 50% silking

The impact of the cropping system and different levels of fertilizers on the days to 50% silking of sole and intercrop maize during the 2020 and 2021 *khariif* seasons and mean data are shown in Table 4.1.5. The days to 50 % silking were recorded as lesser when maize was grown as the intercrop with mungbean, while longer days taken to 50% silking were recorded when maize was cultivated as the monocrop in both seasons i.e., 2020, 2021, and mean data. The extended duration required for 50% silking in sole maize cultivation may be attributed to the absence of competition for nutrients, light, and moisture. This absence of competition

results in a higher availability of nutrients compared to intercropped maize. Furthermore, the elevated nitrogen levels, associated with the increased nutrient availability, contribute to a delay in the silking of maize, thus necessitating a longer duration for the silking process. Alemayehu *et al.* (2018) reported comparable results in the intercropping of maize and common beans, while Kassahun *et al.* (2013) documented similar findings in the context of maize-bean intercropping.

Application of different levels of fertilizer to maize significantly affected the days to 50% silking in both seasons and in the case of mean data. Plots treated with 50 % RDF + 50 % Nano NPK fertilizers took longer days to attain 50% silking followed by 100 % NPK fertilizers and 100 % Nano NPK fertilizers in both 2020 and 2021 and when data were mean. The shortest no. of days to 50% silking was recorded in the control in both seasons (2020 and 2021). A similar trend was observed when the data were mean (Table 4.1.5). The prolonged duration for maize to achieve 50% silking with a combination of 50% NPK fertilizers and 50% Nano NPK fertilizers could stem from improved nutrient availability, gradual growth supported by enhanced nutrient uptake, potential synergistic effects on plant physiology, delayed physiological responses, and interactions with environmental factors. Similarly, Sarwar *et al.* (2021) noted that the utilization of nano nitrogen fertilizer in maize significantly reduced the time needed for 50% silk emergence. El-Habbak and colleagues (2019) reported conflicting findings, asserting that nano fertilizers exhibited no significant impact on the duration of days to 50% silking of maize. Mahesh and colleagues (2022) noticed a notable influence of Zinc oxide nanoparticles on both the 50% tasseling and 50% silking stages of maize. This outcome contradicts the findings of Gurm and Mintesnot (2020), who observed that plants subjected to lower nutrient applications exhibited slow growth attributed to nutrient deficiency. Conversely, plants exposed to higher nutrient applications demonstrated early maturity characterized by robust development, premature tasseling, and early silking of the crop.

The interaction between the cropping system and different levels of fertilizers in both the years (2020 and 2021) and when data was mean was found to be significant ($P=0.05$) in all the sampling periods (Table 4.1.5b). In both the 2020 and 2021 growing seasons, sole maize combined with 50 % RDF +50% Nano NPK fertilizers have taken the longest days to 50% tasseling followed by

sole maize combined with 100% RDF, sole maize couple with 50 % RDF + 50% Nano NPK fertilizers, sole maize coupled with 100% Nano NPK fertilizers, intercrop maize coupled with 100% RDF, sole maize couple with control, intercrop maize coupled with 100% Nano NPK fertilizers. However, intercrop maize in combination with the control showed the shortest days to 50% silking, in both seasons (2020 and 2021) and when data were mean (Table 4.1.5b).

4.1.1.1.7 Days to 90 % maturity

The influence of the cropping system and different levels of fertilizers on the days to 90% maturity of sole and intercrop maize during the 2020 and 2021 *kharif* seasons and when data was mean are shown in Table 4.1.5. In both seasons (2020 and 2021) as well as in mean data, cropping systems, and different fertilizer levels had a significant impact on sole and intercrop maize. The intercrop maize plot recorded a lesser no. of days for 90% maturity which was comparable with sole maize in both seasons i.e., 2020 and 2021. A similar result was also observed when the data were mean (Table 4.1.5). The results showed that intercropped maize took the longest days of time to attain maturity, but sole maize took the shortest days of time to reach physiological maturity, which may be because intercropped maize has access to more nitrogen than sole maize. This result was consistent with findings from Kidist (2013) and Takele *et al.* (2017), who found that increase in nitrogenous fertilizer had a significant impact on the no. of days it undertook for plants to reach physiological maturity, with plants in sole cropping maturing earlier and crop with the highest nitrogen rates maturing later. The delay in maturation in intercrops could be also related to prolonged vegetative growth caused by the availability of moisture, which is considered adequate in intercrop maize compared to sole maize. In addition, Amanu *et al.* (2021) noted a significant increase in days to maturity as a result of the cropping system effect.

The application of 50% RDF + 50% Nano NPK fertilizers took more days to reach 90% maturity, followed by 100% RDF and 100% Nano NPK fertilizers, and so forth in both the years (2020 and 2021) and when the data were average. The lowest no. of days taken for 90% maturity was noted in the control plot in both seasons (2020 and 2021) and when the data were mean. The prolonged period required for maize to reach 90% maturity, when employing a combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, can be ascribed to the optimized uptake of nutrients, leading to a gradual and sustained growth pattern. The

heightened efficiency in nutrient absorption, combined with potential synergistic effects and delayed physiological responses, is likely to have impacted the timing of crucial developmental stages, notably 50% tasseling and 50% silking. Furthermore, the interaction with environmental factors may have contributed to the protracted duration necessary for maize to attain 90% maturity. This intricate interplay between fertilization components and environmental conditions underscores the complexity of factors influencing crop development and maturation. Similarly, Ashenafi and colleagues (2023) reported a significant impact on the duration to reach 90% physiological maturity in maize through the application of a combination of nanofertilizers and organic manures. They explained that the increased nutrients, particularly nitrogen, were known to potentially shorten the days to tasseling, silking, and overall maturity by promoting early establishment, rapid growth, and development of the crop. Additionally, the positive interaction of nutrients in both fertilizers, along with the supplementary benefits such as enhanced soil moisture retention, reduced nutrient leaching, and the release of nutrients like nitrogen and phosphorus, could further stimulate plant vegetative development, thereby extending the time until maize plants reach maturity. Moreover, Mahesh and colleagues (2022) identified a notable influence of Zinc nanoparticles on the physiological maturity of maize.

There was a significant interaction between the cropping system and different fertilizer levels in the years (2020 and 2021) and when the data were mean (Table 4.1.5c). In both the 2020 and 2021 growing seasons, sole maize combined with 50% RDF and 50% Nano NPK fertilizers took the longest to reach 90% maturity. This was followed by intercrop maize combined with 50% RDF and 50% Nano NPK fertilizers, intercrop maize combined with 100% RDF, sole maize combined with 100% RDF, intercrop maize coupled with 100% Nano NPK fertilizers, sole maize coupled with 100% Nano NPK fertilizers, and sole maize combined with control. However, the intercrop maize in combination with the control had the shortest day taken for 90% maturity. When the data were mean, similar outcomes were noted (Table 4.1.5c).

Table 4.1.5.: Effect of cropping system and different levels of fertilizers on the days to 50% tasseling, days to 50% silking and days to 90% maturity of sole and intercrop maize during the growing years (2020-21) and mean data.

Treatments	2020			2021			Mean data		
	Days to 50 % tasseling	Days to 50% silking	Days to 90% maturity	Days to 50 % tasseling	Days to 50% silking	Days to 90% maturity	Days to 50 % tasseling	Days to 50% silking	Days to 90% maturity
A - Cropping System									
M₁	59.08 ^a	67.28 ^a	98.10 ^a	58.37 ^a	66.23 ^a	101.65 ^a	58.73 ^a	66.76 ^a	100.23 ^a
M₃	56.09 ^b	63.31 ^b	97.18 ^a	57.29 ^a	63.60 ^a	99.79 ^a	56.69 ^a	63.54 ^a	98.48 ^a
SEm (±)	0.34	0.24	0.26	0.18	0.33	0.30	0.26	0.28	0.28
CD (P=0.05)	2.08	1.44	1.60	1.08	2.00	1.83	1.58	1.72	1.71
B- Different levels of fertilizer									
S₁	55.22 ^d	61.94 ^d	89.38 ^d	56.01 ^d	60.25 ^d	90.30 ^d	55.62 ^d	60.26 ^d	89.75 ^d
S₂	58.41 ^b	66.39 ^b	100.00 ^b	58.14 ^b	65.56 ^b	103.45 ^b	58.28 ^b	65.64 ^b	101.72 ^b
S₃	56.52 ^c	64.08 ^c	97.28 ^c	56.20 ^c	63.13 ^c	99.77 ^c	56.36 ^c	63.19 ^c	98.52 ^c
S₄	60.21 ^a	69.08 ^a	105.32 ^a	60.97 ^a	70.74 ^a	109.54 ^a	60.59 ^a	69.19 ^a	107.43 ^a
SEm (±)	0.93	0.40	0.47	0.89	0.53	0.53	0.91	0.46	0.50
CD (P=0.05)	2.87	1.24	1.44	2.73	1.62	1.62	2.80	1.43	1.53
Interaction (A x B)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize(sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.5a: Interaction between cropping systems and different fertilizers levels on the days to 50% tasseling of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	56.97 ^b	61.40 ^a	56.74 ^b	65.20 ^a	56.43 ^b	59.22 ^b	57.54 ^b	64.30 ^a	56.79 ^c	60.31 ^{bc}	57.29 ^b	64.75 ^a
M₃	53.48 ^b	55.43 ^b	56.30 ^b	55.23 ^b	55.43 ^{bc}	57.06 ^b	54.85 ^b	57.65 ^c	54.45 ^d	56.25 ^d	55.42 ^d	56.44 ^{cd}
SEm (±)	1.32				1.25				1.28			
CD(P=0.05)	4.06				3.86				3.96			

Table 4.1.5b: Interaction between cropping systems and different fertilizers levels on the days to 50% silking of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	63.59 ^c	68.04 ^b	66.98 ^b	70.16 ^a	63.55 ^c	66.50 ^c	63.25 ^{cd}	71.64 ^a	63.74 ^c	67.27 ^b	65.11 ^c	70.90 ^a
M₃	59.95 ^d	64.74 ^c	61.19 ^d	68.00 ^b	56.95 ^e	64.63 ^c	63.02 ^d	69.83 ^b	58.45 ^e	64.68 ^c	62.10 ^d	68.22 ^b
SEm (±)	0.57				0.74				0.66			
CD(P=0.05)	1.75				2.29				2.02			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize(sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄= 50% RDF+50% Nano NPK fertilizers.

Table 4.1.5c: Interaction between cropping systems and different fertilizers levels on the days to 90% maturity of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	93.42 ^{cd}	98.34 ^c	96.23 ^d	107.22 ^a	92.73 ^e	101.97 ^{cd}	100.86 ^c	111.05 ^a	93.08 ^e	100.16 ^{cd}	98.55 ^d	109.14 ^a
M₃	85.33 ^e	101.65 ^b	98.32 ^c	103.41 ^b	87.53 ^f	104.92 ^b	98.67 ^d	108.03 ^b	86.43 ^f	103.29 ^c	98.50 ^d	105.72 ^b
SEm (±)	0.66				0.74				0.70			
CD(P=0.05)	2.04				2.29				2.16			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize(sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄= 50% RDF+50% Nano NPK fertilizers.

4.1.1.1.8 Shoot dry weight (g)

Table 4.1.6 shows the impact of the cropping system and different fertilizer levels on the shoot dry weight of sole and intercrop maize. The cropping method significantly affected the maize shoot's dry weight. When maize was grown as an intercrop with mungbean, higher shoot dry weight was recorded at all sampling intervals, whereas lower shoot dry weight was noted when maize was grown as a sole crop in both the seasons, i.e., 2020 and 2021, and when data were mean. The enhanced shoot dry weights of intercrop maize were likely caused by the greater leaf area, more sunlight, increased soil resources, and lower competition caused by the mungbean short stature. The fact that maize is a more aggressive component crop in the intercropped system may be another explanation for greater dry matter production in intercropped maize in comparison to sole maize. Bedoussac *et al.* (2015) substantiated comparable results in the intercropping of wheat and pea; Latati *et al.* (2016) in the case of maize and common bean; and Streit *et al.* (2019) in wheat and faba bean.

In the case of different levels of fertilizer treatments, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the maximum shoot dry weight at all sampling periods followed by 100% RDF and 100% Nano NPK fertilizers in both seasons. At all sampling intervals, in both the year, 2020 and 2021, the control had the lowest shoot dry weight. When the data from the two seasons were mean, a similar tendency was revealed. The highest shoot dry weight observed in maize with the combined application of 50% NPK fertilizers and 50% Nano NPK fertilizers can be attributed to the nanoscale properties of the nanofertilizers which may have facilitated enhanced nutrient absorption, optimizing the availability of essential elements for the plant. Additionally, there could be an improvement in nutrient utilization efficiency, with the synergistic effects between NPK fertilizers and nanofertilizers leading to the optimization of various physiological processes within the plant. Furthermore, the application of nanofertilizers might have stimulated cell division and growth, promoting a more robust and vigorous development of maize plants. This increased cellular activity could contribute to the overall rise in shoot dry weight. Another potential contributing factor is a delay in senescence, the natural aging process of plant cells, which could extend the period during which biomass accumulates, leading to an overall increase in shoot dry weight. Taken together, these various mechanisms collectively contribute to the

observed enhancement in shoot dry weight in maize, showcasing the complex and multifaceted impacts of the combined use of NPK and Nano NPK fertilizers on plant growth and development. A comparable outcome was documented by Ajirloo *et al.* (2014), who asserted that the utilization of potassium (K) nano fertilizer can induce positive effects on plant growth by directly stimulating both shoot and root growth, with a more pronounced impact on the roots. Rashmi and Prakash, 2023 observed a parallel outcome in the case of dry matter production when applying nano phosphorous to maize. The ability of nano fertilizers to release nutrients precisely, to increase nutrient use efficiency, and to prevent the nutrient ions from either getting fixed or losing to the environment may be another factor in the increase in yield and yield components of combined applications of nano and non-nano fertilizers and also because nanofertilizers were administered as a foliar spray, which may have to increase the rate of absorption and help plants produce more dry matter. Zunejo *et al.* (2012) validate these findings.

In both the sampling periods, the interaction between the cropping system and different fertilizer levels was found to be significant ($P=0.05$). This significance persisted when considering the mean data from both seasons. In all the sampling intervals, sole maize coupled with control in both the years and when data were mean, had the lowest average value of shoot dry weight whereas inter-crop maize with 50% RDF + 50% Nano NPK fertilizers had the highest mean value (Table 4.1.6a, 4.1.6b, 4.1.6c, and 4.1.6d).

Table 4.1.6.: Effect of cropping system and different levels of fertilizers on the shoot dry weight (g) of the sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A - Cropping system												
M₁	36.63 ^b	117.27 ^b	240.36 ^b	262.85 ^b	39.69 ^b	129.98 ^b	264.17 ^b	286.02 ^b	38.16 ^b	123.62 ^b	252.27 ^b	274.43 ^b
M₃	41.12 ^a	147.78 ^a	345.31 ^a	382.88 ^a	44.53 ^a	163.46 ^a	378.54 ^a	415.68 ^a	42.82 ^a	155.62 ^a	361.92 ^a	399.28 ^a
SEm (±)	0.65	4.22	7.57	7.23	0.70	4.56	8.08	8.56	0.67	4.39	7.83	7.90
CD (P=0.05)	3.95	25.65	46.08	44.01	4.23	27.75	49.17	52.10	5.75	26.70	47.63	48.06
B- Different levels of fertilizer												
S₁	30.56 ^c	86.85 ^d	157.32 ^d	167.01 ^d	31.02 ^d	88.73 ^d	159.50 ^d	170.00 ^d	30.79 ^d	87.79 ^d	158.41 ^d	168.51 ^d
S₂	40.64 ^b	144.70 ^b	308.14 ^b	340.92 ^b	44.70 ^b	162.63 ^b	342.18 ^b	373.98 ^b	42.67 ^b	153.67 ^b	325.16 ^b	357.45 ^b
S₃	32.03 ^c	108.99 ^c	268.20 ^c	293.49 ^c	35.23 ^c	122.49 ^c	297.83 ^c	321.96 ^c	33.63 ^c	115.74 ^c	283.01 ^c	307.72 ^c
S₄	52.27 ^a	189.55 ^a	437.68 ^a	490.04 ^a	57.49 ^a	213.04 ^a	485.91 ^a	537.47 ^a	54.88 ^a	201.29 ^a	461.79 ^a	513.75 ^a
SEm (±)	0.73	2.73	6.11	6.78	0.87	3.52	7.55	7.88	1.14	3.12	6.83	7.33
CD (P=0.05)	2.26	8.04	18.84	20.90	2.69	10.85	23.25	24.28	3.50	9.62	21.04	22.59
Interaction (Ax B)	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.6a: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize dry weight at 30DAS.

30DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	29.89 ^f	37.40 ^d	30.65 ^e	48.57 ^b	30.49 ^f	41.14 ^d	33.72 ^{ef}	53.42 ^b	30.19 ^f	39.27 ^d	32.18 ^f	50.99 ^b
M₃	31.23 ^e	43.88 ^c	33.40 ^e	55.97 ^a	31.54 ^f	48.26 ^c	36.74 ^e	61.56 ^a	31.39 ^f	46.07 ^c	35.07 ^e	58.76 ^a
SEm (±)	1.04				1.24				1.14			
CD(P=0.05)	3.19				3.81				3.50			

Table 4.1.6b: Interaction between cropping systems and different fertilizer levels on sole and intercrop maize dry weight at 60DAS.

60DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	76.02 ^e	126.34 ^c	101.18 ^d	165.52 ^b	78.21 ^e	141.99 ^c	113.72 ^d	186.01 ^b	77.11 ^g	134.17 ^c	107.45 ^e	175.77 ^b
M₃	97.68 ^d	163.06 ^b	116.80 ^c	213.57 ^a	99.25 ^d	183.26 ^b	131.27 ^c	240.06 ^a	98.47 ^e	173.16 ^b	124.04 ^c	226.82 ^a
SEm (±)	3.86				4.98				4.42			
CD(P=0.05)	11.88				15.34				13.61			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.6c: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize dry weight at 90DAS.

90DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	120.15 ^f	249.91 ^d	217.94 ^e	373.45 ^b	122.56 ^f	277.52 ^d	242.01 ^e	414.59 ^b	121.36 ^f	263.71 ^d	229.98 ^e	394.02 ^b
M ₃	194.49 ^e	366.38 ^b	318.45 ^c	401.91 ^a	196.44 ^e	406.85 ^b	353.65 ^c	457.22 ^a	195.47 ^e	386.61 ^b	336.05 ^c	429.57 ^a
SEm (±)	8.65				10.67				9.66			
CD(P=0.05)	26.64				32.88				29.76			

Table 4.1.6d: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize dry weight at harvest.

At harvest	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	124.21 ^g	273.36 ^d	236.26 ^f	417.57 ^b	127.07 ^g	299.17 ^d	259.17 ^f	457.97 ^b	125.64 ^g	286.27 ^d	247.71 ^f	437.77 ^b
M ₃	209.82 ^f	408.48 ^b	350.72 ^c	462.51 ^a	212.93 ^f	448.09 ^b	384.75 ^c	516.96 ^a	211.37 ^h	428.28 ^b	367.73 ^c	489.73 ^a
SEm (±)	9.59				11.15				10.37			
CD(P=0.05)	29.56				34.34				31.95			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.1.9 Crop growth rate (g/m²/day)

The cropping system and different fertilizer levels effect on the crop growth rate (CGR) of sole and intercrop maize, are shown in Table 4.1.7. The CGR of maize was significantly impacted by the cropping system. The CGR was higher when maize was cultivated as an intercrop with mungbean in 2020 at all the sampling intervals, however it was lower when maize was cultivated as the sole crop. A similar result was also observed in the year 2021 and when the data were mean. The significant compensatory effect between the intercrops was observed, which led to the change in CGR of intercropped maize compared to sole maize. This might be a result of the mungbean early harvest, which enlarges the area and makes it optimal for aeration and sunlight, allowing intercropped maize to build up aboveground biomass. Moreover, intercropped maize has access to nutrients and water that were left over from mungbean during the mid-filling stage. Aminifar and Ghanbari (2014); Xu *et al.* (2021) showed similar findings, with an increase in crop growth rate in intercropped maize compared to monocrop maize. Another explanation for the higher crop growth in intercrop maize may be related to the higher nitrogen availability from mungbean and the reduced intra-crop competition caused by the low stature of mungbean. This outcome is consistent with that of Amanullah *et al.* 2020, who obtained comparable outcomes in intercropping of sorghum-mungbean and pearl millet-pigeon peas. According to Yang *et al.* (2018), the crop growth rate (CGR) for intercropped maize exceeded that of sole maize.

In the case of different levels of fertilizer treatments, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the maximum CGR at all sampling intervals, followed by 100% RDF and 100% Nano NPK fertilizers in both seasons. While the lowest was observed in control at all sampling periods. The highest crop growth rate observed in maize with the combined application of 50% NPK fertilizers and 50% Nano NPK fertilizers may be attributed to various factors like the nanoscale properties of nanofertilizers optimizing nutrient supply and uptake efficiency, synergistic effects between NPK and nanofertilizers enhancing overall physiological processes, stimulation of key metabolic activities promoting accelerated growth, and the potential improvement in water use efficiency contributing to a more robust crop growth rate. This could also be attributed to nano fertilizers' ability to supply major essential nutrients faster to cells via foliar

spraying through stomata or wounds and scratches in the leaves, which enhances the speed and uniformity of nutrient delivery for plant metabolisms and promotes maize growth attributes. The outcome is coherent with the research outcomes of (Rajasekar *et al.* 2014), who reported an increase in growth attributes due to faster delivery of nano fertilizers nutrients via foliar spraying. Analogous conclusions were made by [Reddy *et al.* 2022; Kumar *et al.* (2022); AL-Gym and Al-Asady (2020)], they stated that of all the treatments, the one supplemented with 50% N via urea+50% N via nano urea significantly affected the growth parameters of maize. Benzon and colleagues (2015) suggested an additional explanation, proposing that the use of nano-phosphorus enhances nutrient absorption, leading to optimal growth of plant parts and improved metabolic processes, including photosynthesis. This, in turn, contributes to higher accumulation of photosynthates and their translocation to the economically significant parts of the plant, thereby enhancing overall crop growth and development. Choudhary and colleagues (2023) reported similar findings, highlighting an enhanced crop growth rate through the foliar application of both nano urea and conventional urea in wheat.

In the years (2020 and 2021) and when data were mean, the interaction between the cropping system and different fertilizer levels was significant ($P=0.05$) at all the sampling periods (30 – 60 DAS) and (60-90 DAS), but it was non-significant during the latter period (90 DAS- At harvest). In both sample period (30-60 DAS and 60-90 DAS) the highest value was acquired in interop maize combined with 50% RDF + 50% Nano NPK fertilizers while the lowest mean value CGR was acquired in sole maize coupled with control in both the growing seasons as well as when the data were mean (Table 4.1.7a and 4.1.7b).

Table 4.1.7.: Effect of cropping system and different levels of fertilizers on the crop growth rate (g/m²/day) of the sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	30-60 DAS	60-90 DAS	90 DAS-At harvest	30-60 DAS	60-90 DAS	90 DAS-At harvest	30-60 DAS	60-90 DAS	90 DAS-At harvest
A - Cropping System									
M₁	2.69 ^b	4.10 ^b	0.75 ^b	3.01 ^b	4.47 ^b	0.73 ^b	2.85 ^b	4.29 ^b	0.74 ^b
M₃	3.56 ^a	6.58 ^a	1.25 ^a	3.96 ^a	7.17 ^a	1.24 ^a	3.76 ^a	6.88 ^a	1.25 ^a
SEm (±)	0.073	0.095	0.039	0.079	0.109	0.048	0.076	0.102	0.043
CD (P=0.05)	0.446	0.577	0.039	0.478	0.663	0.290	0.462	0.620	0.263
B- Different levels of fertilizer									
S₁	1.88 ^d	2.35 ^d	0.32 ^d	1.92 ^d	2.36 ^d	0.35 ^d	1.90 ^d	2.35 ^d	0.34 ^d
S₂	3.47 ^b	5.45 ^b	1.09 ^b	3.93 ^b	5.99 ^b	1.06 ^b	3.70 ^b	5.72 ^b	1.08 ^b
S₃	2.57 ^c	5.31 ^c	0.84 ^c	2.91 ^c	5.84 ^c	0.80 ^c	2.74 ^c	5.58 ^c	0.82 ^c
S₄	4.58 ^a	8.27 ^a	1.75 ^a	5.18 ^a	9.10 ^a	1.72 ^a	4.88 ^a	8.68 ^a	1.73 ^a
SEm (±)	0.064	0.129	0.057	0.071	0.143	0.066	0.067	0.136	0.066
CD (P=0.05)	0.196	0.396	0.177	0.220	0.440	0.202	0.208	0.418	0.190
Interaction (A x B)	S	S	NS	S	S	NS	S	S	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.7a: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize crop growth rate.

30-60 DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	1.54 ^e	2.96 ^c	2.35 ^d	3.90 ^b	1.59 ^e	3.36 ^c	2.67 ^d	4.42 ^b	1.56 ^e	3.16 ^c	2.51 ^d	4.16 ^b
M ₃	2.21 ^d	3.97 ^a	2.78 ^c	4.25 ^a	2.26 ^d	4.50 ^b	3.15 ^c	4.95 ^a	2.24 ^d	4.24 ^b	2.97 ^c	4.60 ^a
SEm (±)	0.09				0.10				0.10			
CD(P=0.05)	0.28				0.31				0.29			

Table 4.1.7b: Interaction between cropping systems and different fertilizers levels on the sole and intercrop maize crop growth rate.

60-90 DAS	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	1.47 ^e	4.12 ^c	3.89 ^c	6.93 ^b	1.48 ^e	4.52 ^c	4.28 ^c	7.62 ^b	1.47 ^e	4.32 ^c	4.08 ^c	7.28 ^b
M ₃	3.23 ^d	6.78 ^b	6.72 ^b	8.61 ^a	3.24 ^d	7.45 ^b	7.41 ^b	9.57 ^a	3.23 ^d	7.11 ^b	7.07 ^b	9.09 ^a
SEm (±)	0.18				0.20				0.19			
CD(P=0.05)	0.56				0.62				0.59			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.1.10. Relative Growth Rate (g/g/day)

Table 4.1.8 shows the impact of the cropping system and different fertilizer levels on the Relative Growth Rate (RGR) of maize grown as a sole crop and as an intercrop. The cropping system had a significant impact RGR. A higher RGR was noted when maize was cultivated as an intercrop with mungbean at all sample intervals, while lower RGR was noted when maize was grown solely in both seasons, i.e., 2020 and 2021. Likewise, a similar trend was observed when the data were mean. The rise in the RGR of intercropped maize can be attributed to the nitrogen-fixing effect of mungbean. This effect promotes corn root growth, reducing nutrient competition and enhancing photosynthetic efficiency. This, in turn, leads to increased dry matter accumulation and a higher relative growth rate. Similar findings are supported by Latati *et al.* (2016) suggest that intercropping corn with leguminous crops leads to a rise in the RGR of corn in comparison to other intercrops, ultimately yielding the highest observed RGR. Lin *et al.* (2018) suggested that the rise in the RGR of intercropped maize might stem from the nitrogen-fixing influence of mungbean. This impact facilitates corn root growth, minimizing nutrient competition, improving photosynthetic efficiency, and enhancing both dry matter accumulation and the relative growth rate.

The plot treated with 50% RDF + 50% Nano NPK fertilizers in the case of different fertilizer treatments had the highest CGR at all sampling stages in both the growing years and when the data was mean. In the year 2020, at the sampling period of 30-60 DAS, the plot treated with 50% RDF and 50% Nano NPK fertilizers had the highest RGR while in 2021, plot treated with 50% RDF and 50% Nano NPK fertilizers was at par with 100 % RDF and 100% Nano NPK fertilizers but considerably superior to the other treatments. Similar data like that to 2020 while noted when the data was mean. While in the sampling period of 60-90 DAS, in both the growing years, and in the mean data, the highest RGR was noted in the plot that received 50% RDF + 50% Nano NPK fertilizers. The combination of 50% RDF and 50% Nano NPK fertilizers had the highest RGR at 90 DAS- at harvest sampling period, which was at par with 100% RDF which was also at par with 100 % Nano NPK fertilizers in the year 2020. While in the year 2021, the highest RGR was recorded in the plot treated with 50% RDF and 50% Nano NPK fertilizers followed by 100% RDF which was at par with 100 % Nano NPK fertilizers. Similarly in case of mean data, the highest RGR was reported in

the plot treated with 50% RDF + 50% Nano NPK fertilizers which was at par with 100 % RDF, followed by 100 % Nano NPK fertilizers. In both 2020 and 2021 as well as when the data was mean, at all sampling intervals, the control showed the lowest relative growth rate. The elevated relative growth rate observed in maize, stemming from the simultaneous use of 50% NPK fertilizers and 50% Nano NPK fertilizers, could be linked to various factors. These include the nanoscale attributes of nanofertilizers that enhance nutrient uptake and utilization efficiency. The synergistic effects between NPK and nanofertilizers play a pivotal role in promoting overall plant growth processes, exerting a positive influence on the crop growth rate. Furthermore, the stimulation of essential metabolic activities supports heightened cellular division and elongation, contributing to the increased relative growth rate. Another contributing factor is the potential enhancement in water and resource use efficiency. Additionally, the delayed senescence facilitated by nanofertilizers extends the growth period, thereby further amplifying the crop growth rate. Elsayed and colleagues in 2022, noted a comparable outcome, asserting that the utilization of nanofertilizers led to increased growth characteristics and physiological indices in rosemary compared to the traditional method of fertilizer application. Choudhary *et al.* (2023) observed a noteworthy enhancement in the relative growth rate of wheat when applying nano urea and urea through foliar spray. These conclusions are consistent with the findings reported by Jakiene *et al.* (2015).

The interaction between the cropping system and different fertilizer levels was found to be significant ($P=0.05$) in the sampling periods of 30–60 DAS and 60–90 DAS, but not in the sampling period of 90 DAS to harvest in both the years (2020 and 2021) and when data was mean (Table 4.1.8). The interop maize combined with 50% RDF + 50% Nano NPK fertilizers had the highest mean value of RGR, followed by sole maize combined with 50% RDF + 50% Nano NPK fertilizers, followed by intercrop maize + 100% NPK, sole maize combined with 100% Nano NPK fertilizers, sole maize +100% NPK, sole maize coupled with Nano NPK fertilizers and interop maize coupled with control. While sole maize combined with control had the lowest mean relative growth rate in both the years (2020 and 2021) and when the data were mean.

Table 4.1.8.: Effect of cropping system and different levels of fertilizers on the relative growth rate (g/g/day) of the sole and intercrop maize at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	30-60 DAS	60-90 DAS	90 DAS-At harvest	30-60 DAS	60-90 DAS	90 DAS-At harvest	30-60 DAS	60-90 DAS	90 DAS-At harvest
A - Cropping System									
M ₁	0.0381 ^b	0.0227 ^b	0.0026 ^b	0.0387 ^b	0.0223 ^b	0.0023 ^b	0.0384 ^b	0.0225 ^b	0.0024 ^b
M ₃	0.0420 ^a	0.0280 ^a	0.0033 ^a	0.0426 ^a	0.0276 ^a	0.0030 ^a	0.0423 ^a	0.0278 ^a	0.0031 ^a
SEm (±)	0.00018	0.0002	0.0001	0.00019	0.0002	0.0001	0.00019	0.0002	0.0001
CD (P=0.05)	0.0112	0.0090	0.0005	0.0116	0.0010	0.0004	0.0114	0.0095	0.00045
B- Different levels of fertilizer									
S ₁	0.0346 ^d	0.0191 ^d	0.0018 ^c	0.0348 ^b	0.0189 ^d	0.0019 ^d	0.0347 ^b	0.0190 ^d	0.00186 ^c
S ₂	0.0422 ^b	0.0248 ^c	0.0033 ^{ab}	0.0429 ^a	0.0244 ^c	0.0029 ^{bc}	0.0425 ^a	0.0246 ^c	0.00308 ^a
S ₃	0.0408 ^c	0.0295 ^a	0.0029 ^b	0.0415 ^a	0.0291 ^a	0.0025 ^c	0.0411 ^a	0.0293 ^a	0.00272 ^b
S ₄	0.0428 ^a	0.0278 ^b	0.0038 ^a	0.0435 ^a	0.0274 ^b	0.0034 ^a	0.0431 ^a	0.0276 ^b	0.00356 ^a
SEm (±)	0.00016	0.00043	0.00016	0.00015	0.00043	0.00018	0.00015	0.00043	0.00017
CD (P=0.05)	0.00490	0.00133	0.00050	0.00450	0.00132	0.00055	0.00470	0.00131	0.00052
Interaction (A x B)	S	S	NS	S	S	NS	S	S	NS

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.2. Yield components and Yield

4.1.1.2.1 Number of cobs/plant

Table 4.1.9 depicts the effects of the cropping system and different fertilizer levels on the no. of cobs/plant during the *kharif* seasons of 2020 and 2021, and in the mean data. The cropping system did not exhibit a statistically significant effect on the no. of cobs/plant in both growing years, as well as in the mean data analysis (Fig.4.1.9a).

In the case of varied fertilizer levels, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the most cobs/plant, which was statistically similar with 100% RDF but significantly superior to all other treatments in both 2020 and 2021. The plot treated with 100% RDF was also statically similar to 100% Nano NPK fertilizers but considerably higher than control. A similar pattern was seen in the plot treated with 100% Nano NPK fertilizers, which were much superior to the control but statistically comparable in both seasons. The control had the lowest cobs/plant in the growing years of 2020 and 2021, as well as when data were mean. However, in the mean data, the plot fertilized with 50% RDF and 50% Nano NPK fertilizers had the most cobs/plant, followed by 100% RDF and 100% Nano NPK fertilizers (Table 4.1.9 and Fig.4.1.9a). The increased no. of cobs/plant in maize resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers may be attributed to the nanoscale properties of nano fertilizers, enhance nutrient uptake by plant roots, ensuring an optimal and balanced nutrient supply when combined with NPK fertilizers. This synergy improves nutrient utilization efficiency, allowing maize plants to convert absorbed nutrients into reproductive structures more effectively, contributing to a higher count of cobs/plant. Additionally, the combined application may result in synergistic effects, positively influencing overall plant physiological processes and promoting the development of multiple cobs/plant. Furthermore, nano fertilizers might stimulate reproductive growth processes and influence hormonal balance, leading to the formation of additional cobs. The increased biomass production facilitated by nano fertilizers provides the necessary resources for the development of multiple cobs/plant. Lastly, the potential optimization of environmental conditions, including improved water and resource use efficiency, creates a conducive environment for the increased formation of cobs on each maize plant. Roy *et al.* (2023) reported consistent findings, indicating that the optimal combination of fertilizers such as

NPK, and two foliar sprays of Zn nanofertilizers led to the highest no. of cobs/plant. Likewise, Srivastava and Singh (2023) reported that the application of foliar spray containing both urea and nano urea resulted in the highest no. of cobs/plant in maize.

For both years (2020 and 2021) and in the mean data, the interaction between cropping system and varied fertilizer levels was significant. According to the mean data, sole maize combined with control had the lowest cobs/plant, but interop maize mixed with 50% RDF + 50% Nano NPK fertilizers had the highest mean no. of cobs/plant. This was true for both the 2020 and 2021 growing seasons.

4.1.1.2.2 Cob diameter (cm)

The impact of the cropping system and various fertilizer levels on the diameter of sole maize and intercrop maize cobs during the 2020 and 2021 *kharif* seasons is shown in Table 4.1.9 along with mean data. A higher cob diameter was recorded with maize as the interop crop while a lower cob diameter was recorded when maize was cultivated as the sole crop in both the seasons 2020 and 2021. A similar trend was reported in the mean data (Fig 4.1.9b). The increased cob diameter observed in intercropped maize, as opposed to sole maize cultivation, may arise from the favorable interactions among component crops. These interactions enable a more efficient utilization of the environment compared to separate cultivation, resulting in higher cobs diameter in intercropped systems compared to pure stands while the reduced cob diameter in sole maize cultivation could be attributed to diminished growth performance, particularly in terms of leaf area index, leading to a lower rate of assimilate translocation to seed setting. This may also be linked to the absence of temporal complementarity, resulting in intense competition for growth resources. Deviating findings were presented by Amanu *et al.* (2022), indicating that the cropping system did not exert a significant impact on cob diameter. Saleem (2017) presented comparable findings, indicating that the intercropping of maize with mungbean led to enhance the water use efficiency, light use efficiency, and nutrient use efficiency. These improvements positively influenced various yields, including cob length and cob girth etc. Ro *et al.* (2023) reported analogous findings in the intercropping of maize and mungbean.

In both seasons (2020 and 2021), as well as in the mean data, the cob diameter of maize was significantly impacted by the application of different levels

of fertilizers. The plot treated with 50% RDF + 50% Nano NPK fertilizers had the longest cob diameter in 2020, followed by 100% RDF and 100% Nano NPK fertilizers. While the control plot had the smallest cob diameter. When the data were mean, a similar pattern was shown in 2021 (Table 4.1.9 and Fig.4.1.9b). The increased cob diameter in maize resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers could be attributed to nanofertilizers' nanoscale properties, enhancing nutrient absorption efficiency by maize roots when used with NPK fertilizers. This collaborative effect improves nutrient utilization efficiency, fostering optimal growth, contributing to larger biomass accumulation, and resulting in an expanded cob diameter. The combined application may induce synergistic effects, positively influencing overall plant physiological processes, including cell division and expansion, collectively contributing to an increased cob diameter. The potential stimulation of cellular growth by nanofertilizers impacts the development of larger cobs, as their nanoscale properties play a role in metabolic processes related to cell expansion, enhancing cob diameter. Moreover, nanofertilizers' impact on nutrient uptake and utilization efficiency leads to increased biomass production, providing the necessary resources for larger cob formation. Alshatb and Alamery (2022) reported comparable findings, indicating that the application of fertilizer with nano potassium resulted in the highest cob diameter in maize. They attributed this outcome to the role of potassium in enhancing plant growth through increased photosynthesis and food processing. The increased size and division of cells, facilitated by potassium, contributes to the expansion of leaf area, subsequently leading to an increase in stem and cob diameter. Estrada *et al.* (2019) similarly reported consistent findings regarding cob diameter, noting that it was significantly influenced by the application of nano-zinc.

The interaction between the cropping system and various fertilizer levels was significant in both the years (2020 and 2021) as well as when the data were mean. In 2020, interop maize combined with 50% RDF + 50% Nano NPK fertilizers recorded the highest mean value of cob diameter, while sole maize combined with control recorded the lowest mean value of cob diameter. Similar patterns were seen in 2021 and when the data were mean (Table 4.1.9a).

4.1.1.2.3 Cob length (cm)

The effect of the cropping system and various fertilizer levels on the

length of sole maize and intercrop maize cobs during the *kharif* seasons of 2020 and 2021 is shown in Table 4.1.9 along with the mean data. A higher cob length was recorded with maize as the intercrop while a lower cob length was recorded when maize was cultivated as a monocrop in both seasons. The results obtained in 2021 were equivalent to the results obtained in the mean data (Fig 4.1.9c). The longer cobs observed in maize when intercropped with mungbean may be a result of the two crops efficiently using resources such as water, sunlight, and nutrients, with mungbean nitrogen-fixing ability enhancing nutrient availability. Additionally, the altered microclimate created by the intercropping system, coupled with potential positive effects from allelopathic interactions and synergistic relationships between the crops, contributes to the overall elongation of maize cobs. Huang *et al.* (2019) documented that intercropping corn with peanut resulted in an increased cob length of corn. Conversely, Abuna (2015) found a significant impact on cob length due to the intercropping of haricot bean, noting that the largest cobs were produced under the sole stand of maize which was comparable to the cob length observed when maize was intercropped in a 1:1 row ratio with haricot bean. In contrast, Lin *et al.* (2018) reported conflicting results in the case of maize and mungbean intercropping.

The length of cob in maize was significantly impacted by the application of different fertilizer levels in both seasons (2020 and 2021) as well as when data were mean. The plot treated with 50% RDF + 50% Nano NPK fertilizers in 2020 had the longest cob length; this treatment was statistically comparable to 100% RDF but significantly better than the other treatments. When the data were mean and analyzed in 2021, a similar trend was observed. The control plot had the shortest cob length in both seasons, 2020 and 2021, and in the mean data (Table 4.1.9 and Fig.4.1.9c). The enhanced cob length in maize resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers may be attributed to the nanofertilizers, enhancing nutrient absorption by maize roots. This ensures an optimal nutrient supply when combined with NPK fertilizers, improving nutrient utilization efficiency, and contributing to optimal growth. This impact further influences the number of cobs per plant. The synergistic effects of the combined application positively affect overall plant processes, including cellular elongation, impacting both cob length and diameter. In addition, stimulated cell growth by nanofertilizers contributes to the development of elongated cobs, while

the increased biomass production supports longer and well-developed cobs. Maheta *et al.* (2023) reported comparable findings, noting a notable increase in cob length, when subject to the treatment of 75% RDF + Nano N and P via foliar application with three sprays at 15, 30, and 60 DAS for maize compared to other treatments. Alshatb and Alamery (2022) reported congruent findings, noting a parallel outcome through the combined application of fertilizer with nano potassium, specifically in relation to the cob length of maize. Similarly, Meena and colleagues (2023) documented a notable increase in maize cob length through the simultaneous use of a combination comprising 75% RDN (recommended dose of nitrogen), RD-PK (recommended dose of phosphorus and potassium), and nano nitrogen. Moreover, Al-Saray and Al-Rubaei (2019) documented an augmentation in the length of maize cobs through the application of nanofertilizers.

The interaction between the cropping system and different fertilizer levels was significant in 2020 and 2021 and in the case of mean data. In the year 2020, the longest cob length was recorded in interop maize combined with 50% RDF + 50% Nano NPK fertilizers while the shortest cob length was noted in sole maize + control plot. In 2021, a similar pattern was seen, and when data were mean (Table 4.1.9 b).

4.1.1.2.4 Cob weight(g)

Table 4.1.9 illustrates the impact of the cropping system various fertilizer levels, on the cob weight of maize during the *kharif* seasons of 2020 and 2021 along with the mean data. The cropping system had a significant impact on the weight of the maize cobs in both individual years and mean statistics. In 2020, maize grown in combination with mungbean was shown to have higher cob weight, while maize grown alone had the lower cob weight. A similar tendency was seen in 2021 as well, and when the data were mean (Fig.4.1.9d). Possible factors contributing to a higher cob weight could be attributed to enhanced growth performance, particularly in terms of LAI. This improved growth might result in a higher rate of assimilate translocation to grain filling, promoting the formation of plump and larger-sized cobs. Saleem *et al.* (2017) documented comparable findings in the intercropping of maize and mungbean. In contrast, conflicting results were presented by Bekele *et al.* (2016) in maize-soybean intercropping, and Amanu *et al.* (2022) observed differing outcomes in maize and mungbean intercropping.

The interaction between the cropping system and various fertilizer levels was significant in both the years (2020 and 2021) and when the data were mean (Table 4.1.9c). The interop maize plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest cob weight, while the sole maize plot not treated with fertilizers had the lowest (control). Similarly, when the data was mean, comparable observations were noted (Table 4.1.9c). The heavier cob weight in maize resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers may be attributed to nanofertilizers enhancing nutrient absorption, ensuring an optimal nutrient supply when combined with NPK fertilizer. This improves nutrient utilization efficiency, supporting optimal growth and greater biomass accumulation, leading to increased cob weight and the interactive effects of the combined application of fertilizers positively impact overall plant physiological processes, enhancing cellular functions related to biomass production and contributing to the observed higher cob weight. Nanofertilizers also stimulate overall biomass production, influencing increased cell division and elongation, resulting in greater biomass accumulation and higher cob weight. Moreover, nanofertilizers contribute to improved environmental conditions, fostering enhanced growth and increased cob weight in maize. Ajithkumar and colleagues (2021) documented congruent findings, noting that the highest cob weight was observed in the treatment involving 50% N, 100% P and K, along with two sprays of nano nitrogen. They emphasized the efficacy of nano nitrogen applied through foliar spray as a viable alternative to soil application of fertilizers, particularly when combined with synthetic fertilizers applied through soil application. This approach was found to be highly effective in enhancing both the overall yield and parameters associated with yield in maize. These findings are consistent with those reported by Ekinci *et al.* (2012) and Ekinci *et al.* (2014), who noted the maximum average fruit weight for cucumber and the longest fruit length when using Nano at a rate of 4.0 L ha⁻¹.

In the case of various fertilizer treatments in both years and in the mean data, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the heaviest cob weight. This treatment was statistically comparable to 100% RDF during 2020 but substantially superior to all other treatments during 2021. When the data from the two years were mean, the control plot had the lowest cob weight in both the 2020 and 2021 growing seasons (Table 4.1.9 and Fig.4.1.9d).

Table 4.1.9.: Effect of cropping system and different levels of fertilizer on the yield attributes of the sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	No. of cobs/plant	Cob diameter(cm)	Cob length(cm)	Cob weight(g)	No. of cobs/plant	Cobs diameter(cm)	Cob length(cm)	Cob weight(g)	No. of cobs/plant	Cob diameter(cm)	Cob length(cm)	Cob weight(g)
A - Cropping System												
M₁	1.25 ^b	7.54 ^b	18.21 ^b	232.36 ^b	1.27 ^b	7.91 ^a	19.77 ^b	257.93 ^b	1.26 ^b	7.73 ^b	18.99 ^b	245.14 ^a
M₃	1.42 ^a	8.28 ^a	20.51 ^a	266.39 ^a	1.44 ^a	8.68 ^a	22.23 ^a	296.88 ^a	1.43 ^a	8.48 ^a	21.37 ^a	281.64 ^a
SEm (±)	0.05	0.12	0.31	5.29	0.08	0.12	0.34	5.64	0.07	0.12	0.32	5.47
CD (P=0.05)	NS	0.73	1.86	32.21	NS	0.76	2.09	34.30	NS	0.75	1.98	33.25
B- Different levels of fertilizer												
S₁	1.00 ^c	6.71 ^d	15.48 ^c	163.62 ^c	1.01 ^c	6.98 ^c	17.03 ^c	201.07 ^d	1.00 ^c	6.85 ^c	16.25 ^c	182.34 ^d
S₂	1.47 ^{ab}	8.05 ^{bc}	20.83 ^{ab}	282.30 ^a	1.49 ^{ab}	8.46 ^b	22.55 ^{ab}	303.33 ^b	1.48 ^a	8.26 ^b	21.69 ^b	292.82 ^b
S₃	1.20 ^{bc}	7.72 ^c	19.37 ^b	250.34 ^b	1.22 ^{bc}	8.11 ^b	20.99 ^b	268.83 ^c	1.21 ^b	7.92 ^b	20.18 ^b	259.58 ^c
S₄	1.67 ^a	9.17 ^a	21.76 ^a	301.24 ^a	1.69 ^a	9.64 ^a	23.44 ^a	336.39 ^a	1.68 ^a	9.40 ^a	22.60 ^a	318.81 ^a
SEm (±)	0.11	0.16	0.50	7.13	0.12	0.18	0.55	8.28	0.12	0.17	0.53	7.71
CD (P=0.05)	0.35	0.51	1.55	21.97	0.36	0.54	1.70	25.52	0.36	0.53	1.62	23.75
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

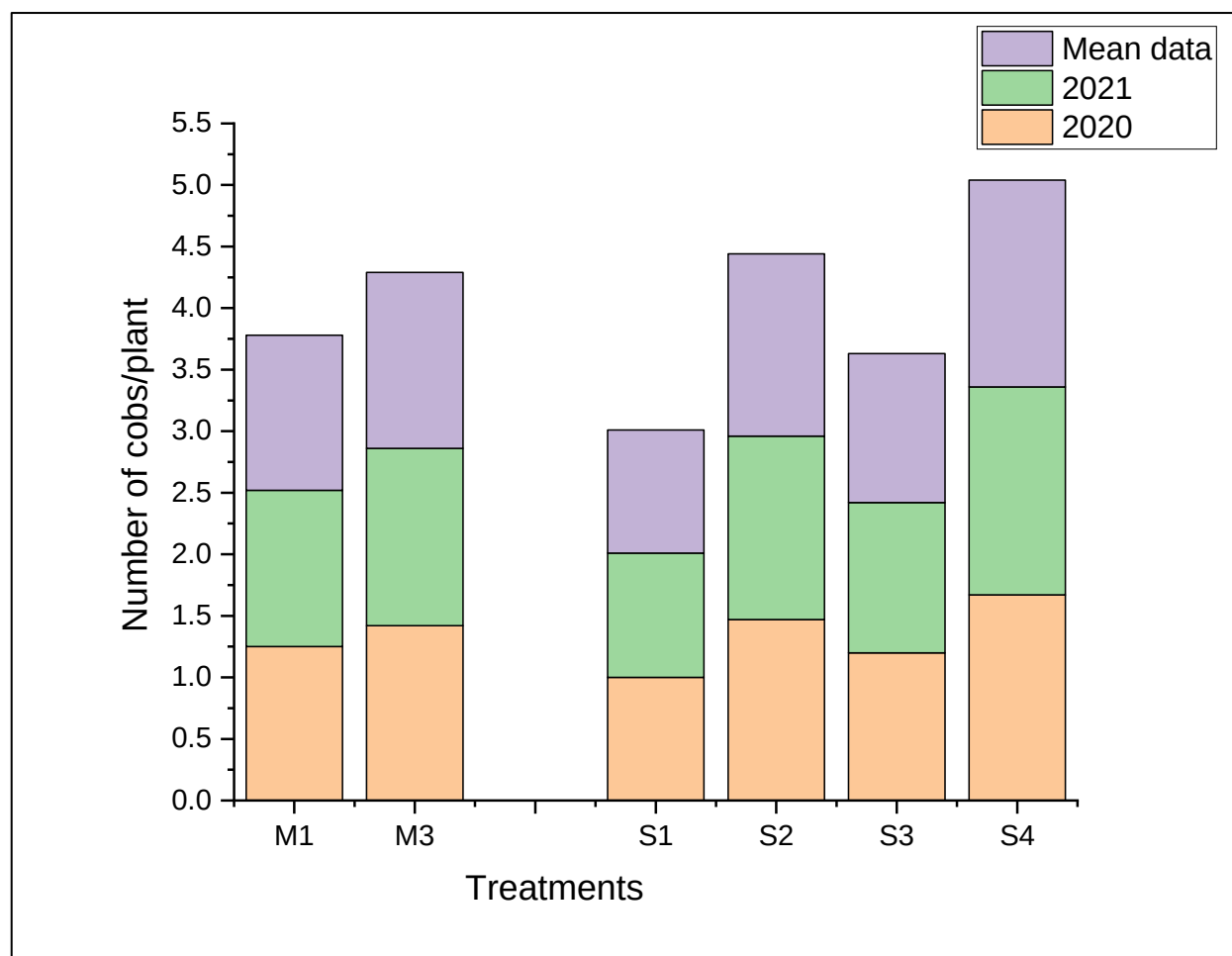


Fig.4.1.9a.: Effect of cropping system and different levels of fertilizer on the no. of cobs/plant of sole and intercrop maize. M₁=Maize (sole) M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

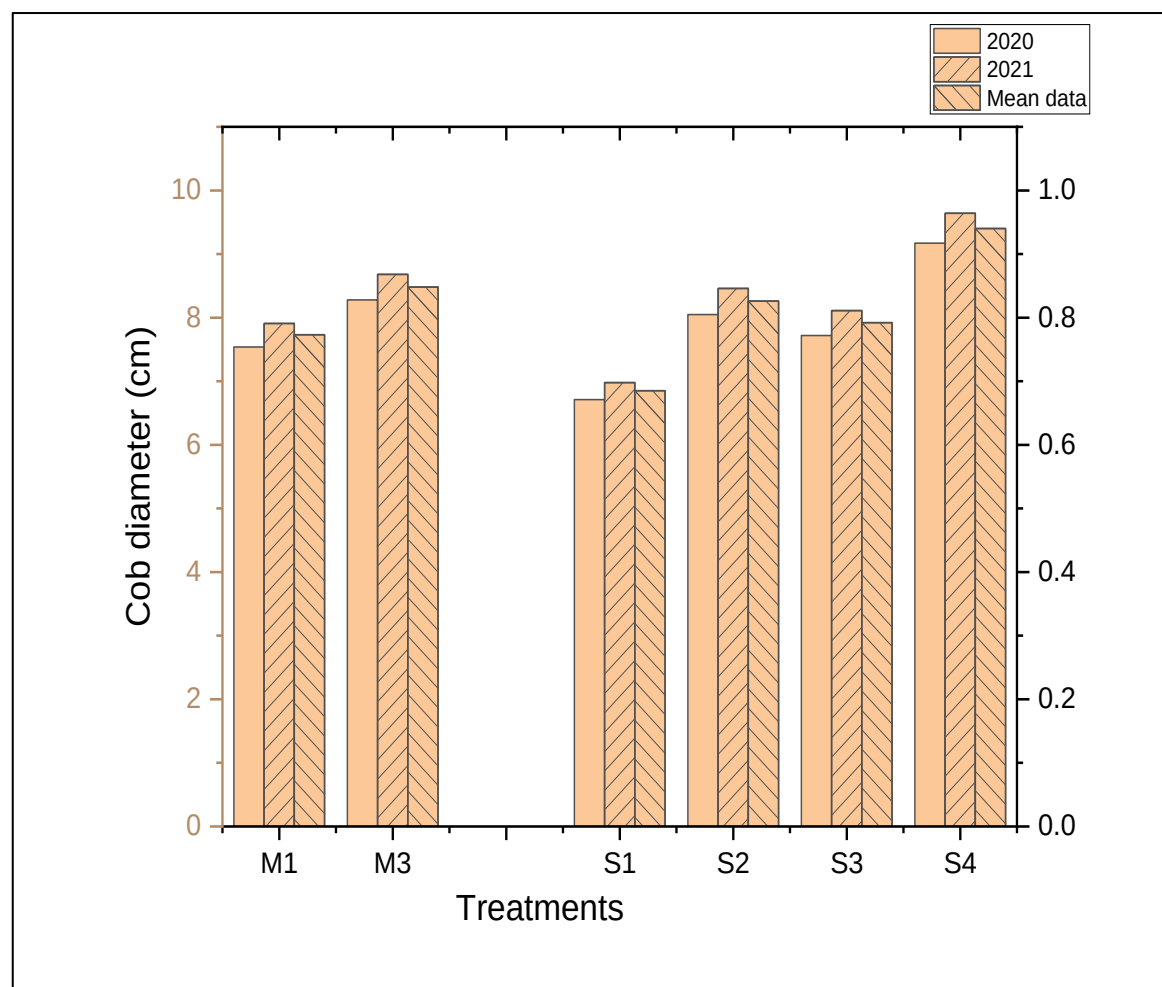


Fig.4.1.9b.: Effect of cropping system and different levels of fertilizer on the cob diameter (cm) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

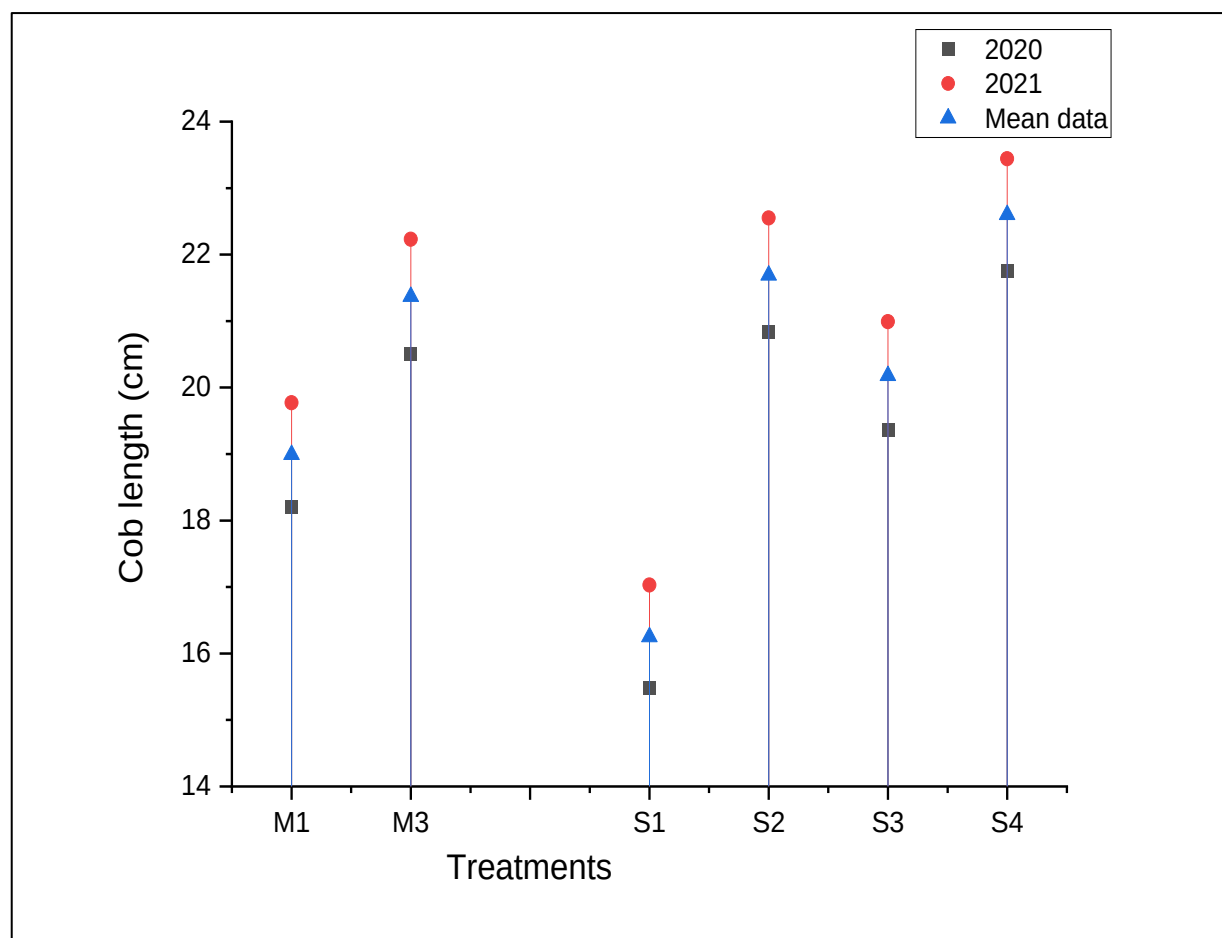


Fig.4.1.9c.: Effect of cropping system and different levels of fertilizer on the cob length (cm) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

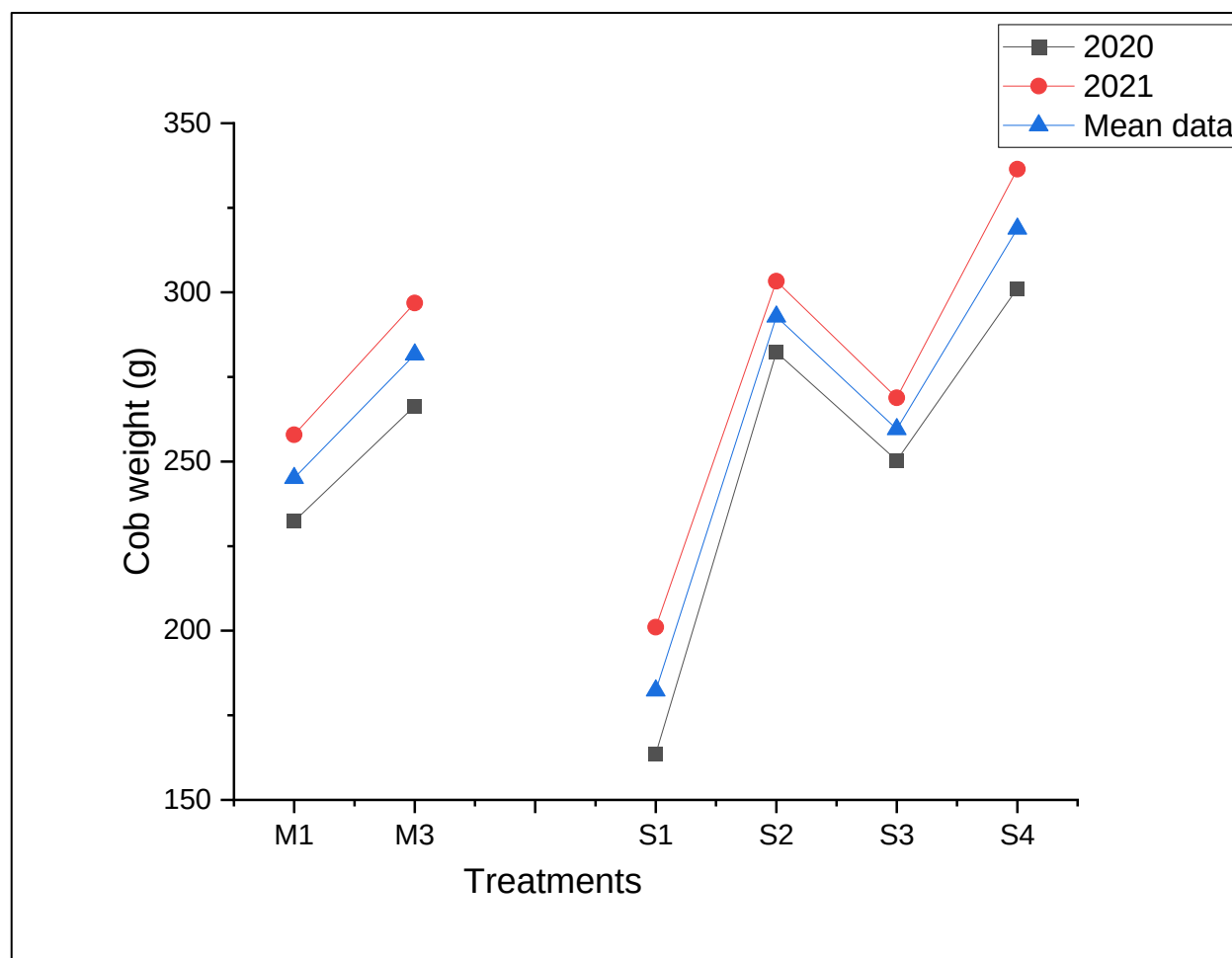


Fig.4.1.9d.: Effect of cropping system and different levels of fertilizer on the cob weight (g) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

Table 4.1.9a: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize cob diameter(cm).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	6.71 ^f	7.53 ^{de}	7.47 ^e	8.95 ^b	6.96 ^f	7.91 ^{de}	7.86 ^e	8.90 ^b	6.84 ^f	7.72 ^{de}	7.66 ^e	8.68 ^b
M₃	6.72 ^f	8.58 ^c	7.96 ^d	9.87 ^a	6.99 ^f	9.02 ^c	8.37 ^d	10.37 ^a	6.85 ^f	8.80 ^c	8.17 ^d	10.12 ^a
SEm (±)	0.23				0.25				0.24			
CD(P=0.05)	0.72				0.77				0.74			

Table 4.1.9b: Interaction between cropping systems and different fertilizers levels on the sole and intercrop maize cob length(cm).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	15.58 ^e	19.07 ^{bc}	17.78 ^d	20.05 ^a	16.24 ^e	20.91 ^{bc}	19.26 ^d	21.35 ^a	15.91 ^e	19.99 ^{bc}	18.52 ^d	20.70 ^a
M₃	15.71 ^e	22.60 ^a	21.62 ^c	23.44 ^a	16.52 ^e	24.52 ^a	24.05 ^c	24.05 ^a	16.11 ^e	23.56 ^{ab}	22.84 ^c	24.15 ^a
SEm (±)	0.63				0.71				0.67			
CD(P=0.05)	1.95				2.20				2.07			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.9c: Interaction between cropping system and different fertilizer levels on the cob weight (g) of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	146.74 ^d	271.41 ^b	214.69 ^c	296.58 ^a	164.61 ^d	302.07 ^b	241.71 ^c	323.32 ^a	155.68 ^d	286.74 ^b	228.20 ^c	309.95 ^a
M₃	180.50 ^b	293.19 ^a	285.98 ^{ab}	305.89 ^a	237.52 ^b	304.60 ^a	295.95 ^{ab}	349.45 ^a	209.01 ^b	298.90 ^a	290.96 ^{ab}	327.67 ^a
SEm (±)	10.09				11.71				10.90			
CD(P=0.05)	31.07				36.09				33.58			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercrop-ping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.2.5. Number of grains/cob

The impact of the cropping system and various fertilizer levels on the number of grains/cob of sole maize and intercrop maize during the 2020 and 2021 *kharif* seasons along with the data were mean, is shown in Table 4.1.10. When maize was cultivated as the sole crop in both the seasons 2020 and 2021 and when data were mean, a higher no. of grains/cob were noted in intercrop maize while a lower no. of grains/cob were observed (Fig 4.1.10a). Maize and mungbean have distinct morphologies, and their peak demand for light, nutrients, and water also differs therefore complementary effects between crops are highly common. Moreover, improved space and light interception as well as the nutrient contribution of mungbean to maize may be responsible for the increase in no. of grains/cob in intercropping systems. The outcomes of Raza *et al.* (2019); Gutu *et al.* (2016) supported the findings of the current study in maize-soybean intercropping. In contrast to these findings, Tohura *et al.* (2014) reported a significantly higher no. of grains/cob in sole maize in the context of maize/mung bean intercropping. Also differing from the findings, Temesgen *et al.* (2015) observed no significant impact of the cropping system on the no. of grains/cob.

The application of 50% RDF + 50% Nano NPK fertilizers on maize had the maximum no. of grains/cob and was statistically superior to all other treatments except 100% RDF in the year 2020, whereas the control plot contained the minimum number of grains/cob. Similar patterns were observed in 2021 and when the data were mean (Table 4.1.10. and Fig.4.1.10a). The higher no. of grains/cob in maize resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers may be due to enhanced nutrient availability, leading to improved pollination and fertilization. This, combined with increased nutrient utilization efficiency, ensures a balanced nutrient supply, promoting optimal conditions for grain development. Synergistic effects between NPK and nanofertilizers positively impact overall plant processes, including reproductive growth, contributing to the observed increase in the no. of grains/cob. Additionally, nanofertilizers stimulate reproductive growth and create an optimized environment for enhanced grain development, resulting in a higher grain count on each cob in maize. A comparable outcome was documented by Reddy and colleagues in 2022, affirming that the utilization of 50% Nitrogen in the form of urea combined with 50% Nitrogen in the form of Nano urea, had a substantial influence on the no. of

grains/cob. Likewise, Manikandan and Subramanian (2016); Dwivedi *et al.* (2016), stated that combining conventional and nanofertilizers improved photosynthesis and nutrient translocation, increasing productivity and grain production. They also asserted that nanofertilizers have a larger surface area than conventional fertilizers and have the ability to synchronize nitrogen release, thus, increasing the no. of grains in the cob. Farnia *et al.* (2015) obtained comparable results, revealing that the simultaneous application of nano zinc resulted in the highest no. of grains/cob in maize.

In 2020, 2021 and mean data, the interaction between the cropping system and different fertilizer levels was significant (Table 4.1.10a). The interop maize combined with 50% RDF + 50% Nano NPK fertilizers had the highest no. of grains/cob, followed by interop maize combined with 100% RDF, intercrop maize + 100 % Nano NPK fertilizers, sole maize combined with 50% RDF + 50% Nano NPK fertilizers, sole maize combined with 100% RDF, sole maize combined with 100% Nano NPK fertilizers, and interop maize control. The sole maize combined with control had the lowest no. of grains/cob. In both the growing seasons (2020 and 2021) and after the data had been average, these observations were noted (Table 4.1.10a).

4.1.1.2.6. Number of grains/row

The number of grains/row in both the 2020 and 2021 growing seasons, and in the mean data, was significantly impacted by the cropping system and various fertilizer levels (Table 4.1.10). In both the seasons 2020 and 2021, and when data were mean, a higher no. of grains/row was recorded with maize as the intercrop with mungbean while a lower no. of grains/row was observed with sole maize (Fig 4.1.10c). The rise in the no. of grains/row could be attributed to improved photosynthetic activity observed in maize-mungbean intercropping. Furthermore, the intercropping of maize and mungbean may have contributed to increased biomass production, driven by higher crop growth indices and more efficient utilization of available resources such as light, water, and nutrients. Comparable findings were documented by Nurgi *et al.* (2023) in their study on maize and mash bean cropping. Roshini *et al.* (2022) similarly documented that the intercropping of maize with mungbean resulted in a higher no. of kernel rows/cob in comparison to sole maize cultivation.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the most grains/row in the case of different levels of fertilizer treatment in 2020, followed by 100 % RDF and 100 % Nano NPK nanofertilizers, which were comparatively higher to all other treatments. In the control plot, the least average no. of grains/row was found. Similar trends were seen in 2021 and when data was mean (Table 4.1.10. and Fig.4.1.10c). The increased no. of grains/row in maize, resulting from combining 50% NPK fertilizers and 50% Nano NPK fertilizers, may be due to improved nutrient availability, supporting better pollination and fertilization. The enhanced nutrient utilization efficiency from NPK fertilizer contributes to a higher no. of grains along each row. Collaborative effects between NPK and nanofertilizers positively influence overall plant processes, promoting more grains/row. Furthermore, nanofertilizers stimulate reproductive growth, and their nanoscale properties impact metabolic activities related to grain development. Optimized environmental conditions further enhance grain formation, resulting in a higher count of grains/row in maize. Likewise, Estrada *et al.* (2019) observed that the no. of kernels/row in maize was notably influenced by the application of nanofertilizers. Nouraein (2019) also documented an enhancement in the production of various traits in maize with the application of zinc and boron nanofertilizers. Ajirloo *et al.* (2015) noted that the use of K nano fertilizer resulted in the highest no. of fruits/plant, as well as increased fruit weight, diameter, and overall yield in tomato crops. These findings align with the research conducted by Farnia and Ghorbani (2014), which also confirmed an increase in both yield and yield components in red beans.

The interaction between the cropping system and different fertilizer levels was significant in 2020, 2021, and when the data were mean (Table 4.1.10c).

4.1.1.2.7. Number of grain rows/cob

Table 4.1.10 illustrates the effects of the cropping system and various fertilizer levels on the number of grain rows/cob of sole and intercrop maize. In both growing years as well as in the mean data, maize as an intercrop with mungbean was recorded as having a higher no. of grain rows/cob compared to sole maize (Fig.4.1.10d). The variation in the no. of grain rows/cob may stem from unequal competition for growth resources, influenced by distinct root systems and critical growth stages. Additionally, the complementary effects between maize and mungbean could play a role. Comparable findings were noted by Gutu *et al.*

(2016) in their study on maize-soybean intercropping. Temesgen *et al.* (2015) similarly observed such results in the context of maize and common bean intercropping.

The application of 50% RDF + 50% Nano NPK fertilizers on maize in the year 2020 and 2021 had the most no. of grain rows/cob, followed by 100% RDF and 100% Nano NPK nanofertilizers, which was statistically higher than all the other treatments, while the control plot had the least no. of grain rows/cob. When the data were mean, a similar pattern was reported (Table 4.1.10 and Fig.4.1.10d). The application of a combination comprising 50 % NPK fertilizers and 50 % Nano NPK fertilizers, in maize cultivation has proven a noteworthy augmentation in the no. of grain rows/cob in comparison to alternative treatments. This observed improvement in maize productivity can be attributed to several factors inherent in the unique characteristics of this fertilizers blend. Primarily, the success of this combination may be linked to the enhanced availability of nutrients in the soil. The inclusion of Nano NPK fertilizers, characterized by their nano-sized particles, facilitates a more efficient dissolution of nutrients. This, in turn, ensures a readily accessible and abundant supply of essential elements such as N, P, and K for the burgeoning maize plants. The increased availability of these vital nutrients plays a pivotal role in fostering the robust growth and development of maize cobs. Moreover, the nano-sized particles in the Nano NPK fertilizers are believed to be instrumental in enhancing nutrient uptake by plant cells. This heightened efficiency in nutrient absorption was anticipated to result in more substantial and healthier maize plants, thereby contributing to an augmented no. of grain rows/cob. Roy *et al.* (2023) reported similar findings, indicating that the highest no. of rows/cob in maize was achieved through the combined application of non-nano and nano fertilizers. Yomso *et al.* (2022) similarly reported consistent findings regarding the no. of grains/cob in maize. Nouraein (2019) observed consistent findings in the no. of rows/maize cob using both nanofertilizers and bio-fertilizers, demonstrating a comparable impact on maize yield. Likewise, Farnia *et al.* (2015) obtained similar results in maize yield.

The interaction between the cropping system and various fertilizer levels was significant in 2020, 2021 and in the mean data (Table 4.1.10d). Interop maize combined with 50 % RDF + 50 % Nano NPK fertilizers had the highest mean no. of grains/cob, followed by interop maize + 100% RDF, sole maize + 50% RDF +

50% Nano NPK fertilizers, interop maize + 100% Nano NPK fertilizers, sole maize +RDF, sole maize +100% Nano NPK fertilizers, and interop maize + control. Sole maize + control had the lowest mean no. of grains/cob. These outcomes were noted throughout the two growing seasons (2020 and 2021) and in the mean data (Table 4.1.10d).

4.1.1.2.8. Test weight(g)

The test weight was significantly affected by the cropping system and various fertilizer levels in both seasons, 2020 and 2021 and in the mean data (Table 4.1.10). When maize was cultivated as the sole crop in 2020, 2021 and when data were mean, a lower test weight was observed. However, a higher test weight was recorded when maize was planted as intercropped maize (Fig 4.1.10b). The increase in test weight in intercropped maize can be attributed to improved growth performance, particularly in terms of leaf area, resulting in maximum photosynthetic assimilate translocation to grain filling and promoting robust seed size. Conversely, the lighter kernel weight in sole maize may be attributed to decreased growth performance, leading to a lower rate of assimilate translocation to grain filling and the formation of shriveled and smaller kernels. In contrast to these observations, Tohura *et al.* (2014) reported the highest test weight in sole maize compared to intercropping in maize/mung bean intercropping. Similarly, Alemayehu *et al.* (2018) found the highest test weight in sole cropped maize compared to intercropped maize in maize/common bean intercropping. Moreover, in alignment with the obtained results, Amanu *et al.* (2022) documented a parallel conclusion, emphasizing the significant influence of the cropping system on test weight in maize-mungbean intercropping. Moreover, Abdel Aziz *et al.* (2012) documented analogous results in the intercropping of maize and soybean.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest test weight in the case of varying levels of fertilizer treatment in 2020, followed by 100% RDF and 100% Nano NPK nanofertilizers, which was statistically higher than all other treatments. The control plot had the lowest test weight on a statistical basis. Similar trend was seen in 2021 and when data was mean (Table 4.1.10.). This phenomenon can be attributed to the presence of nano-sized particles in nanofertilizers, which play a crucial role in enhancing nutrient absorption. The nanofertilizers also contribute to improved nutrient availability in the soil and mitigate nutrient losses. This synergistic combination of traditional and

nano fertilizers, with its precision in nutrient delivery, creates favorable conditions for kernel development, potentially leading to an augmentation in test weights. In line with these findings, Farnia *et al.* (2015) similarly observed noteworthy results pertaining to the thousand weight in maize, further supporting the potential benefits of incorporating nano-sized particles in fertilization practices for enhanced agricultural outcomes. Ajithkumar *et al.* (2021) discovered analogous findings in the thousand weight of maize through the application of nanofertilizers. Furthermore, Bahubhai *et al.* (2019) highlighted a significant increase in test weight under various levels of chemical and nano potassic fertilizers. They attributed this improvement to the slow-release nature of nano potassic fertilizer, which, in turn, reduces fertilizer losses, enhances nutrient use efficiency, and ensures a well-balanced crop nutrition. Additionally, nano fertilizers are recognized for their gradual and consistent nutrient release throughout the crop growth period, potentially contributing to enhancement without any adverse effects. These findings align closely with the work of earlier researchers, including Ma *et al.* (2017) in maize, Gerdini (2016) in pumpkin, and Maqsood *et al.* (2013) in maize.

Both 2020, 2021 and the mean data showed significant interactions between the cropping system and various fertilizer levels (Table 4.1.10b). The interop maize treated with 50% RDF + 50% Nano NPK fertilizers had the highest mean test weight, whereas sole maize treated with control had the lowest mean test weight. These outcomes were noted throughout the two growing seasons (2020 and 2021) and following the averaging of the data (Table 4.1.10b).

Table 4.1.10.: Effect of cropping system and different levels of fertilizers on the yield and yield components of the sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	No. of grains/cob	No. of grains/row	No. of grain rows/cob	Test weight(g)	No. of grains/cob	No. of grains/row	No. of grain rows/cob	Test weight(g)	No. of grains/cob	No. of grains/row	No. of grain rows/cob	Test weight(g)
A - Cropping System												
M₁	363.90 ^b	25.81 ^b	13.50 ^b	31.25 ^b	367.33 ^b	28.04 ^b	14.23 ^b	30.63 ^b	365.62 ^b	26.59 ^b	13.71 ^b	30.94 ^b
M₃	464.16 ^a	32.35 ^a	15.86 ^a	41.64 ^a	468.46 ^a	35.14 ^a	16.98 ^a	40.81 ^a	466.31 ^a	33.75 ^a	16.39 ^a	41.23 ^a
SEm (±)	10.47	0.66	0.23	0.32	9.41	0.73	0.27	0.33	9.94	0.69	0.25	0.32
CD (P=0.05)	63.69	4.02	1.39	1.93	57.23	4.44	1.64	2.01	60.46	4.23	1.52	1.97
B- Different levels of fertilizer												
S₁	286.21 ^c	20.72 ^d	11.28 ^d	29.90 ^c	286.50 ^c	20.38 ^c	11.30 ^c	29.30 ^c	286.35 ^c	20.30 ^c	10.83 ^d	29.60 ^c
S₂	463.96 ^a	31.72 ^b	15.88 ^b	40.90 ^a	474.29 ^a	34.90 ^{ab}	17.42 ^a	40.08 ^a	469.13 ^a	33.31 ^{ab}	16.57 ^b	40.49 ^a
S₃	419.26 ^b	29.80 ^c	14.53 ^c	33.03 ^b	420.52 ^b	32.78 ^b	15.49 ^b	32.38 ^b	419.89 ^b	31.29 ^b	15.01 ^c	32.70 ^b
S₄	486.69 ^a	34.08 ^a	17.04 ^a	41.95 ^a	490.27 ^a	37.49 ^a	18.20 ^a	41.11 ^a	488.48 ^a	35.79 ^a	17.78 ^a	41.53 ^a
SEm (±)	11.91	0.85	0.32	0.47	12.35	0.97	0.34	0.44	12.13	0.91	0.33	0.46
CD (P=0.05)	36.69	2.60	1.00	1.45	38.05	2.98	1.04	1.35	37.37	2.79	1.02	1.40
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

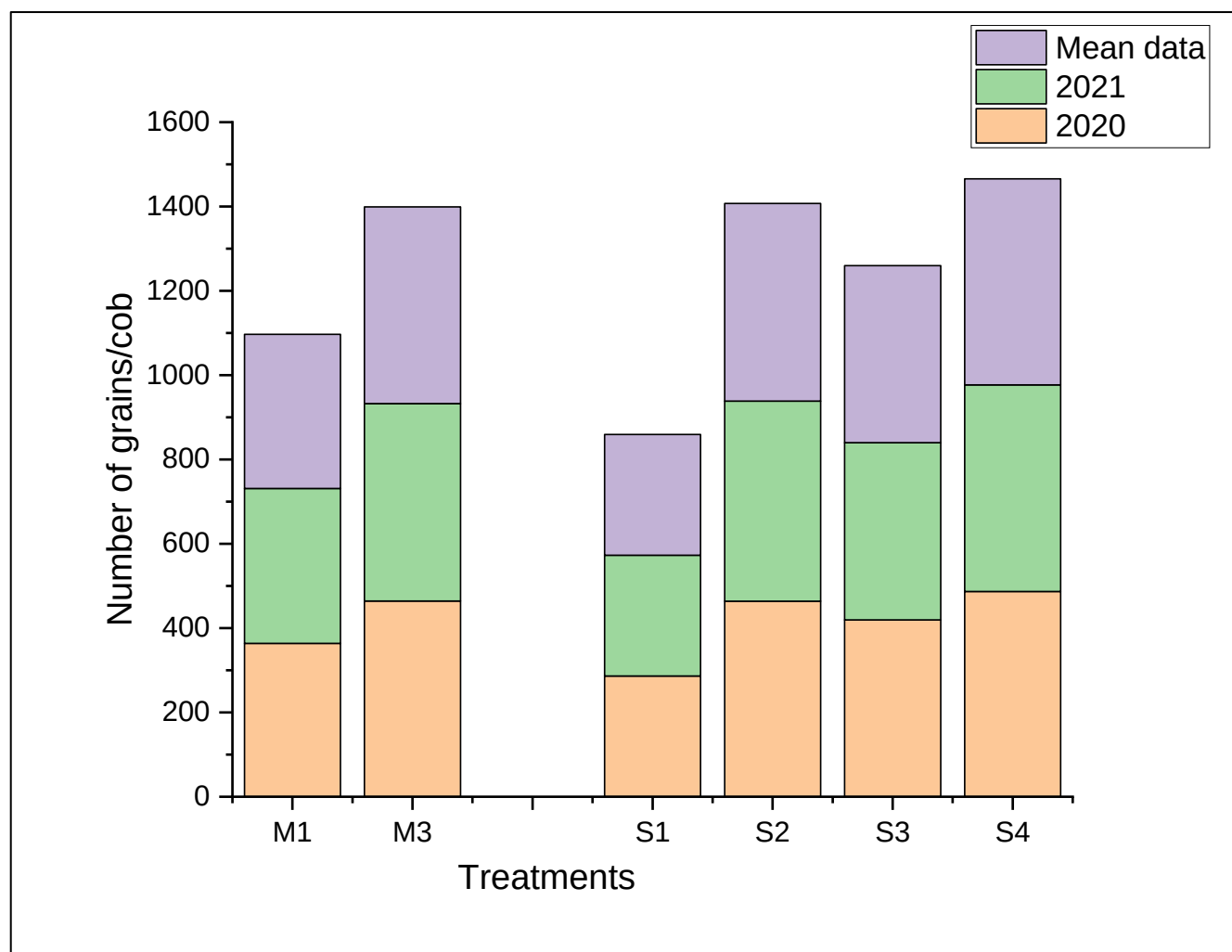


Fig.4.1.10a.: Effect of cropping system and different levels of fertilizer on the no. of grains/cob of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

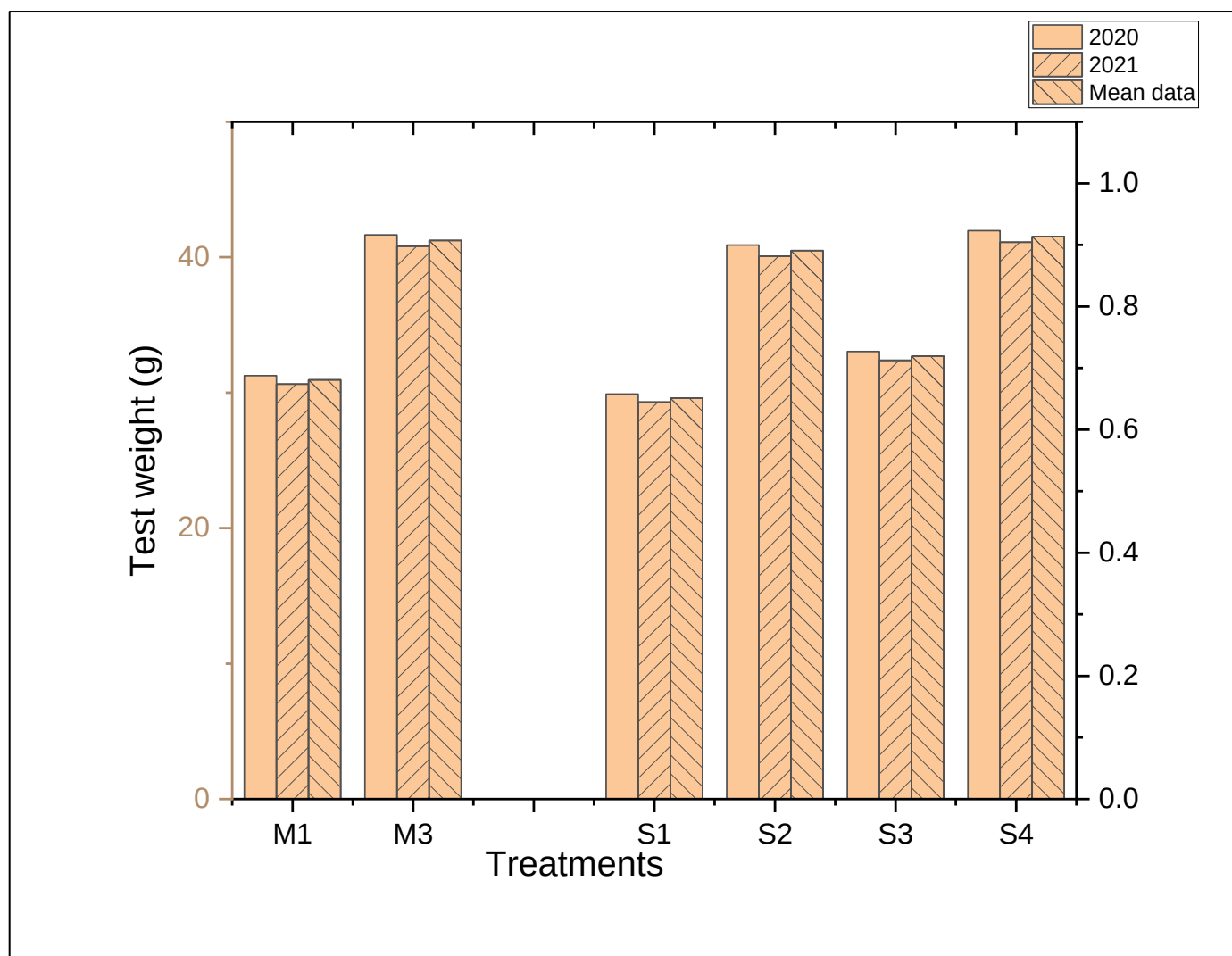


Fig.4.1.10b.: Effect of cropping system and different levels of fertilizer on the test weight(g) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

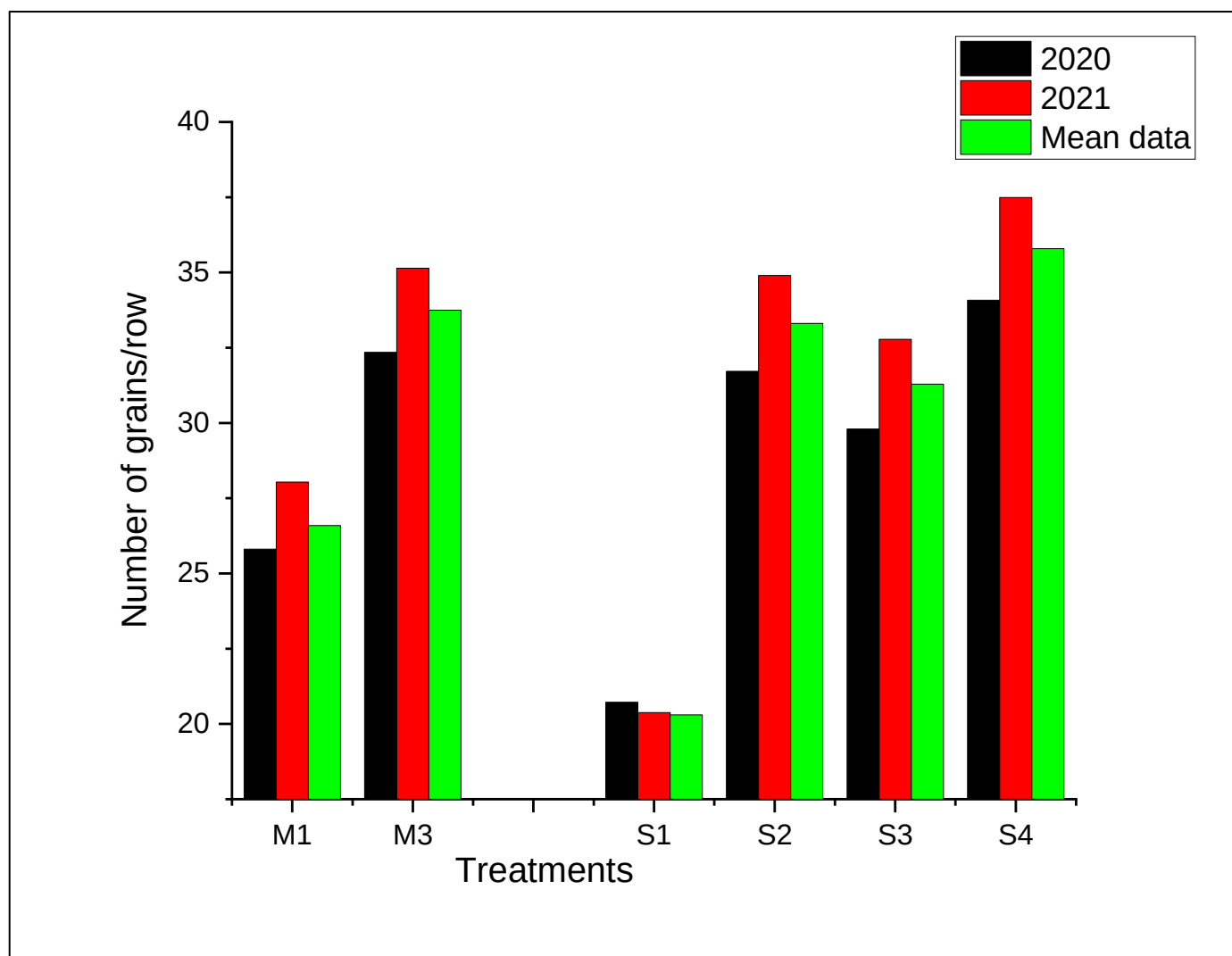


Fig.4.1.10c.: Effect of cropping system and different levels of fertilizer on the no. of grains/row of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

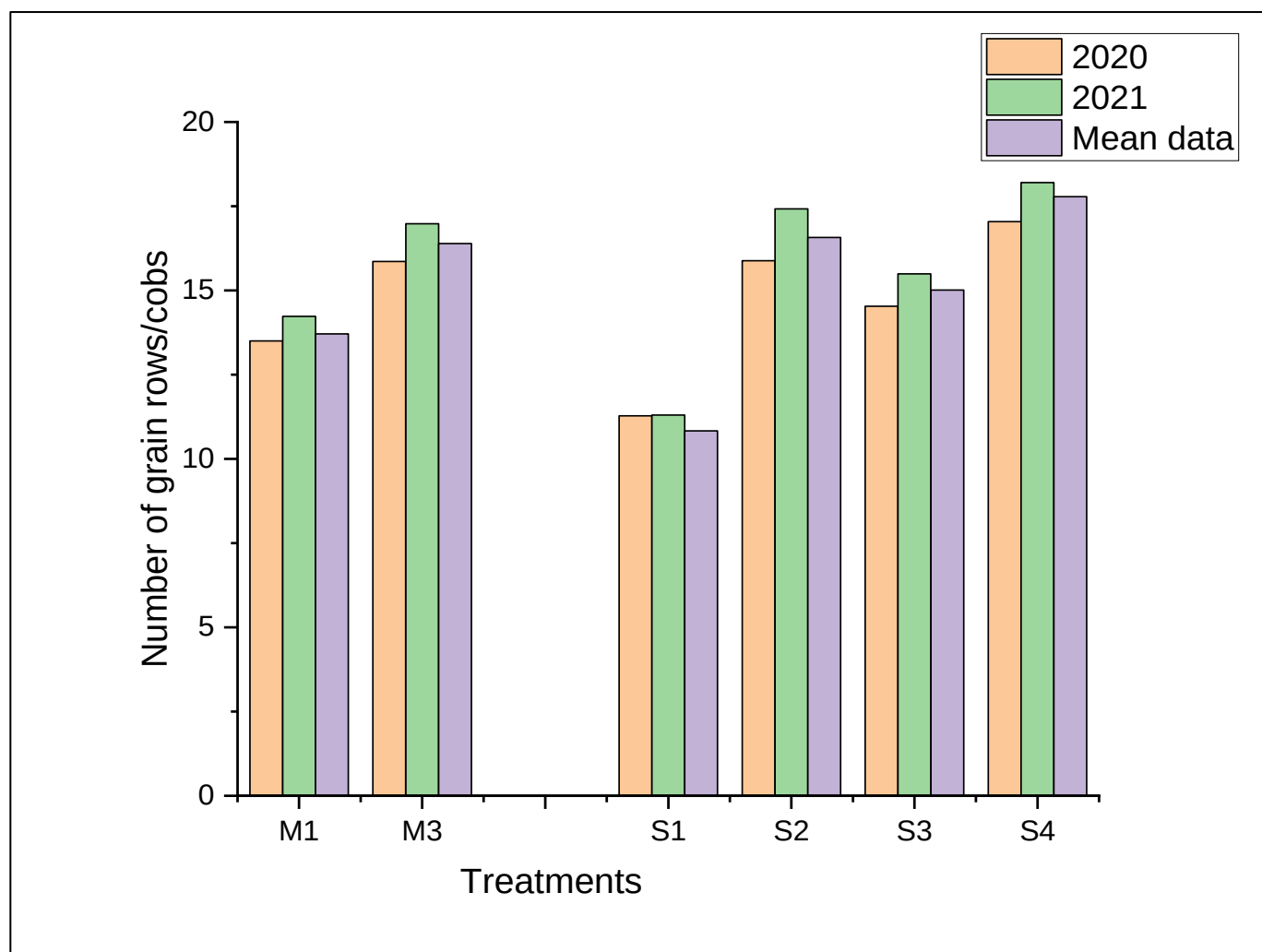


Fig. 4.1.10d.: Effect of cropping system and different levels of fertilizer on the number of grain rows/cob of sole and intercrop maize. M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table4.1.10a: Interaction between cropping system and different fertilizers levels on sole and intercrop maize no. of grains/cob.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	261.46 ^e	390.08 ^b	388.89 ^c	415.18 ^b	257.99 ^e	408.34 ^b	389.42 ^c	413.58 ^b	259.73 ^e	399.21 ^b	389.15 ^c	414.38 ^b
M₃	310.95 ^d	537.85 ^a	449.63 ^b	558.20 ^a	315.00 ^d	540.24 ^a	451.63 ^b	566.95 ^a	312.98 ^d	539.05 ^a	450.63 ^b	562.58 ^a
SEm (±)	16.84				17.47				17.15			
CD(P=0.05)	51.88				53.81				52.85			

Table4.1.10b: Interaction between cropping system and different fertilizers levels on sole and intercrop maize test weight (g).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	22.20 ^d	37.60 ^c	26.60 ^e	38.60 ^c	21.76 ^d	36.85 ^c	26.07 ^e	37.83 ^c	21.98 ^d	37.22 ^c	26.33 ^e	38.22 ^c
M₃	37.60 ^c	44.20 ^b	39.47 ^c	45.30 ^a	36.85 ^c	43.32 ^b	38.68 ^c	44.40 ^a	37.22 ^c	43.76 ^b	39.07 ^c	44.85 ^a
SEm (±)	0.67				0.62				0.64			
CD(P=0.05)	2.05				1.92				1.98			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table4.1.10c: Interaction between cropping system and different fertilizers levels on sole and intercrop maize no. of grain/row.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	20.50 ^f	26.51 ^d	25.75 ^d	30.48 ^c	21.17 ^f	29.16 ^d	28.32 ^d	33.52 ^c	20.84 ^f	27.84 ^d	27.04 ^d	32.00 ^c
M₃	20.94 ^e	36.94 ^{ab}	33.85 ^b	37.69 ^a	21.25 ^e	40.63 ^{ab}	37.23 ^b	41.46 ^a	21.10 ^e	38.78 ^{ab}	33.54 ^b	39.57 ^a
SEm (±)	1.20				1.37				1.28			
CD(P=0.05)	3.68				4.21				3.95			

Table4.1.10d: Interaction between cropping system and different fertilizers levels on sole and intercrop maize no. of grain rows/cob.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	9.72 ^e	14.20 ^c	13.23 ^c	16.17 ^b	10.58 ^e	15.18 ^c	14.14 ^c	17.28 ^b	10.64 ^e	14.55 ^c	13.69 ^c	16.59 ^b
M₃	11.85 ^d	17.83 ^a	15.79 ^b	17.94 ^a	12.03 ^f	19.67 ^a	16.84 ^b	19.37 ^a	11.94 ^d	18.75 ^a	16.33 ^b	18.65 ^a
SEm (±)	0.45				0.48				0.46			
CD(P=0.05)	1.38				1.47				1.42			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.2.9. Straw yield (kg/ha)

Table 4.1.11 illustrates the impact of cropping system and fertilizer levels on maize straw yield for the 2020 and 2021 *kharif* seasons, as well as the mean data. The cropping system had a significant impact on maize straw yield. In both the years and in the mean data, higher straw yield was observed in the plot where maize was planted as an intercrop with mungbean, while lower straw yield was observed in the plot where maize was cultivated as a sole crop (Fig.4.1.11a). The elevated straw yield in intercropped maize could be attributed to the enhanced efficiency of intercropping maize in utilizing growth resources such as light, water, and nutrients. This efficiency leads to increased biomass production and higher straw yields in the maize intercrop. Additionally, in intercropping systems involving legumes and non-legume crops, the non-legume crop often benefits from shared atmospheric nitrogen fixed by the legumes. In the context of the maize-mungbean intercropping system, mungbean might have contributed nitrogen to the maize component, thereby augmenting maize production of straw. Comparable explanations were provided by Maitra *et al.* (2019) and Maitra *et al.* (2020) in the context of maize and legume intercropping. Similarly, Owusu and Sadick (2016) also presented similar reasons in the case of maize and soybean intercropping. Additionally, Herve *et al.* (2017) also noted that the maize-cowpea intercropping produced higher straw yields compared to the pure stands. This encounter aligns with the findings of Khan *et al.* (2018); Yang *et al.* (2018); Sebetha (2015) observed that intercropping corn with garden pea increased corn straw production, attributing the potential advantage of sole maize over intercropped maize to the symbiotic nitrogen fixation of garden pea and the subsequent transfer of nitrogen to the associated maize plants.

The plot treated with 50% RDF + 50% Nano NPK fertilizers produced the most straws in the year 2020, followed by the plot treated with 100% RDF, 100% Nano NPK fertilizers, which was statistically superior to all other treatments. The control plot had the lowest straw yield in 2020. A similar pattern was observed in 2021 and for mean data (Table 4.1.11 and Fig.4.1.11a). The combination of 50% NPK fertilizers and 50% Nano NPK fertilizers in maize was thought to promote the highest straw yield due to the nano-sized particles which enhance nutrient uptake, improve nutrient availability in the soil, and provide a balanced nutrient supply, fostering overall plant health and robust growth. Additionally,

nanofertilizers help minimize nutrient losses, contributing to sustained growth and higher straw yield. The stimulation of plant metabolism by nanofertilizers further enhances biomass accumulation, influencing the formation of a substantial straw yield in maize. Yomso and Menon (2021) reported analogous findings in the rice cultivation. Srivastava and Singh (2023) reported comparable findings, indicating a parallel outcome achieved through the combined application of both chemical and nanofertilizers in the stover yield of maize. The higher stover yield can be attributed to the improvement in the quantity of dry matter within the stem at harvest, coupled with an increase in the percentage of photosynthesis for the sink. These enhancements contributed to the augmented production of stover (Ajitkumar *et al.* 2021). Comparable findings were observed in investigations conducted by Middle *et al.* (2022) in rice, Sahu *et al.* (2022) in rice.

In both seasons (2020 and 2021) as well as in the case of mean data, it was determined that there was a significant interaction between the cropping system and different fertilizer levels. The plot where intercrop maize was grown along with 50% RDF+50% Nano NPK fertilizers recorded the highest mean value of straw yield, whereas the plot with sole maize along with the control was determined to have the lowest in both seasons and in the mean statistics (Table 4.1.11a).

4.1.1.2.10. Grain yield (kg/ha)

Table 4.1.11 illustrates the grain yield per hectare as influenced by various fertilizer levels and cropping system for the *kharif* seasons of 2020 and 2021 as well as mean data. Different cropping systems and fertilizer levels both have a significant impact on grain yield. Plots with maize as the intercrop with mungbean provided higher grain yields than those with maize as the sole crop in both the 2020 and 2021 growing seasons and in the mean data. A higher yield was recorded in intercrop maize compared to sole maize. The possible reason for that is the maize's ability to utilize growth and yield resources more efficiently and convert them into crop biomass, leading to higher yield production. Additionally, mungbean fixes atmospheric nitrogen, which supplies additional nitrogen for the maize, leading to high dry matter production and grain yield other than the sole maize. This also may be attributed to the complementing effect of the mungbean, which added nitrogen to the maize, and the improved use of solar radiation, space, and soil nutrients by the Maize+Mungbean intercropping. Also, the highest

values of plant height, no. of leaves, leaf area, and LAI may be the cause of greater yield production in intercrop maize. Since all of these growth parameters are significant yield-contributing components, the yield was increased when compared to sole maize. Intercropping maize with cereals demonstrated improved grain yields compared to monocropping, as evidenced by Du *et al.* (2018) and Liu *et al.* (2020). In alignment with the findings of Muoneke *et al.* (2012) and Choudhary *et al.* (2014), the inclusion of cowpea alongside maize was associated with an increase in maize production. However, Ustundag and Unay (2016) reported conflicting results, indicating higher grain yields in sole maize cultivation compared to maize/soybean intercropping over two growing seasons.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest grain yield across all fertilizer treatments in both the 2020 and 2021 growing seasons, as well as in the case of mean data, followed by the plot fertilized with 100% RDF and 100% Nano NPK fertilizer. The control plot has produced the lowest grain yield in 2020. However, mean data and 2021 statistics showed a similar tendency (Fig. 4.1.11b and Table 4.1.11). The application of 50% NPK fertilizers and 50% Nano NPK fertilizers in maize was associated with highest grain yield which may be due to the nano-sized particles in nanofertilizers which boost absorption of nutrient, improved the availability of nutrient in the soil, and provide a balanced nutrient supply, supporting robust plant growth and larger grain development. Furthermore, nanofertilizers may help in minimizing nutrient losses and stimulate plant metabolism, contributing to increased biomass and higher grain yields. Sannathimmappa and colleagues in 2023 reported comparable findings, highlighting a notably increased seed yield in the treatment involving 100 % N along with two sprays of 0.4% nano N and nano Zn. They attributed this enhanced yield to the small size and substantial effective surface area of nanoparticles, facilitating easy penetration into plants. This penetration, in turn, leads to the generation of additional cells and dry matter, which is stored as a sink in seeds. These outcomes align with the findings reported by Parmar in 2016. This concurs with the findings of Liu and Lal (2015), who found a synergistic effect between traditional fertilizer and nano fertilizers for higher nutrient uptake in the cells of the plant which led to increased photosynthesis resulting in the accumulation of higher photosynthates, and transportation of nutrients to the economic parts of the plant which correlate in a final grain yield. Additionally, the results

were comparable to those found by Tarafdar *et al.* (2014); Gomaa *et al.* (2017), who found that nano fertilizers significantly impacted yield components. The present study's results agree with Mekkei and El Haggan (2014); Zain *et al.* (2015), who found that applying nano-fertilizers by foliar spraying enhanced wheat yield and yield components.

Both the years (2020 and 2021) and the mean data revealed a significant interaction between the cropping system and fertilizer levels. In both 2020 and 2021, as well as when data were mean, the maximum mean value of grain yield was found in interop maize combined with 50 % RDF, whereas the minimum was recorded in sole maize combined with the control (Table 4.1.11b).

4.1.1.2.11. Biological yield (kg/ha)

Table 4.1.11 illustrates biological yield/hectare as influenced by different fertilizer levels and cropping systems throughout the 2020 and 2021 *kharif* seasons, as well as the mean data. Biological yield significantly responded to different fertilizer levels and different cropping systems treatments. Plots, where maize was grown as an intercrop with mungbean, produced higher biological yield compared to the plot where maize was cultivated as sole maize in both seasons i.e., 2020 and 2021 as well as when the data were mean (Fig.4.1.11c). The increase in biological yield may be attributed to a rise in both grain and straw yield, influenced by higher yield and related factors like grains/cob, test weight, and cob diameter. This improvement could be a consequence of positive competitive interactions for common growth resources with the companion crop. Comparable findings were documented by Tesfaye *et al.* (2020), highlighting the significant influence on sorghum biomass in sorghum/cowpea intercropping. In harmony with these results, Gutu *et al.* (2016) observed a significant effect on the above-ground biomass yield of maize in maize intercropped with soybean. Additional research on intercropping done by Mucheru-Muna *et al.* (2010), also revealed that how crop species with different niches might have higher biological yield. However, according to them, the choice of compatible genotypes with appropriate attributes for establishing minimal competition and maximum complementarity determines the yield in intercropping systems.

The plot treated with 50% RDF + 50% Nano NPK fertilizers provided the maximum biological yield in the case of varying degrees of fertilizer treatment in the year 2020, followed by the plot treated with 100% RDF and 100% Nano NPK

fertilizers, which was noticeably superior to all other treatments. According to statistics, the control plot's lowest biological yield occurred in 2020. However, when data were mean and in the year 2021, a similar pattern was reported (Table 4.1.11 and Fig.4.1.11c). The combination of 50 % NPK fertilizers and 50 % Nano NPK fertilizers resulted in the highest biological yield which may be due to enhanced overall plant growth, a balanced nutrient supply, improved nutrient availability, reduced nutrient loss, and stimulation of plant metabolism. This comprehensive approach supports the development of both grain and straw components, contributing to a greater overall biological yield. Reddy and colleagues (2022) similarly reported that the combination of nano fertilizers with conventional fertilizers enhances nutrient absorption efficiency, promotes photosynthesis, and facilitates nutrient translocation, ultimately augmenting productivity and grain yield. Nanoparticles can penetrate through stomatal pores and traverse vascular systems, influencing the effectiveness of nanoparticles through alterations in chemical composition and shape, consequently impacting biological yield. These outcomes align with findings reported by Varshney *et al.* (2018) and Talan *et al.* (2018) who stated that nanoparticles' reduced size allows them to enter through stomatal pores and flow through circulatory systems. By altering their chemical composition and structure, nanoparticles can also affect biological yield and increase their effectiveness.

It was observed that the interaction between the cropping system and fertilizer levels in both seasons (2020 and 2021) and in the mean data was significant. In 2020 and 2021 growing seasons, and in the mean data, interop maize in combination with 50% RDF + 50% Nano NPK fertilizers recorded the highest mean value of biological yield, whereas sole maize in combination with the control found the lowest (Table 4.1.11c).

4.1.1.2.12. Harvest index (%)

Table 4.1.11 depicts the influence of various fertilizer rated and cropping system on the index of maize harvested in the 2020 and 2021 *khari*f seasons together with mean data. In the year 2020, the cropping system significantly affected the maize HI but in the next year and when data were mean, this influence was no longer there. Although the plot where maize was cultivated as an intercrop with mungbean had a higher HI in the year 2020, it was statistically equivalent to the plot where maize was produced as the sole crop (Fig.4.1.11d). The HI was

unaffected by the cropping system, with no significant impact observed. This outcome aligns with the findings of Tohura *et al.* (2014), who similarly reported a non-significant effect of the cropping system on the HI of maize in maize/mung bean intercropping. Consistent with this, Hirpa (2014); Lulie *et al.* (2016) also reported non-significant effects of the cropping system on the HI of maize in maize-haricot bean intercropping systems.

In the year 2020, the plot applied with 50% RDF + 50% Nano NPK fertilizers had the highest HI, which was comparable with the plot treated with 100% RDF but significantly superior to all other treatments. In the year 2021, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest mean value of the HI, which was statistically similar to the plots treated with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot's HI was lowest in 2020. A similar trend was observed in 2021 and mean data (Table 4.1.11). The HI in maize, achieved through the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, hinges on optimizing key yield parameters and a balanced nutrient supply from NPK fertilizers supports both vegetative (straw) and reproductive (grain) growth, contributing to a favorable harvest index. Stimulation of reproductive processes by nanofertilizers prioritizes resource allocation to grain development. Reduced nutrient loss conserves resources, maximizing economic output relative to plant biomass and improving the HI. Improved stress tolerance from nanofertilizers minimizes environmental impact on grain development, further enhancing the overall harvest index in maize cultivation. El-Naggar *et al.* (2020) identified a comparable pattern to the aforementioned results, noting that the combined use of nanofertilizers and mineral fertilizers demonstrated similar effects in maize crops. This observation aligns with the findings of other researchers, such as Suriyaprabha *et al.* (2012) in maize, Alsaeedi *et al.* (2017) in common beans, Azimi *et al.* (2014) in wheatgrass, Lu *et al.* (2015) in tomatoes, and Qados (2015) in capsicum.

The interaction between the cropping system and different fertilizer levels was determined to be non-significant in both seasons (2020 and 2021) and in mean data.

Table 4.1.11.: Effect of cropping system and different levels of fertilizer on the yield and harvest index of sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	Straw yield(kg/ha)	Grain yield(kg/ha)	Biological yield(kg/ha)	Harvest Index (%)	Straw yield(kg/ha)	Grain yield(kg/ha)	Biological yield(kg/ha)	Harvest Index (%)	Straw yield(kg/ha)	Grain yield(kg/ha)	Biological yield(kg/ha)	Harvest Index (%)
A - Cropping System												
M₁	5130.54 ^b	4056.03 ^b	9186.40 ^b	43.05 ^a	5604.97 ^b	4158.99 ^b	9763.97 ^b	41.61 ^a	5367.67 ^b	4107.51 ^b	9475.18 ^b	42.33 ^a
M₃	7531.09 ^a	5118.74 ^a	12649.84 ^a	39.08 ^b	7674.18 ^a	5233.60 ^a	12907.78 ^a	39.14 ^b	7602.64 ^a	5176.17 ^a	12778.81 ^a	39.11 ^b
SEm (±)	143.04	106.65	221.72	0.43	132.22	96.88	228.24	0.45	137.63	101.77	224.98	0.44
CD(P=0.05)	870.27	648.88	1348.91	2.59	804.42	589.41	1388.60	2.71	837.35	619.13	1368.76	2.65
B- Different levels of fertilizer												
S₁	4451.09 ^c	2109.00 ^c	6560.09 ^c	32.27 ^c	4512.51 ^c	2128.23 ^c	6640.74 ^c	34.13 ^b	4481.80 ^c	2118.61 ^c	6600.41 ^c	34.20 ^c
S₂	7081.59 ^{ab}	5685.37 ^a	12766.96 ^a	44.96 ^a	7495.93 ^a	5781.67 ^a	13277.60 ^a	43.70 ^a	7288.76 ^{ab}	5733.52 ^a	13022.28 ^a	44.33 ^{ab}
S₃	6490.19 ^b	4687.93 ^b	11178.12 ^b	42.04 ^b	6893.58 ^b	4909.72 ^b	11803.31 ^b	41.57 ^a	6691.89 ^b	4798.83 ^b	11490.71 ^b	41.81 ^b
S₄	7300.08 ^a	5867.23 ^a	13167.31 ^a	44.99 ^a	7656.30 ^a	5965.56 ^a	13621.86 ^a	42.09 ^a	7478.19 ^a	5916.39 ^a	13394.58 ^a	44.54 ^a
SEm (±)	197.11	142.19	300.55	0.30	199.08	141.12	300.21	0.43	196.89	141.28	300.38	0.36
CD(P=0.05)	607.28	438.06	925.94	1.80	613.33	434.78	924.88	2.61	606.59	435.25	925.41	2.20
Interaction (A x B)	S	S	S	NS	S	S	S	NS	S	S	S	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

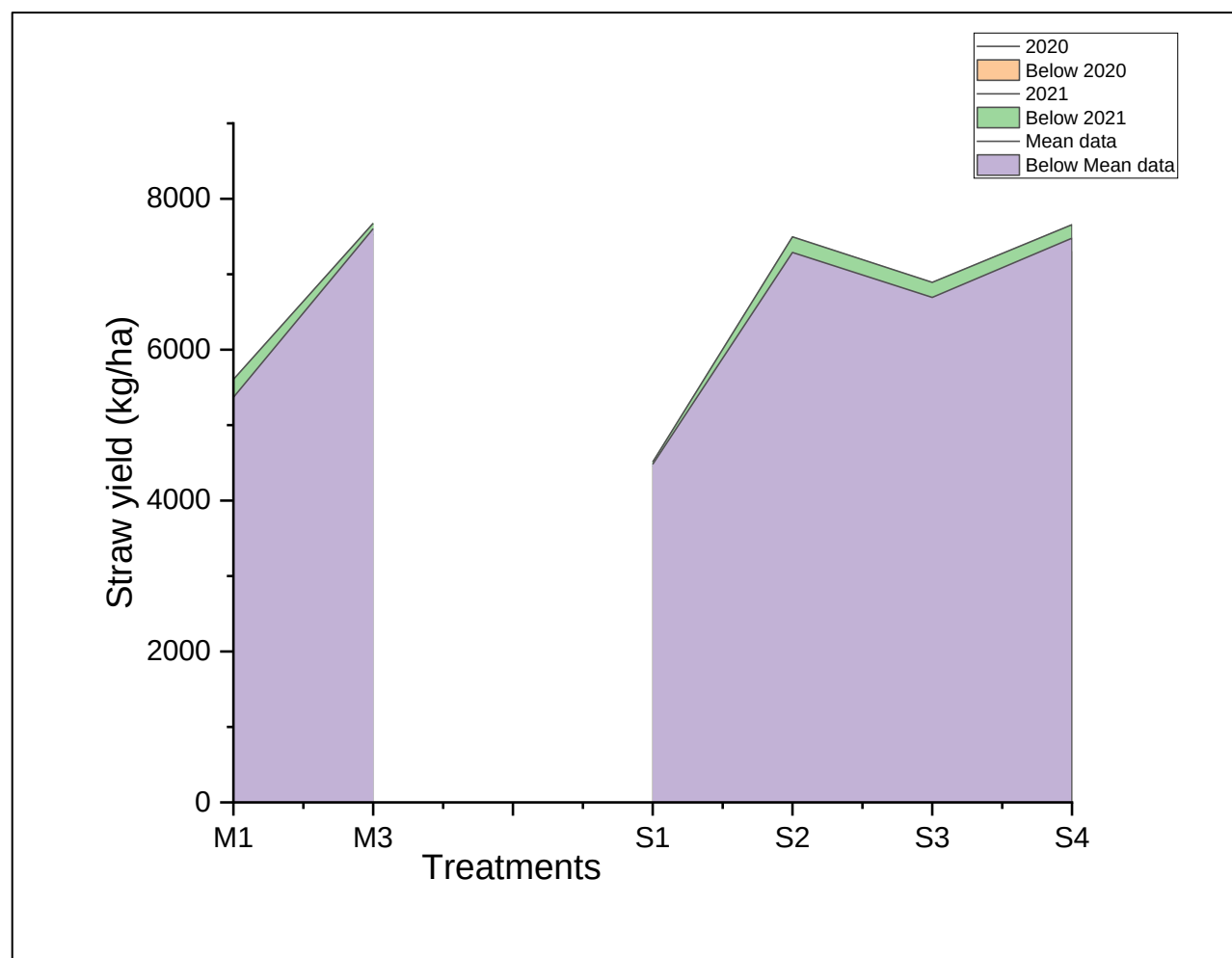


Fig.4.1.11a.: Effect of cropping system and different levels of fertilizer on the straw yield (kg/ha) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

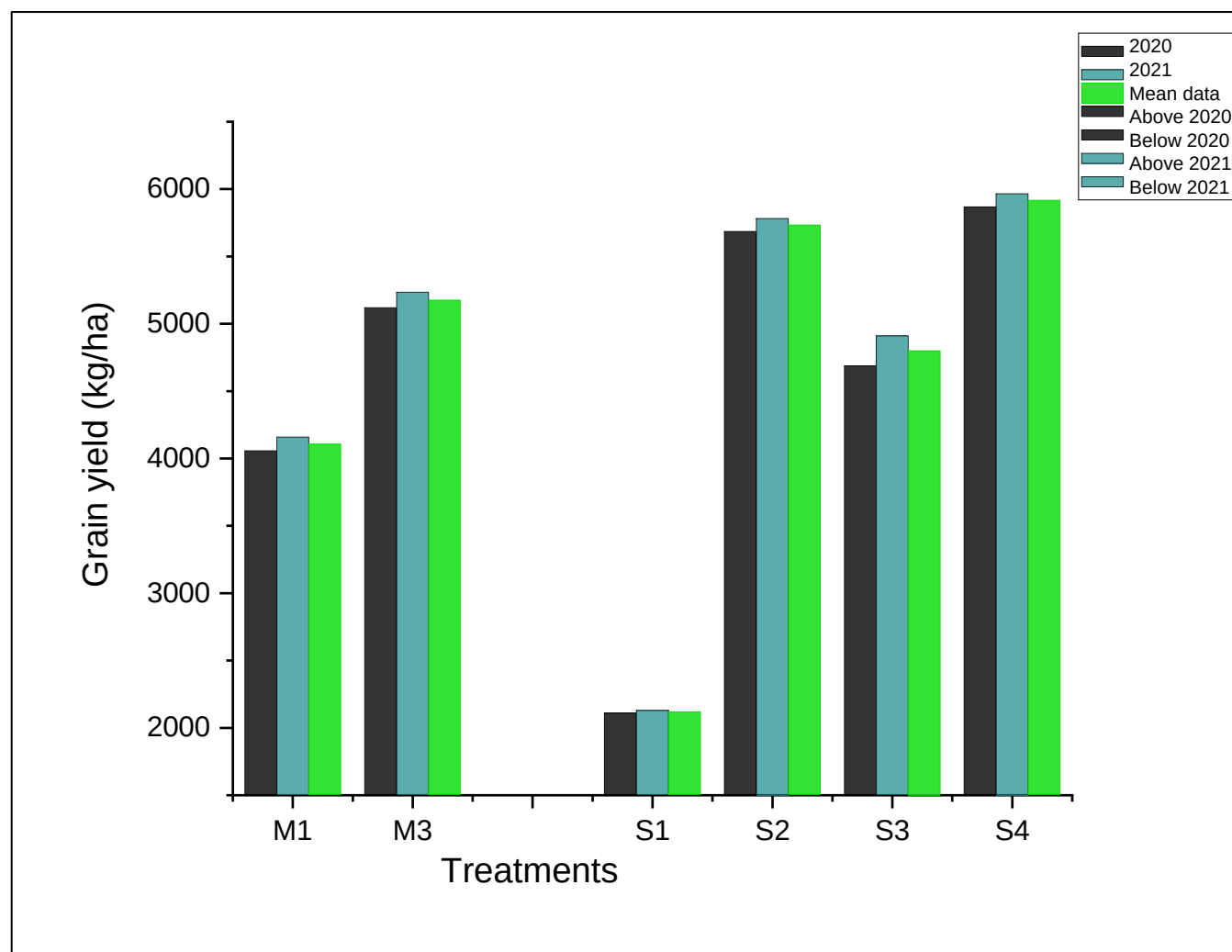


Fig.4.1.11b.: Effect of cropping system and different levels of fertilizer on the grain yield (kg/ha) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

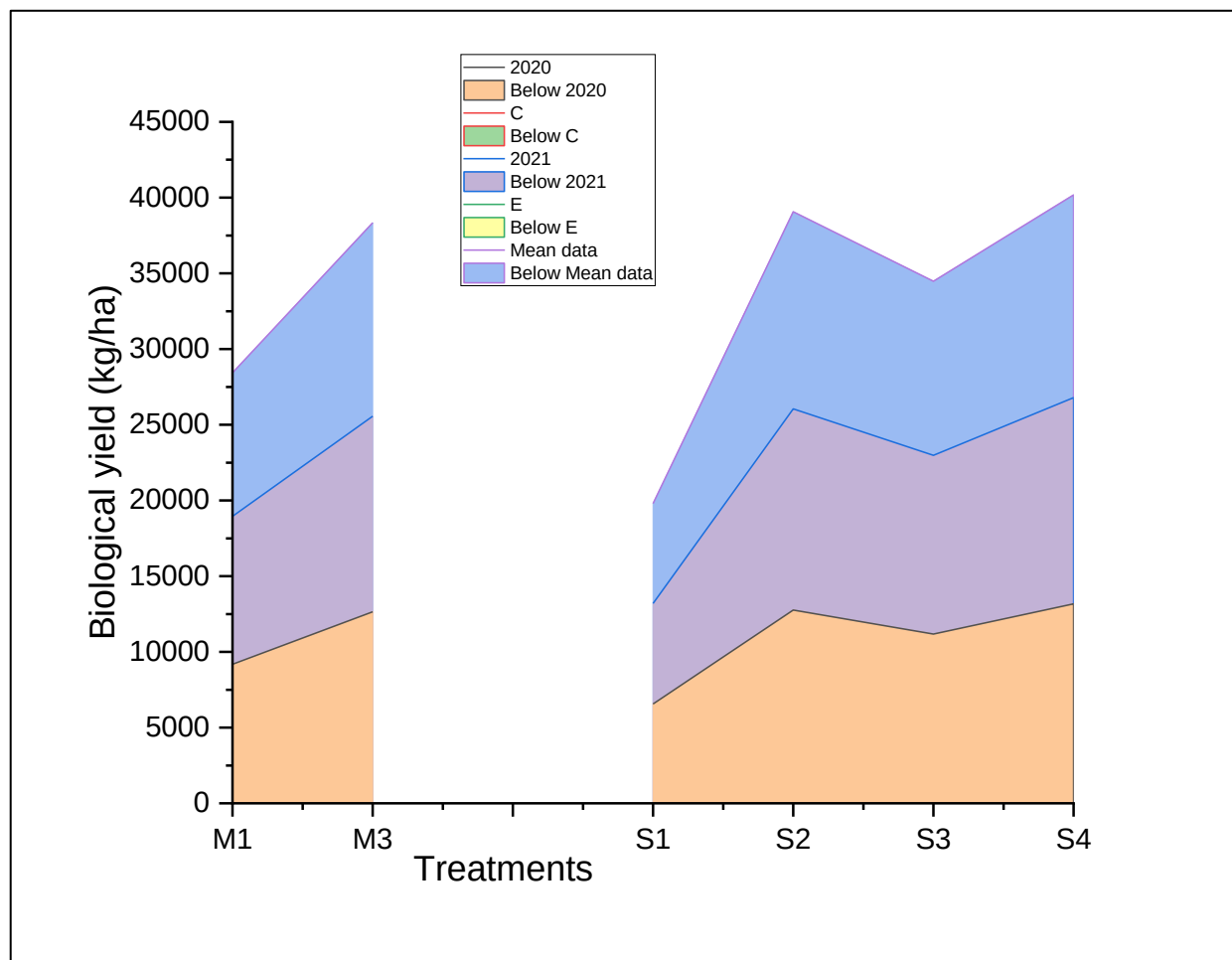


Fig.4.1.11c.: Effect of cropping system and different levels of fertilizer on the biological yield (kg/ha) of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

Table 4.1.11a: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize straw yield (kg/ha).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	3771.80 ^d	5490.11 ^c	5551.83 ^c	5707.76 ^c	3839.17 ^e	6145.33 ^c	6210.05 ^c	6225.36 ^c	3805.48 ^d	5817.72 ^c	5880.94 ^c	5966.56 ^c
M₃	5130.39 ^c	8673.06 ^a	7428.55 ^b	8892.40 ^a	5185.86 ^d	8846.52 ^a	7577.12 ^b	9087.24 ^a	5158.12 ^c	8759.79 ^a	7502.83 ^b	8989.82 ^a
SEm (±)	278.76				281.54				278.45			
CD(P=0.05)	858.82				867.38				857.85			

Table 4.1.11b: Interaction between cropping systems and different fertilizers levels on the sole and intercrop maize grain yield (kg/ha).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	2080.75 ^d	4909.16 ^b	4093.05 ^c	5141.15 ^b	2096.08 ^d	4940.84 ^{bc}	4344.92 ^c	5254.13 ^b	2088.41 ^d	4925.00 ^b	4218.99 ^c	5197.64 ^b
M₃	2137.35 ^d	6461.58 ^a	5282.81 ^b	6593.30 ^a	2160.37 ^d	6622.50 ^a	5474.33 ^b	6677.61 ^a	2148.81 ^d	6542.04 ^a	5378.67 ^b	6635.15 ^a
SEm (±)	201.08				199.58				199.80			
CD(P=0.05)	619.51				614.87				615.54			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.11c: Interaction between cropping systems and different fertilizers levels on the sole and intercrop maize biological yield (kg/ha).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	5852.54 ^e	10399.27 ^c	9644.89 ^c	10848.90 ^c	5935.25 ^e	11086.17 ^c	10554.96 ^c	11479.49 ^c	5893.90 ^e	10742.72 ^c	10099.93 ^c	11164.20 ^c
M₃	7267.64 ^d	15134.65 ^a	12711.36 ^b	15485.71 ^a	7346.23 ^d	15469.03 ^a	13051.65 ^b	15764.24 ^a	7306.93 ^d	15301.84 ^a	12881.50 ^b	15624.97 ^a
SEm (±)	425.04				424.55				424.80			
CD(P=0.05)	1309.48				1307.98				1304.73			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercrop-ping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.3. Maize Equivalent Yield (MEY) (kg/ha)

In both seasons, 2020 and 2021, as well as when data were mean, the impact of various fertilizers levels and cropping system on the maize equivalent yield was significant (Table 4.1.12). In both the seasons 2020 and 2021, as well as when data were mean, a higher MEY was reported in the plot where maize was grown intercrop with mungbean, but a lower MEY was recorded in the plot where maize was grown as the sole crop. The higher maize equivalent yield observed in maize and mungbean intercropping, compared to sole maize cropping, results from various contributing factors that collectively enhance overall productivity. Complementary resource utilization plays a crucial role, as maize and mungbean have differing nutrient requirements and can efficiently utilize sunlight, water, and nutrients in a complementary manner. This minimizes competition for the same resources, optimizing input efficiency. Intercropping also improves land use efficiency, utilizing space effectively and maximizing productivity per unit area. Consistently, studies by Paudel *et al.* (2015) and Nurgi *et al.* (2023) underscore the profitability of intercropping systems, reporting higher maize equivalent yield compared to sole cropping. Amanu *et al.* (2022) and Amani *et al.* (2021) emphasize the economic advantages of intercropping, showing significantly higher productivity and maize equivalent yield. This aligns with research by Mohanty and Mishra (2014), Parimaladevi *et al.* (2019), and Assefa *et al.* (2016), supporting the superior yield of maize equivalent in intercropping systems compared to sole cropping.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest MEY in the case of varying levels of fertilizer treatment in 2020, followed by 100% RDF and 100% Nano NPK nanofertilizers, which was statistically higher than all other treatments. The control plot had the lowest MEY. A similar tendency was seen in 2021 as well in mean data (Table 4.1.12). The highest maize equivalent yield achieved through the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers might have been attributed to the overall enhancement of plant health by nanofertilizers. This extension of benefits to all components may have resulted in an increased maize equivalent yield. The combination of fertilizers might have also optimized reproductive processes, such as flowering and pollination, contributing to enhanced overall reproductive success. The combination of NPK fertilizers and nanofertilizers might have ensured comprehensive

nutrient management, supporting grain development and the growth of other plant parts for a higher maize equivalent yield. Additionally, nanofertilizers might have improved plant resilience, promote better overall performance, and extend the growing season, leading to increased biomass production and a higher maize equivalent yield. The efficient resource allocation facilitated by nano-sized particles might have benefited all plant components, providing a comprehensive enhancement of the maize equivalent yield. This may be owing to higher productivity brought on by the effective use of resources as well as enhanced grain and seeds yields of the maize as a result of optimal fertilizer availability due to the use of 50 % RDF and 50 percent Nano NPK fertilizers to both crops. Comparable conclusions were made by Pandita *et al.* (2000), Hugar and Palled (2008) and Rana *et al.* (2013). In contrast, it was observed that the control plot's MEY was lower due to decreased grain yields brought on by a shortage of fertilizers.

The interaction between the cropping system and various fertilizer levels was significant in 2020, 2021 and in the mean statistics. The maximum mean value of maize equivalent yield was recorded in interop maize in conjunction with 50% RDF while the minimum was found in sole maize in combination with the control in both seasons (2020 and 2021) as well as when data were mean (Table 4.1.12a).

Table 4.1.12.: Effect of cropping system and different levels of fertilizers on the maize equivalent yield of sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020	2021	Mean data
	Maize equivalent yield	Maize equivalent yield	Maize equivalent yield
A - Cropping System			
M₁	6869.88 ^b	7141.25 ^b	7005.56 ^b
M₃	7932.58 ^a	8215.86 ^a	8074.22 ^a
SEm (±)	98.09	114.73	106.41
CD(P=0.05)	596.77	698.02	647.39
B- Different levels of fertilizer			
S₁	3633.83 ^d	3668.08 ^d	3650.96 ^d
S₂	8992.50 ^b	9288.41 ^b	9140.45 ^b
S₃	7426.22 ^c	7836.32 ^c	7631.27 ^c
S₄	9552.37 ^a	9921.40 ^a	9736.88 ^a
SEm (±)	156.69	171.86	164.27
CD(P=0.05)	482.73	529.47	506.10
Interaction (Ax B)	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

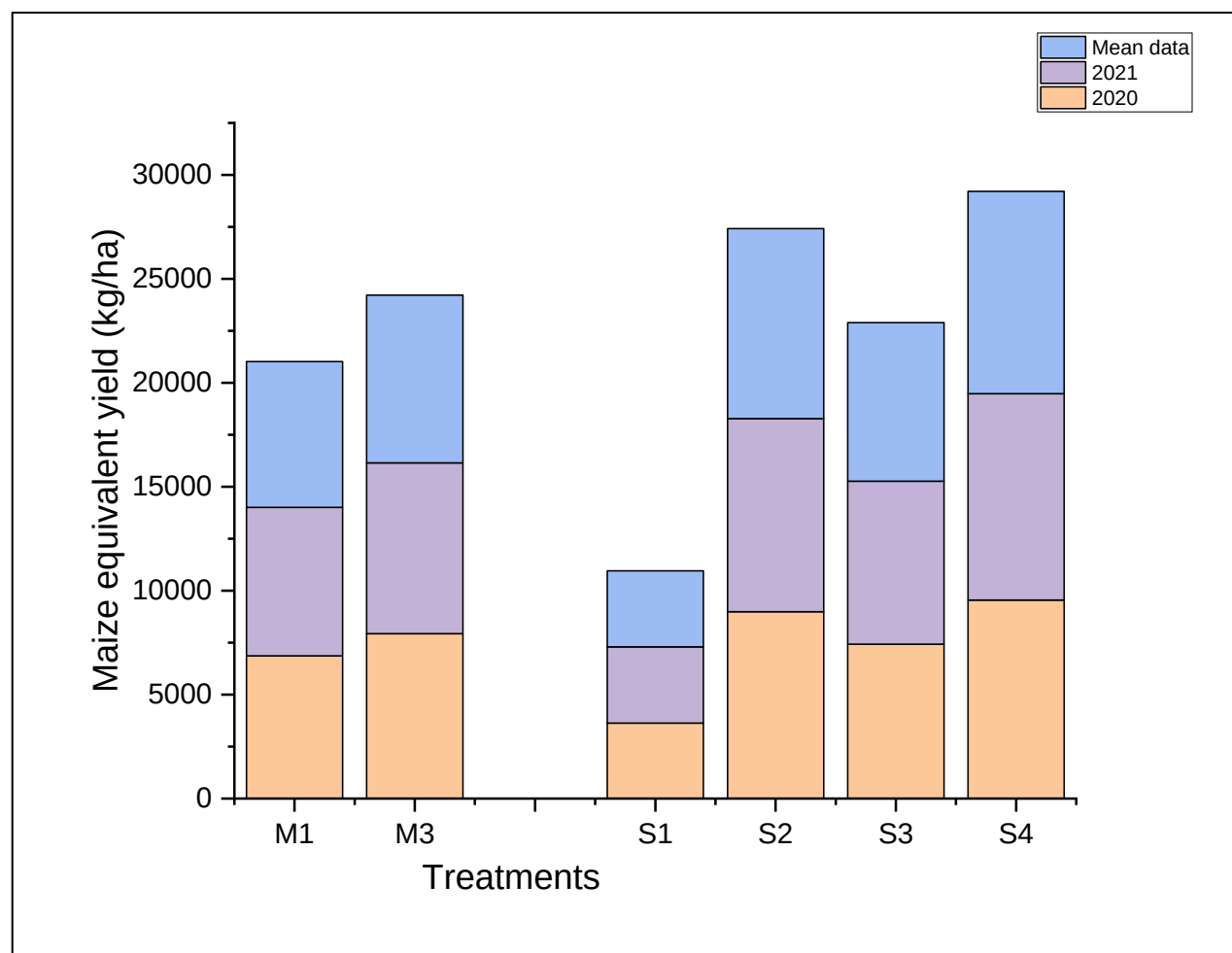


Fig.4.1.12.: Effect of different levels of fertilizer on the maize equivalent yield of sole and intercrop maize. M₁=Maize (sole), M₃=Maize+Mung-bean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK nanofertilizers, S₄=50% RDF+50% Nano NPK fertilizers.

Table 4.1.12a: Interaction between cropping systems and different fertilizers levels on sole and intercrop maize equivalent yield (kg/ha).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	3605.58 ^f	8216.29 ^{cd}	6831.34 ^e	8826.29 ^c	3635.93 ^f	8447.57 ^{cd}	7271.51 ^e	9209.97 ^c	3620.76 ^f	8331.93 ^{cd}	7051.43 ^e	9018.13 ^c
M₃	3662.08 ^f	9768.71 ^b	8021.10 ^d	10278.44 ^a	3700.22 ^f	10129.24 ^b	8401.12 ^d	10632.84 ^a	3681.15 ^f	9948.98 ^b	8211.11 ^d	10455.64 ^a
SEm (±)	221.59				243.05				232.32			
CD(P=0.05)	682.69				748.79				715.74			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.4 Nutrient uptake (kg/ha)

4.1.1.4.1 Nitrogen uptake in straw (kg/ha)

The impact of various fertilizer treatments and cropping systems on the maize nitrogen uptake in straw during the 2020 and 2021 *kharif* seasons are shown in Table 4.1.13 along with mean data. In the year 2020, the plot where maize was planted in combination with mungbean had the maximum nitrogen uptake, whereas the plot where maize was cultivated as the monocrop had the lowest nitrogen uptake. Similar patterns were seen in 2021 and mean data. The highest uptake of nitrogen in the straw of maize when intercropped with mungbean can be attributed to the complementary nature of nitrogen utilization by the two crops (maize and mungbean). Maize and mungbean are also known to exhibit complementary characteristics in their nitrogen utilization patterns. Maize, being a grass, tends to efficiently capture nitrogen from the soil through its robust root system. On the other hand, mungbean, being a leguminous crop, forms a mutualistic association with nitrogen-fixing bacteria in its root nodules. This allows mungbean to access atmospheric nitrogen and convert it into a form that is readily available for plant uptake. The leguminous nature of mungbean facilitated nitrogen fixation, enriching the soil with available nitrogen. This, in turn, benefited the nitrogen-demanding maize crop, leading to a higher uptake of nitrogen in the straw. Many researchers have shown higher nitrogen uptake by the intercropping system, which is commonly mentioned as the cause of the intercropping method's yield advantage Olujobi *et al.* (2013). Similarly, Doutaniya *et al.* (2023) reported the highest nitrogen uptake in the intercropping of mungbean and sesame in their study. Gao *et al.* (2020) uncovered that the average nitrogen uptake was diminished in sole maize cultivation when contrasted with intercropping maize alongside peanuts.

The nitrogen uptake of straw was significantly impacted by varied fertilizer levels in both the 2020 and 2021 growing seasons as well as in the mean data (Table 4.1.13). The plot treated with 50% RDF + 50% Nano NPK fertilizer noted the highest nitrogen uptake in straw in the year 2020, which was statistically comparable to the plot treated with 100% RDF and 100% Nano NPK fertilizer. The control plot recorded the least uptake of nitrogen in stover. The results for 2021 and the mean data were comparable to those for 2020. The highest nitrogen uptake in maize straw, achieved through the combination of 50% NPK fertilizers

and 50% Nano NPK fertilizers, stemmed from specific factors distinct from those influencing grain and straw yield. Firstly, the use of nanofertilizers, featuring nano-sized particles, likely improved the absorption of essential nutrients by maize plants, particularly benefiting the development of nutrient-rich straw. Additionally, nanofertilizers played a crucial role in facilitating the efficient distribution of nutrients within the plant, directing a targeted supply to the straw during crucial growth stages and contributing to increased nutrient uptake. Moreover, the combination of NPK fertilizers and nanofertilizers might have enhanced the overall utilization of nutrients by maize plants, ensuring a more effective use of applied nutrients specifically for straw development. Furthermore, nanofertilizers were instrumental in selectively delivering nutrients to the straw, optimizing nutrient supply during key growth phases and leading to higher nutrient accumulation. Lastly, the application of nanofertilizers likely contributed to a reduction in nutrient losses, preserving a greater proportion of applied nutrients in the soil and facilitating uptake by developing straw, potentially resulting in higher nutrient content in the harvested straw. In summary, the combination of NPK fertilizers and nanofertilizers played a significant role in achieving the highest nutrient uptake in maize straw, with improved absorption, efficient distribution, enhanced utilization, selective delivery, and reduced nutrient loss collectively contributing to the nutritional quality of the harvested maize straw. Abdel-Aziz *et al.* (2018) reported comparable results, indicating that foliar application of nano-fertilizers in conjunction with mineral fertilizers increased nitrogen uptake in crops. Comparable outcomes were stated by Liu and Lal (2015) and Salama *et al.* (2022), who observed a synergistic impact between conventional fertilizers and nano fertilizers that results in greater nutrient uptake in the plant's cells.

In both the years (2020 and 2021) as well as when the data from both years were mean, it was determined that there was no significant interaction between the cropping system and different fertilizer levels.

4.1.1.4.2 Nitrogen uptake in grain (kg/ha)

Table 4.1.13 depicts the impact fertilizer levels and the cropping system on the maize nitrogen uptake in grain during the 2020 and 2021 *kharif* seasons and in the mean statistics. In the year 2020, the utmost uptake of N in grain was noted in the plot where maize was grown as interop with mungbean whereas N uptake in grain was lower in the plot where maize was grown as the sole crop. In

2021 and mean data, similar outcomes to those of 2020 were observed. The highest uptake of nitrogen in the grain of maize when intercropped with mungbean can be attributed to the synergistic relationship between the two crops. Intercropping maize with mungbean may have led to a more efficient utilization of nitrogen resources. Mungbean, being a leguminous crop, could form symbiotic relationships with nitrogen-fixing bacteria in its root nodules which enables mungbean to convert atmospheric nitrogen into a form that is easily accessible to plants. As a result, the intercropped maize plants benefited from the increased availability of nitrogen, particularly during critical growth stages. The collaborative nitrogen acquisition strategies between maize and mungbean might have contributed to a higher uptake of nitrogen in the grain of maize. Moreover, according to Nasar *et al.* (2020), the intercropping of maize-alfalfa was found to enhance the nitrogen content in both grain and leaves of maize, along with an increase in total nitrogen uptake compared to monocropping. Ramirez-Garcia *et al.* (2015) observed an improvement in nitrogen uptake for barley in the intercropping system when compared to monocrops. In contrast, Zhang *et al.* (2022) reported divergent outcomes, noting that intercropping with soybean led to an increase in the biomass of wheat while concurrently reducing its nitrogen uptake from organic forms.

The effect of different levels had a significant ($P=0.05$) impact on the nitrogen uptake of grain in both seasons i.e., 2020 and 2021 as well as when the data were mean. In 2020, the plot applied with 50% RDF +50% Nano NPK fertilizer recorded the highest uptake of N in grain followed by 100% RDF and 50% Nano NPK fertilizers respectively. The least uptake of N in grain was noted in the control in the year 2020. However, a comparable pattern was noted in 2021 as well when statistics were mean. Nano NPK fertilizers have the highest nutrient uptake in maize grains, resulting from the combination of 50 % NPK fertilizers and 50 % Nano NPK fertilizers, can be attributed to specific factors. Nano-sized particles in nanofertilizers likely optimized the absorption of essential nutrients by maize plants, especially benefiting grain development. These nanofertilizers may have facilitated selective nutrient delivery to developing grains, ensuring an efficient and targeted supply during crucial growth stages. The combination of NPK fertilizers and nanofertilizers potentially enhanced nutrient partitioning towards grains, contributing to higher nutrient concentrations. Furthermore, nanofertilizers could have improved the overall efficiency of nutrient use by

maize plants, directing a greater proportion of nutrients towards grain development. Moreover, the use of nanofertilizers may have contributed to reduced nutrient losses, allowing a larger portion of applied nutrients to be retained in the soil and taken up by developing grains. In addition, nanofertilizers are more efficient in absorbing and using nutrients, which results in much lower losses from leaching and volatilization. This justification is supported by Iqbal (2019) who also stated that nanoparticles show considerably higher absorption of nutrients due to root exudates, an open passage from nanosized pores, and molecular transporters. Wang *et al.* (2012), and Jhanzab *et al.* (2015); Rathore *et al.* (2022), stated similar findings.

In both the years (2020 and 2021) as well as when the data from both years were mean, it was determined that there was no significant interaction between the cropping system and different fertilizer levels.

Table 4.1.13.: Effect of cropping system and different levels of fertilizers on the nitrogen uptake of straw and grain of the sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Nitrogen uptake(kg/ha)		Nitrogen uptake(kg/ha)		Nitrogen uptake(kg/ha)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M₁	28.03 ^b	54.70 ^b	30.78 ^b	60.41 ^b	29.41 ^b	57.56 ^b
M₃	37.39 ^a	61.36 ^a	41.04 ^a	66.69 ^a	39.22 ^a	64.03 ^a
SEm (±)	0.18	0.94	0.20	1.01	0.19	0.98
CD(P=0.05)	1.13	5.73	1.21	6.13	1.17	5.93
B- Different levels of fertilizer						
S₁	17.54 ^b	37.13 ^d	18.06 ^c	37.87 ^d	17.80 ^d	37.50 ^d
S₂	31.16 ^a	65.07 ^b	35.84 ^b	72.20 ^b	33.50 ^c	68.63 ^b
S₃	34.90 ^a	57.05 ^c	40.14 ^b	63.29 ^c	37.52 ^b	60.17 ^c
S₄	47.25 ^a	72.88 ^a	49.61 ^a	80.85 ^a	48.43 ^a	76.86 ^a
SEm (±)	0.46	2.83	0.55	2.96	0.50	2.90
CD(P=0.05)	1.41	3.72	1.70	4.13	1.56	3.92
Interaction (A x B)	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.4.3 Phosphorous uptake in straw (kg/ha)

The phosphorus uptake of stover was significantly impacted by various fertilizer levels and cropping systems in both seasons (2020 and 2021) and mean data (Table 4.1.14). The uptake of phosphorous in straw was recorded higher in the plot where maize was grown as the intercrop with mungbean whereas a lower uptake of phosphorous in straw was recorded in the plot where maize was cultivated as a sole crop in 2020, 2021 and also when both data were mean. The observation of the highest phosphorus uptake in the straw of maize during intercropping with mungbean can be explained by the collaborative nutrient acquisition strategies employed by both crops. Several studies have shown that intercropping maize with mungbean enhances phosphorus uptake in the straw of maize. Mungbean might have formed symbiotic relationships with mycorrhizal fungi and other soil microorganisms. These combinations might have facilitated the efficient phosphorus uptake from the soil, making it more accessible to the intercropped maize and the root systems of mungbean might have played a vital role in acquiring phosphorus from the soil and transferring it to the rhizosphere. This process might not only have increased phosphorus availability for mungbean but also might have positively impacted neighboring maize plants. These results support Maitra (2020) findings, who found that the intercropping of cereal and legumes significantly boosted phosphorus uptake compared to the solo planting of cereals as well as growing legumes have an increased ability to spare nutrients when added to cereals. Mohan *et al.* (2023) presented differing results, indicating that they did not observe any notable impact on nitrogen (N), phosphorus (P), and potassium (K) uptake in seed and stover attributed to the cropping system. The study noted significantly higher N, P, and K uptake in both seed and stover in the case of sole groundnut, while the lowest uptake was recorded in rice intercropped with groundnut. Nasar *et al.* 2023 when compared with mono-cropping, intercropping significantly enhanced the N concentration and total N uptake of maize crops under different N fertilization treatment.

In the case of different levels of fertilizer treatment, in the year 2020, the plot treated with 50% RDF +50% Nano NPK fertilizers had the highest uptake of phosphorous in straw followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot's 2020 uptake of phosphorous from straw was the lowest. A similar trend was also seen in 2021 and

when all sets of data were mean (Table 4.1.14). The attainment of the highest phosphorus uptake in maize straw, resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, may be attributed to distinct factors, diverging from those impacting grain and straw yield. Firstly, the utilization of nanofertilizers, featuring nano-sized particles, likely heightened the absorption of phosphorus by maize plants, particularly enhancing the development of phosphorus-rich straw. Additionally, nanofertilizers played a pivotal role in facilitating the efficient distribution of nutrients within the plant, directing a focused supply of phosphorus to the straw during critical growth stages and contributing to an augmented phosphorus uptake. Moreover, the combination of NPK fertilizers and nanofertilizers might have elevated the overall utilization of phosphorus by maize plants, ensuring a more efficacious use of applied phosphorus, specifically for straw development. Furthermore, nanofertilizers were instrumental in selectively delivering phosphorus to the straw, optimizing nutrient supply during key growth phases and leading to heightened phosphorus accumulation. Dhansil *et al.* (2018) documented that the utilization of nano phosphorus resulted in an augmentation of phosphorus levels in both straw and grain of pearl millet. Similarly, Kandil and Marie (2017) observed that the application of nanofertilizers to wheat plants led to the highest micronutrient uptake in both grain and straw. Furthermore, Poudel *et al.* (2023) found increased nutrient uptake in wheat through the application of nano phosphorous. Sarkar *et al.* (2013) noted that the utilization of nano phosphatic fertilizer led to a substantial increase in phosphorus concentration and uptake by pearl millet. This enhancement could be attributed to the more efficient release and uptake of phosphorous from the nano fertilizer compared to conventional fertilizers. Likewise, Moghaddasi *et al.* (2017) demonstrated that the foliar application of nanofertilizers, in conjunction with 100% Recommended Dose of Fertilizers (RDF) of NPK, resulted in an increased uptake of nitrogen (N), phosphorus (P), and potassium (K) compared to the application of 100% RDF of NPK alone. Neogi, and Das (2022) observed that the foliar application of nano fertilizers, in conjunction with 100% Recommended Dose of Fertilizers (RDF) of soil applied NPK, proved to be more effective than their sole foliar application, without any RDF of NPK. This enhanced approach resulted in increased nutrient uptake, encompassing both macro and micronutrients, in potatoes.

In 2020, 2021, and when statistics were average, the interaction between the cropping system and various fertilizer levels was found to be significant. The highest mean value of phosphorous uptake in straw was recorded in interop maize in conjunction with 50% RDF+50% Nano NPK fertilizers which was statically comparable to sole maize in conjunction with 100% RDF but was comparable significantly in all other treatments while the minimum was found in sole maize in combination with the control in both years (2020 and 2021) as well when both the data were mean (Table 4.1.14a).

4.1.1.4.4 Phosphorous uptake in grain (kg/ha)

The phosphorous uptake of grain in both seasons and when both data were Mean, was significantly impacted by various fertilizers levels, and cropping system (Table 4.1.14). A higher uptake of phosphorous in grain was recorded in the plot where maize was grown as the interop with mungbean whereas a lower uptake of P in grain was recorded in the plot where maize was cultivated as the sole crop in both 2020 and 2021 as well as when both the data were mean. The highest uptake of phosphorus in the grain of maize due to intercropping with mungbean can be linked with the complementary nutrient acquisition mechanisms of both crops. Mungbean, being a leguminous crop might have formed beneficial associations with mycorrhizal fungi and other soil microorganisms which might have facilitated the efficient phosphorus uptake from the soil, contributing to higher phosphorus availability for both mungbean and the adjacent maize plants. Several researchers also have observed that the root systems of mungbean were involved in acquiring phosphorus from the soil, thereby positively impacting the overall phosphorus content in the maize grain. In a study by Fan *et al.* (2020), comparable findings were observed in the context of maize-soybean intercropping in comparison to sole crops. Xia *et al.* (2019) documented comparable findings in the intercropping of maize with legumes. Miheguli *et al.* (2018) observed a substantial increase in phosphorus uptake by wheat grain after rotations with forage legumes. This enhancement could be attributed to the overall improved conditions for wheat growth following rotations with alfalfa and red clover.

In the case of different levels of fertilizer treatment, in the year 2020, the plot treated with 50% RDF +50% Nano NPK fertilizers had the highest uptake of phosphorous in grain followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot experienced the

lowest uptake of P in grain in 2020. A similar pattern was seen in the year 2021 and in the mean statistics (Table 4.1.1.14). The attainment of the highest phosphorus uptake in maize grains, resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, may have been influenced by distinct factors different from those affecting grain and straw yield. Firstly, the use of nanofertilizers, featuring nano-sized particles, could have enhanced the absorption of phosphorus by maize grain. This improved absorption likely played a significant role in the development of phosphorus-rich grains. Furthermore, nanofertilizers may have facilitated the efficient transport of nutrients within the plant, directing a targeted supply of phosphorus to the developing grains during crucial growth stages. This efficient transport contributed to increased phosphorus uptake in the grains. Moreover, the combination of NPK fertilizers and nanofertilizers might have improved the overall utilization of phosphorus by maize plants, ensuring a more effective use of applied phosphorus specifically for grain development. Furthermore, nanofertilizers could have been instrumental in selectively delivering phosphorus to the grains, optimizing nutrient supply during key growth phases, and leading to higher phosphorus accumulation. Lastly, the application of nanofertilizers might have contributed to a reduction in phosphorus losses, preserving a greater proportion of applied phosphorus in the soil. This preservation facilitated uptake by developing grains, potentially resulting in higher phosphorus content in the harvested grains. Similarly, Hanif *et al.* (2015) documented an increased phosphorus uptake facilitated by the application of nanofertilizers. They suggested that this enhancement might be attributed to the penetration of nanoparticles into plants, stimulating metabolic activity, and consequently, elevated exudation causing acidification. As a result, the desorption of PO_4^{3-} could potentially occur via a ligand exchange reaction triggered by plant root exudation, potentially disrupting the adsorption-desorption equilibrium and releasing P into the soil solution, thereby making it more readily available for uptake. Furthermore, Hussien *et al.* (2015) observed that synthetic nanoparticles have the theoretical capacity to supply adequate P nutrients to crops throughout the entire growth period, leading to increased phosphorus uptake in cotton. These findings align with the studies conducted by Kaviani *et al.* (2016), Soliman *et al.* (2016) and Togas *et al.* (2017).

The interaction between the cropping system and various fertilizer levels was found to be significant for both the years (2020 and 2021) and when both sets of data were mean. The highest mean value of phosphorous uptake in grain was noted in interop maize in conjunction with 50% RDF + 50% Nano NPK fertilizers which was statically superior to all other interactions effect while the minimum was found in sole maize in combination with the control in both seasons (2020 and 2021). Likewise, a comparable pattern was noted when both the data were mean (Table 4.1.14b).

Table 4.1.14.: Effect of cropping system and different levels of fertilizers on the phosphorous uptake of straw and grain of the sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Phosphorous uptake(kg/ha)		Phosphorous uptake(kg/ha)		Phosphorous uptake(kg/ha)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M₁	15.46 ^b	18.86 ^b	16.80 ^b	20.60 ^b	16.13 ^b	19.73 ^b
M₃	17.91 ^a	20.97 ^a	19.39 ^a	22.65 ^a	18.65 ^a	21.81 ^a
SEm (±)	0.12	0.17	0.16	0.26	0.22	0.14
CD(P=0.05)	1.04	1.10	1.07	1.16	1.13	1.06
B- Different levels of fertilizer						
S₁	7.94 ^d	11.26 ^d	8.11 ^d	11.99 ^d	8.02 ^d	11.62 ^d
S₂	20.00 ^b	23.27 ^b	21.86 ^b	25.35 ^b	20.93 ^b	24.31 ^b
S₃	17.00 ^c	18.55 ^c	18.57 ^c	20.20 ^c	17.78 ^c	19.37 ^c
S₄	21.82 ^a	26.59 ^a	23.84 ^a	28.96 ^a	22.83 ^a	27.78 ^a
SEm (±)	0.22	0.41	0.29	0.66	0.53	0.25
CD(P=0.05)	1.25	1.43	1.27	1.51	1.47	1.26
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.14a: Interaction between cropping systems and different fertilizers levels on the uptake of phosphorous in the maize grain (kg/ha).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	10.14 ^f	22.80 ^b	17.38 ^d	25.05 ^a	10.89 ^f	24.96 ^b	19.02 ^d	27.51 ^a	10.51 ^f	23.88 ^b	18.20 ^d	26.32 ^a
M₃	12.37 ^e	23.73 ^b	19.72 ^c	28.05 ^a	13.09 ^e	25.73 ^b	21.38 ^c	30.41 ^a	12.73 ^e	24.73 ^b	20.55 ^c	29.23 ^a
SEm (±)	0.21				0.34				0.22			
CD(P=0.05)	1.61				1.72				1.67			

Table 4.1.14b: Interaction between cropping systems and different fertilizers levels on the uptake of phosphorous in the maize straw (kg/ha).

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	6.74 ^f	19.04 ^d	15.20 ^c	20.86 ^b	6.99 ^f	20.81 ^d	16.61 ^c	22.80 ^b	6.86 ^f	19.93 ^d	15.91 ^c	21.83 ^b
M₃	9.14 ^e	20.95 ^b	18.79 ^d	22.77 ^a	9.23 ^e	22.90 ^b	20.54 ^d	24.89 ^a	9.18 ^e	21.93 ^b	19.66 ^d	23.83 ^a
SEm (±)	0.12				0.26				0.15			
CD(P=0.05)	1.36				1.39				1.36			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.4.5 Potassium uptake in straw (kg/ha)

The impact of the cropping system on the potassium uptake of both sole and intercrop maize showed non-significance in both years, and this trend persisted when the data was mean, as illustrated in Table 4.1.15.

In the case of different fertilizer levels, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the maximum uptake of potassium in straw in the year 2020, followed by 100% RDF and 100% Nano NPK fertilizers. The control plot had the lowest potassium uptake in straw statistically in 2020. However, a similar pattern was observed in 2021 and when data were mean (Table 4.1.15). The attainment of the highest potassium uptake in maize straw, resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, may be attributed to distinct factors, diverging from those influencing grain and straw yield. Firstly, the use of nanofertilizers, featuring nano-sized particles, likely heightened the absorption of potassium by maize plants. This improved absorption played a significant role in the development of potassium-rich straw. Additionally, nanofertilizers facilitated the efficient transport of nutrients within the plant, directing a targeted supply of potassium to the straw during crucial growth stages. This efficient transport contributed to increased potassium uptake in the straw. Moreover, the combination of NPK fertilizers and nanofertilizers improved the overall utilization of potassium by maize plants, ensuring a more effective use of applied potassium specifically for straw development. Furthermore, nanofertilizers were instrumental in selectively delivering potassium to the straw, optimizing nutrient supply during key growth phases, and leading to higher potassium accumulation. The application of nanofertilizers likely contributed to a reduction in potassium losses, preserving a greater proportion of applied potassium in the soil. This preservation facilitated uptake by developing straw, potentially resulting in higher potassium content in the harvested straw. Sarkar *et al.* (2013) noted a significant increase in phosphorus concentration and uptake in pearl millet with the application of nano phosphatic fertilizer. This effect could be attributed to the superior release and uptake of potassium from the nano fertilizer compared to conventional fertilizers. Likewise, Soliman *et al.* (2016) drew a conclusion that the application of nano phosphatic fertilizer exposes plant nutrients (NPK) to a larger surface area, enhancing both fixation and uptake of plant nutrients by nano particles. This mechanism helps minimize losses, with nutrient release occurring

later in the crop growth stage when the plant requires it. Dhansil *et al.* (2018) reported analogous findings, indicating increased phosphorous uptake as a result of the application of nano phosphatic fertilizer.

The interaction between the cropping system and various fertilizer levels was shown to be significant in both years (2020 and 2021) and when data were mean. The highest mean value of potassium uptake in straw was recorded in interop maize in conjunction with 50% RDF+ 50% Nano NPK fertilizers which was comparable higher than all other interaction effects. While the minimum uptake of potassium in straw was found in sole maize in combination with the control in both years i.e., 2020 and 2021 as well as when data were mean (Table 4.1.15b).

4.1.1.4.6 Potassium uptake in grain (kg/ha)

The uptake of potassium of grain was significantly impacted by the cropping system and various fertilizer levels in both 2020 and 2021, as well as when the data were mean (Table 4.1.15). In the year 2020, a higher uptake of potassium in grain was recorded in the plot where maize was cultivated as the interop with mungbean whereas lower uptake of potassium in grain was recorded in the plot where maize was cultivated as the sole crop. A similar pattern was also recorded in 2021 and when data were mean. The highest potassium uptake in the grain of maize due to the intercropping with mungbean can be attributed to the synergistic interactions between these two crops. Studies also indicated that a cooperative relationship between maize and mungbean might have played a key role in enhancing potassium content in the maize grain. Mungbean might have fostered beneficial associations with soil microorganisms, including mycorrhizal fungi. These interactions might have facilitated efficient potassium uptake from the soil, leading to elevated potassium availability for both mungbean and the neighboring maize plants. Likewise, in a study by Fan *et al.* (2020), it was found that the uptake and utilization of potassium in grain were notably elevated in maize-soybean intercropping compared to sole crops. The observed nutrient advantage primarily stems from increased nutrient uptake rather than enhanced nutrient use efficiency. In the study conducted by Zhang *et al.* (2021), it was observed that intercropping markedly increased the uptake of nitrogen (N), phosphorus (P), and potassium (K) in maize. The intercropped maize exhibited the highest uptake of K, with the most significant increase in K uptake noted at the nitrogen level compared to monoculture. Zhao *et al.* (2023) also identified elevated nutrient uptake in the

intercropping of maize and peanuts.

In the case of different levels of fertilizer treatment, in the year 2020, the plot applied with 50% RDF +50% Nano NPK fertilizers had the highest uptake of potassium in grain followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot reported the lowest K uptake in grain in 2020. A comparable trend was observed in the mean statistics for the year 2021. The accomplishment of the highest potassium uptake in maize grains, resulting from the combination of 50% NPK fertilizers and NPK Nano fertilizers, can be ascribed to distinctive factors separate from those influencing grain and straw yield. Nano-sized particles in nanofertilizers likely enhanced the absorption of potassium by maize plants, playing a pivotal role in the development of potassium-rich grains. Moreover, nanofertilizers efficiently facilitated nutrient transport within the plant, directing a targeted supply of potassium to the developing grains during crucial growth stages and contributing to an increase in potassium uptake. The combination of NPK fertilizers and nanofertilizers may have improved the overall utilization of potassium by maize plants, ensuring a more effective use of applied potassium specifically for grain development. Furthermore, nanofertilizers were likely instrumental in selectively delivering potassium to the grains, optimizing nutrient supply during key growth phases, and leading to higher potassium accumulation. The application of nanofertilizers may have contributed to a reduction in potassium losses, preserving a greater proportion of applied potassium in the soil and facilitating uptake by developing grains, potentially resulting in a higher potassium content in the harvested grains. In summary, the collaborative effect of NPK fertilizers and nanofertilizers played a crucial role in achieving the highest potassium uptake in maize grains, encompassing enhanced absorption, efficient transport, improved utilization, selective delivery, and reduced nutrient loss, all contributing to the nutritional quality of the harvested maize grains. Soliman *et al.* (2016) concluded that applying nano phosphatic fertilizer could expose plant nutrients (NPK) to a larger surface area, thereby enhancing the fixation and uptake of nutrients by nano particles. This process minimizes losses, with nutrient release occurring at a later stage of crop growth when the plant requires them. Similarly, Kaviani *et al.* (2016) observed significant positive effects on nitrogen (N), phosphorus (P), and potassium (K) uptake through the foliar application of nanofertilizers. These findings align with

the results reported by Kumar *et al.* (2014) and Shrivastava *et al.* (2017).

The interaction between the cropping system and various fertilizer levels was found to be significant for both the years and data were mean. Whereas sole maize in combination with the control was found to have the lowest uptake of K in grain in both years as well as when data were mean, while interop maize in combination with 50% RDF+50% Nano NPK fertilizers recorded the highest mean value of K uptake in grain (Table 4.1.15a).

Table 4.1.15.: Effect of cropping system and different levels of fertilizers on the potassium uptake of straw and grain of the sole and intercrop maize during the growing years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Potassium uptake(kg/ha)		Potassium uptake(kg/ha)		Potassium uptake(kg/ha)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M₁	104.98	16.34 ^b	113.51	17.84 ^b	109.24	17.09 ^b
M₃	116.52	19.99 ^a	125.49	21.74 ^a	121.01	20.87 ^a
SEm (±)	2.39	0.23	2.43	0.25	2.40	0.22
CD(P=0.05)	NS	1.76	NS	1.81	NS	1.78
B- Different levels of fertilizer						
S₁	65.06 ^c	9.37 ^d	66.17 ^d	9.52 ^d	65.61 ^d	9.44 ^d
S₂	120.58 ^b	22.47 ^b	137.08 ^b	24.72 ^b	128.83 ^b	23.59 ^b
S₃	113.03 ^b	15.92 ^c	120.32 ^c	17.51 ^c	116.68 ^c	16.72 ^c
S₄	144.34 ^a	24.91 ^a	154.44 ^a	27.40 ^a	149.39 ^a	26.16 ^a
SEm (±)	2.14	0.12	2.30	0.28	2.22	0.23
CD(P=0.05)	10.50	1.74	11.75	1.85	11.02	1.80
Interaction (Ax B)	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.15a: Interaction between cropping systems and different fertilizer levels on the uptake of potassium in the maize grain.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	7.58 ^g	21.92 ^c	12.31 ^e	23.56 ^b	7.77 ^g	24.11 ^c	13.54 ^e	25.92 ^b	7.68 ^g	23.01 ^c	12.93 ^e	24.74 ^b
M₃	11.15 ^f	23.02 ^b	19.53 ^d	26.26 ^a	11.26 ^f	25.33 ^b	21.49 ^d	28.89 ^a	11.21 ^f	24.17 ^b	20.51 ^d	27.57 ^a
SEm (±)	0.34				0.39				0.37			
CD(P=0.05)	1.05				1.21				1.13			

Table 4.1.15b: Interaction between cropping systems and different fertilizers levels on the uptake of potassium in the maize straw.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	60.74 ^e	111.74 ^d	110.33 ^b	137.10 ^b	62.25 ^e	127.04 ^d	118.05 ^b	146.70 ^b	61.50 ^e	119.39 ^d	114.19 ^b	141.90 ^b
M₃	69.38 ^e	129.41 ^{bc}	115.74 ^{cd}	151.57 ^a	70.08 ^e	147.12 ^{bc}	122.60 ^{cd}	162.18 ^a	69.73 ^e	138.26 ^{bc}	119.17 ^{cd}	156.87 ^a
SEm (±)	1.61				1.84				1.72			
CD(P=0.05)	14.95				15.68				15.31			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.5 Correlation Analysis

For each season (2020 and 2021) and the mean data, a simple correlation analysis was performed to examine the degree of relationship between the growth and yield component with the grain yield. The correlation between maize yield, growth, and yield characteristics for the 2020 *kharif* season is shown in Table 4.1.16. The correlation between grain yield and growth, yield and yield characteristics like plant height, no. of leaves, leaf area index (LAI), shoot dry weight, cob length, test weight, cob weight, no. of grains/cob, no. of grain/row, no. of grain row/cob and cob diameter was found to be positive and highly significant ($P=0.05$). The plant height and the other growth and yield parameters were positively and significantly correlated. The no. of leaves, LAI and the growth and yield parameters have a significant and positive correlation. All the growth and yield parameters were also found to be significantly correlated with one another.

The *kharif* season of 2021's maize grain yield, growth, and yield characteristics are correlated, as shown in Table 4.1.17. In the year 2021, there was a significant and positive correlation between grain yield, and all the growth and yield parameters. A similar, significant positive correlation between the plant height and yield parameters was also recorded. All the growth and yield parameters were found to be significantly and positively correlated with one another. A similar trend was reported in the mean data (Table 4.1.18).

The positive correlation observed between grain yield and growth, yield parameters in maize can be attributed to the availability of essential nutrients, including nitrogen, phosphorus, and potassium, which may have played a crucial role in promoting both vegetative growth and reproductive processes, contributing to increased grain yield. Additionally, the consistent and sufficient supply of water may have played a vital role for optimal plant growth and development, positively influencing both vegetative and reproductive stages and the favorable environmental conditions, such as suitable temperature and light levels might have created an environment conducive to healthy plant growth, ultimately enhancing grain yield. Moreover, effective management of pests and diseases may have ensured minimal yield losses, allowing crops to achieve their full potential. Implementation of sound agricultural practices, including timely fertilization, irrigation, and weed control, may have enhanced growth parameters, and lead to higher grain yield. The outcome confirms Halidu *et al.* (2015) findings that

growth indicators such as plant height, ear length, and grain yield were significantly and positively associated. Aman *et al.* (2020) also noted that grain production per hectare showed a positive phenotypic connection with all variables, except days to 50% tasselling. Several other scholars [Filipovic *et al.* (2014), Adu *et al.* (2016), Singh and Kumar (2017), Izzam *et al.* (2017), and Shengu (2017)], also discovered strong and positive correlations between plant height, ear height, ear length, grains per row, and grain yield. These results imply that simultaneous improvements in all yield components are necessary for effective yield improvement. In fact, selection efforts that are only based on grain yield are usually less effective and productive, choices must be based on a variety of characteristics of the crop [Aman *et al.* 2020].

Table 4.1.16: Matrix of correlation coefficient between growth and yield attributes of sole and intercrop maize during the year 2020.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.721*)	1.0000										
3	(0.874*)	(0.847*)	1.000									
4	(0.871*)	(0.902*)	(0.962*)	1.000								
5	(0.574*)	(0.476*)	(0.691*)	(0.605*)	1.000							
6	(0.843*)	(0.693*)	(0.850*)	(0.842*)	(0.459*)	1.000						
7	(0.710*)	(0.806*)	(0.840*)	(0.844*)	(0.393*)	(0.733*)	1.000					
8	(0.884*)	(0.801*)	(0.948*)	(0.933*)	(0.648*)	(0.813*)	(0.818*)	1.000				
9	(0.908*)	(0.727*)	(0.834*)	(0.851*)	(0.426*)	(0.891*)	(0.777*)	(0.823*)	1.000			
10	(0.885*)	(0.701*)	(0.869*)	(0.872*)	(0.446*)	(0.944*)	(0.780*)	(0.874*)	(0.935*)	1.000		
11	(0.912*)	(0.712*)	(0.862*)	(0.877*)	(0.539*)	(0.897*)	(0.792*)	(0.871*)	(0.942*)	(0.954*)	1.000	
12.	(0.734*)	(0.682*)	(0.836*)	(0.806*)	(0.598*)	(0.804*)	(0.727*)	(0.818*)	(0.804*)	(0.875*)	(0.806*)	1.000

1.Grain yield

4. Leaf area index

7. Test weight

10.No. of grains per row

2.Plant height

5. Shoot dry weight

8. Cob weight

11. No. of grain row per cob

3.No. of leaves

6. Cob length

9. No of grains per cob

12. Cob diameter

*= Significant at 5% level of probability

Table 4.1.17: Matrix of correlation coefficient between growth and yield attributes of sole and intercrop maize during the year 2021.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.735*)	1.0000										
3	(0.860*)	(0.875*)	1.000									
4	(0.887*)	(0.918*)	(0.965*)	1.000								
5	(0.604*)	(0.543*)	(0.674*)	(0.680*)	1.000							
6	(0.852*)	(0.740*)	(0.855*)	(0.842*)	(0.480*)	1.000						
7	(0.709*)	(0.812*)	(0.871*)	(0.865*)	(0.427*)	(0.747*)	1.000					
8	(0.808*)	(0.877*)	(0.914*)	(0.920*)	(0.708*)	(0.806*)	(0.859*)	1.000				
9	(0.896*)	(0.765*)	(0.846*)	(0.874*)	(0.488*)	(0.918*)	(0.799*)	(0.842*)	1.000			
10	(0.906*)	(0.749*)	(0.868*)	(0.886*)	(0.514*)	(0.941*)	(0.768*)	(0.818*)	(0.945*)	1.000		
11	(0.942*)	(0.754*)	(0.867*)	(0.900*)	(0.575*)	(0.887*)	(0.802*)	(0.848*)	(0.937*)	(0.957*)	1.000	
12.	(0.753*)	(0.754*)	(0.827*)	(0.839*)	(0.634*)	(0.797*)	(0.728*)	(0.823*)	(0.855*)	(0.877*)	(0.807*)	1.000

1. Grain yield

4. Leaf area index

7. Test weight

10. No. of grains per row

2. Plant height

5. Shoot dry weight

8. Cob weight

11. No. of grain row per cob

3. No. of leaves

6. Cob length

9. No of grains per cob

12. Cob diameter

*= Significant at 5% level of probability

Table 4.1.18: Matrix of correlation coefficient between growth and yield attributes of sole and intercrop maize (Mean data).

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.728*)	1.0000										
3	(0.867*)	(0.861*)	1.000									
4	(0.881*)	(0.910*)	(0.964*)	1.000								
5	(0.589*)	(0.510*)	(0.683*)	(0.643*)	1.000							
6	(0.848*)	(0.717*)	(0.853*)	(0.842*)	(0.470*)	1.000						
7	(0.710*)	(0.809*)	(0.856*)	(0.855*)	(0.410*)	(0.740*)	1.000					
8	(0.846*)	(0.839*)	(0.931*)	(0.927*)	(0.678*)	(0.810*)	(0.839*)	1.000				
9	(0.902*)	(0.746*)	(0.840*)	(0.863*)	(0.457*)	(0.905*)	(0.788*)	(0.833*)	1.000			
10	(0.897*)	(0.725*)	(0.869*)	(0.879*)	(0.480*)	(0.943*)	(0.774*)	(0.846*)	(0.940*)	1.000		
11	(0.927*)	(0.733*)	(0.865*)	(0.889*)	(0.557*)	(0.892*)	(0.797*)	(0.860*)	(0.940*)	(0.956*)	1.000	
12.	(0.744*)	(0.718*)	(0.832*)	(0.823*)	(0.616*)	(0.801*)	(0.728*)	(0.820*)	(0.830*)	(0.876*)	(0.807*)	1.000

1. Grain yield

4. Leaf area index

7. Test weight

10. No. of grains per row

2. Plant height

5. Shoot dry weight

8. Cob weight

11. No. of grain row per cob

3. No. of leaves

6. Cob length

9. No of grains per cob

12. Cob diameter

*= Significant at 5% level of probability

4.1.1.6. Economics of maize

The impact of various fertilizers levels and cropping system on the economics of maize are shown in Table 4.1.19 (2020, 2021 and Mean data). Considering 2020, 2021, and mean data, the plot with maize planted as the intercrop with mungbean provided better economics than the plot with maize as sole crop, which produced lower values for these metrics. Considering the benefit-cost ratio in both situations exceeded 1, this research is anticipated to add value. The highest economic returns through intercropping with mungbean, as opposed to sole cropping, were attributed to several factors that collectively enhanced overall agricultural productivity and profitability. One key factor might be due to the complementary nature of the two crops, where mungbean might have contributed to nitrogen fixation and enriched the soil with nitrogen, benefiting both crops and reducing the need for external fertilizers. Also, the diverse root systems of maize and mungbean might have facilitated efficient nutrient utilization and minimized competition for resources. This might have optimized resource use and contributed to higher yields in the intercropped system. Lastly, the intercropping with mungbean might have provided natural pest control and disease resistance, reducing the reliance on chemical inputs. This might have been coupled with improved land utilization which might have contributed to a reduction in production costs and an increase in economic returns. Yang *et al.* (2018) similarly reported that the economic returns from pea/maize intercropping were notably greater compared to those from sole cropping. The incorporation of annual legumes into cropping systems, whether through legume-cereal intercropping or cereal-legume rotations, has been shown to substantially decrease the reliance on synthetic nitrogen (N) fertilizer (Grant *et al.* 2016). The intercropping system of mungbean as studied by Anas *et al.* (2017) demonstrated that all intercrops yielded higher economic returns compared to the sole cropping of sunflower and mungbean. Contrary to this, Chamkhi *et al.* (2017) indicated that the inclusion of legumes increased maize production by up to 35% in intercropping systems. The enhanced productivity of the intercropping system may be attributed to the efficient utilization of growth resources by component crops and the advantages of nitrogen fixation and increased light use efficiency, as noted by Amanu *et al.* 2022; Tohura *et al.* (2014) supported this finding, stating that intercropping maize with mungbean led to a

43% increase in land use efficiency. Saleem *et al.* (2015) further asserted that maize/mungbean intercropping proved to be a more productive and efficient system for land utilization compared to sole cropping.

The plot treated with 50% RDF + 50% Nano NPK fertilizers produced the highest gross returns, cultivation costs, net benefits, and B:C ratios among the various fertilizer treatments. As opposed to the control plot, which had the lowest gross returns per hectare, cultivation costs per hectare, net benefits per hectare, and benefit-cost ratio. This research is expected to be valuable because, except for the control plot, all fertilizer application levels yielded BCR values higher than 1 (2020 and 2021), and mean data. The achievement of the highest economic returns from maize grains, stemming from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, can be attributed to distinct factors separate from those influencing grain and straw yield. The utilization of nanofertilizers, featuring nano-sized particles, likely played a role in enhancing the nutrient content and quality of maize grains. This improvement in grain quality could have positively impacted economic returns, particularly in markets where quality is a determining factor. In addition, nanofertilizers may have contributed to optimizing the nutrient composition of maize grains, resulting in grains with desirable nutritional characteristics that could influence market value and contribute to economic gains. The combination of NPK fertilizers and nanofertilizers may have led to maize grains with attributes highly valued in the market, such as enhanced nutritional content, size, or appearance, thereby increasing market value and economic returns. Furthermore, nanofertilizers could have played a role in increasing yield efficiency, ensuring that invested resources, including fertilizers, were effectively converted into marketable grain. This efficiency in resource utilization could have positively influenced economic outcomes. Moreover, the application of nanofertilizers might have allowed for a more efficient use of inputs, potentially contributing to reduced overall production costs. The combination of enhanced grain quality, optimized nutrient composition, increased market value, improved yield efficiency, and potentially reduced input costs collectively contributed to the economic success of maize production. Behzadi *et al.* (2017) and Perez-de-Luque (2013) observed that nanofertilizers offer greater advantages compared to conventional fertilizers, particularly in terms of reducing the cost of fertilizers and preventing soil and water pollution. Neogi, and Das (2022) concluded

that, considering both yield and economic perspectives, the application of 100% recommended dose of NPK, coupled with the foliar application of both nano nitrogen and nano-zinc, emerged as the most effective treatment in enhancing the growth and productivity of potatoes. Sruthi *et al.* (2022) showed that the application of nano NPK led to an improved profit for sesame cultivation by increasing the crop yield. This outcome corresponds with Panda *et al.* (2020), who observed an enhanced benefit-cost ratio in tomatoes with the application of nano NPK. Similarly, Abd El- Azeim *et al.* (2020) obtained comparable results through the foliar spray of nano NPK fertilizer in potatoes.

Significant interaction between the cropping system and various fertilizer levels was observed for both years (2020 and 2021), as well as when the data from both years were mean. The most favorable economic outcomes were identified in the intercrop maize scenario, specifically with the application of 50% RDF + 50% Nano NPK fertilizers. This combination exhibited statistically superior results compared to all other interactions. Conversely, the lowest economic returns were observed in sole maize, particularly when combined with the control in both the 2020 and 2021 seasons. This consistent pattern persisted when the data from both years were mean (Table 4.1.19a, 4.1.19b, and 4.1.19c).

Table 4.1.19.: Economics of sole and intercrop maize as influenced by cropping sysem and different fertilizer levels during the growing years (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	Gross return (Rs/ha)	Net return (Rs/ha)	B: C ratio	Gross return (Rs/ha)	Net return (Rs/ha)	B: C ratio	Gross return (Rs/ha)	Net return (Rs/ha)	B: C ratio
A –Cropping system									
M₁	100688.40 ^b	56100.68 ^b	1.219 ^b	105798.00 ^b	60405.08 ^b	1.289 ^b	103243.20 ^b	58252.88 ^b	1.254 ^b
M₃	132352.13 ^a	92595.61 ^a	2.244 ^a	136239.26 ^a	95677.54 ^a	2.273 ^a	134295.69 ^a	94136.57 ^a	2.259 ^a
SEm (±)	2047.44	2206.91	0.064	2260.93	1679.02	0.059	2355.87	1942.97	0.062
(P= 0.05)	12456.50	13426.75	0.391	13755.39	10215.06	0.361	14332.97	11820.91	0.376
B-Different levels of fertilizer									
S₁	61271.93 ^c	27636.53 ^c	0.840 ^c	62360.37 ^c	27919.77 ^c	0.828 ^c	61816.15 ^c	27778.15 ^c	0.834 ^c
S₂	140587.33 ^a	92086.84 ^a	1.929 ^b	145596.87 ^a	96291.18 ^a	1.982 ^b	143092.10 ^a	94189.01 ^a	1.956 ^b
S₃	119177.70 ^b	77642.80 ^b	1.901 ^b	126279.76 ^b	83939.66 ^b	2.011 ^b	122728.73 ^b	80791.23 ^b	1.957 ^b
S₄	145044.08 ^a	100026.38 ^a	2.257 ^a	149837.52 ^a	104014.62 ^a	2.303 ^a	147440.80 ^a	102020.50 ^c	2.280 ^a
SEm (±)	3229.90	3206.54	0.080	3175.19	3270.69	0.078	3162.77	3238.61	0.079
(P=0.05)	9950.81	9878.83	0.246	9782.25	10076.49	0.240	9744.00	9977.66	0.242
Interaction (AxB)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table.4.1.9a: Interaction between cropping system and different levels of fertilizer on the Gross return (Rs/ha) of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	57353 ^e	118270 ^c	103481 ^d	123650 ^{bc}	58393 ^e	123120 ^{cd}	112300 ^d	129379 ^a	57873 ^e	120695 ^{cd}	107890 ^d	126515 ^{bc}
M₃	65191 ^e	162905 ^a	134875 ^b	166438 ^a	66328 ^e	168073 ^a	140259 ^b	170296 ^a	65760 ^e	165489 ^a	137567 ^b	168367 ^a
SEm (±)	4490				4568				4529			
CD(P=0.05)	13834				14073				13953			

Table.4.19b: Interaction between cropping system and different levels of fertilizer on the Net return (Rs/ha) of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	21302 ^e	67354 ^{cd}	59530 ^d	81140 ^c	21536 ^e	71399 ^{cd}	67544 ^d	81140 ^c	21419 ^e	69376 ^{cd}	63537 ^d	78679 ^c
M₃	33971 ^e	116820 ^a	95755 ^b	126889 ^a	34303 ^e	121183 ^a	100335 ^b	126889 ^a	34137 ^e	119002 ^a	98045 ^b	125362 ^a
SEm (±)	4535				4625				4580			
CD(P=0.05)	13971				14250				14111			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercrop-ping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table.4.11.9c: Interaction between cropping system and different levels of fertilizer on the B:C ratio of sole and intercrop maize.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	0.591 ^e	1.323 ^{cd}	1.354 ^c	1.607 ^c	0.584 ^e	1.380 ^c	1.509 ^c	1.682 ^c	0.588 ^e	1.352 ^{cd}	1.433 ^c	1.645 ^c
M₃	1.088 ^d	2.535 ^b	2.448 ^b	2.907 ^a	1.071 ^d	2.584 ^{ab}	2.513 ^b	2.923 ^a	1.080 ^d	2.560 ^b	2.481 ^b	2.915 ^a
SEm (±)	0.110				0.113				0.111			
CD(P=0.05)	0.339				0.347				0.342			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercrop-ping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.7. Damage of fall armyworm (*Spodoptera frugiperda*)

4.1.1.7.1. Leaf damage by Fall armyworm (FAW) (1-9 scale)

Table 4.1.20 depicts the impact of various fertilizer levels and cropping systems on the leaf damage caused by fall armyworm (2020, 2021 and mean data). The cropping system and different fertilizers levels had a considerable impact on the leaf damage caused by the FAW. FAW damage to leaves was determined to be higher in plots where maize was cultivated as the sole crop throughout both the growing years and in the mean data, while lesser leaf damage was reported in plots where maize was planted in combination with mungbean. The observed reduction in fall armyworm infestation in maize leaves through intercropping with mungbean, as opposed to sole cropping, was attributed to various factors that collectively improved pest management. Intercropping maize with mungbean might have created a less favorable environment for fall armyworm, leading to lower population density. The diversification of the crop environment has also played a crucial role in this reduction. Also, mungbean might have acted as a natural deterrent or repellent to fall armyworm. The specific chemical composition or scent of mungbean may have discouraged the pests from infesting the leaves of maize, providing a protective effect for the intercropped plants. According to Nirmal *et al.* (2020), the allelopathic effects and the release of an odorous smell from intercropped plants may contribute to the intercropping system's efficacy in repelling fall armyworm larvae from sweet corn plants. Additionally, intercropping might have enhanced biological diversity, attracting natural enemies of fall armyworms, such as predators and parasitoids. This natural control mechanism might have contributed to minimizing pest infestation in the leaves of maize. Maitra *et al.* (2019), found a similar outcome and concluded that the intercropping strategy affects disease and pest management because the combination of crops produces functional diversity and prevents the spread of pests and diseases. Moreover, intercropping maize with legumes helps FAW larvae disperse away from the main crop, minimizing damage to the companion host plants. The ability of FAW to disseminate, particularly during the larval stages, may have been physically limited since the intercrops are non-hosts. It is widely recognized that dense host intercrops provide a favorable environment for a variety of natural enemies of insects, including parasitoids and predators, as well as a medium for

the FAW larvae's rapid expansion (Mutyambai *et al.* 2022). Bhagat *et al.* (2022) observed the least intensity of fall armyworm (FAW) infestation in maize + cowpea intercropping with a regular (1:1) row arrangement. They suggested that the reduced infestation might be attributed to the expansive growth of cowpea, creating obstacles for FAW movement between maize rows. Additionally, the secretion of an unfavorable smell or chemicals by cowpea roots could contribute to the lower FAW infestation. Furthermore, Firake *et al.* (2019) found that intercropping maize with legumes like pigeon pea and black gram resulted in lower insect attacks compared to sole cropping. Harrison *et al.* (2019) noted that FAW control could be achieved through intercropping with carefully chosen companion plants, diversifying the environment. Khatri *et al.* (2020) also reported similar findings.

The control plot in the case of various fertilizer treatments reported the most FAW leaf damage, followed by a plot where 100% RDF was sprayed, and 100% Nano NPK fertilizers were applied. The plot applied with 50% RDF + 50% Nano NPK fertilizers, on the other hand, had the least leaf damage. In both growing seasons and mean data, the results were found to be comparable (Table 4.1.20). The mitigation of fall armyworm damage on maize leaves, stemming from the incorporation of NPK (Nitrogen, Phosphorus, Potassium) fertilizers and nanofertilizers, can be attributed to specific factors distinct from those influencing grain and straw yield. Nanofertilizers, featuring nano-sized particles, likely played a pivotal role in enhancing maize plant resistance against fall armyworm infestation, contributing to a reduction in leaf damage. Moreover, the combined application of NPK fertilizers and nanofertilizers may have optimized nutrient levels within maize plants, fostering overall plant health and resilience to pest attacks, thereby diminishing damage to leaves. Furthermore, nanofertilizers could have contributed to strengthening the cell wall structure of maize leaves, acting as a physical barrier that impedes extensive damage by fall armyworms. The application of nanofertilizers might have induced the activation of defense mechanisms in maize plants, potentially involving the production of compounds that deter or inhibit fall armyworm feeding, thereby further reducing leaf damage. Furthermore, nanofertilizers may have influenced the physiological processes within maize plants, creating an environment less conducive to fall armyworm infestation. These alterations in plant physiology, including changes in leaf chemistry or signaling, could discourage pest attacks and contribute to the observed

reduction in damage on maize leaves. Dubey and Mailapalli (2016) provided comparable justifications. The same outcomes were met by Rahman *et al.* in 2022, they found that exposure to copper nanoparticles, FAW larval hemocyte count significantly decreased. Kannan *et al.* (2023) highlighted the positive impact of engineered nanomaterials, whether used as active ingredients or in nano formulations, in controlling insect pests and protecting plants. They emphasized that nano pesticides offer several advantages over conventional pesticides, including enhanced adsorption, reduced volatilization, improved tissue permeation, controlled release, and more. Sadhukhan *et al.* (2021) also noted that nano-fertilizers exhibit favorable characteristics, including disease resistance properties and the ability to combat various fungal infections in crop plants. Tamez *et al.* (2019) reported that copper nanoparticles demonstrated significant efficacy in alleviating disease symptoms in sugarcane. Likewise, Prakashraj *et al.* (2021) recorded that the application of TiO₂ nanofertilizers not only improved the yield but also enhanced disease resistance in Capsicum.

In both the growing years (2020 and 2021) as well as when data were mean, the interaction between the cropping system and various fertilizer rates was shown to be significant. The plot where maize was cultivated as a sole crop in conjunction with control showed the highest mean value of FAW leaf damage, whereas the plots where maize was grown as an intercrop with mungbean in conjunction with 50% RDF + 50% Nano NPK fertilizers showed the lowest mean value of FAW leaf damage (Table 4.1.20a).

4.1.1.7.2. Ear damage by FAW (1-9 scale)

The effect of various fertilizer levels and cropping systems on the ear damage brought on by FAW is depicted in Table 4.1.20. (2020 ,2021 and mean data). The cropping system and different fertilizer levels were significantly impacted by the ear damage brought on by the FAW. FAW damage to the ear was reported to be higher in plots where maize was cultivated as the sole crop in both the growing years and in the mean data, while lesser ear damage was noted in plots where maize was planted in combination with mungbean (Table 4.1.20). The lowest infestation of fall armyworm in the ears of maize due to intercropping with mungbean, compared to sole cropping, was attributed to several factors that collectively contributed to enhanced pest management. Firstly, intercropping maize with mungbean might have created an environment less conducive to fall

armyworm infestation. The diversified cropping system might have disrupted the preferred habitat of FAW, leading to a reduction in their population density around maize ears. Furthermore, the specific chemical composition or aroma of mungbean likely played a role in discouraging pests from infesting the maize ears, providing a protective effect in the intercropped system. Moreover, intercropping might have increased biological diversity, attracting natural enemies of FAW, such as predators and parasitoids. This ecological diversity might have acted as a natural control mechanism, further contributing to the decreased infestation of fall armyworm in the maize ears. The fewer incidences of FAW in intercropped maize may be due to the diversity of crops, which led to higher populations of beneficial insects like parasites and predators. As a result, the presence of pests that constitute harm to the crop (FAW) is kept below the economic threshold. Besides that, when two or more crop types are planted together, it complicates the pests' food source and habitat. Tanyi *et al.* (2020); Makgoba *et al.* 2021 and Richard *et al.* (2022), also observed that insects and pests were less severe in intercropped maize stands than they were in pure maize stands. Hailu *et al.* (2018) reported that intercropping maize with leguminous crops resulted in a substantial reduction of stemborer and FAW compared to mono-cropped maize, particularly during the early growth phases up to tasseling. Tiroesele *et al.* (2019) observed a significantly higher presence of parasitoids in intercropping systems compared to monocropping systems.

FAW ear damage was highest in the control plot, followed by the plot where 100% RDF was applied, and a plot where 100% Nano NPK fertilizers were used, in the event of varied levels of fertilizer treatments. On the other hand, there was the least degree of ear damage in the plot fertilized with 50% RDF and 50% Nano NPK fertilizers. The outcomes were comparable in both growing years and in mean statistics. The limited damage caused by fall armyworm on maize ears, as a result of combining 50% NPK fertilizers and 50% Nano NPK fertilizers, can be ascribed to factors distinct from those influencing grain and straw yield. Nanofertilizers, characterized by nano-sized particles, played a pivotal role in enhancing the resistance of maize plants to fall armyworm infestation, particularly in the sensitive ear region. This heightened plant resistance contributed to a notable reduction in damage inflicted on maize ears. Additionally, the synergy between NPK fertilizers and nanofertilizers optimized nutrient levels within the

maize plant, fostering overall plant health and resilience. Well-nourished and robust plants are inherently more resistant to pest attacks, thereby minimizing damage in vulnerable ear areas. Nanofertilizers further contributed by strengthening the natural protective mechanisms in the maize ear region, potentially reinforcing physical barriers or activating defense mechanisms that deterred fall armyworm feeding. The localized and efficient delivery of nutrients to maize ears facilitated by nanofertilizers played a key role in promoting ear health and resilience, reducing susceptibility to fall armyworm damage. Moreover, the application of nanofertilizers induced changes in the biochemical environment within maize ears, creating conditions less favorable for fall armyworm infestation. These alterations included shifts in the composition of secondary metabolites or biochemical signals that discouraged pest attacks. Chen *et al.* (2022) suggested that nanoparticles could function as carriers for insecticides, offering reduced environmental impact, sustained release properties, and efficient pest control. Wang *et al.* (2021) demonstrated that nano silicon has the potential to substitute synthetic pesticides, providing a more effective and ecologically sustainable approach to managing insect pests in maize crop farming. Elmer and White (2018) observed that nanofertilizers play a role in regulating host defense by suppressing diseases, and they mitigate the release of active metals into the environment when utilized for disease management or antimicrobial purposes. Similarly, Graham *et al.* (2016) documented the antimicrobial effectiveness of nanofertilizers against bacteria in grapefruit.

The interaction between the cropping system and various fertilizer levels was revealed to be significant for both the growing years as well as when data were mean. The plots where maize was planted as an intercrop with mungbean coupled with 50% RDF + 50% Nano NPK fertilizers displayed the lowest mean value of FAW ear damage, whereas the plots where maize was cultivated as a sole crop and combined with no fertilizer treatments (control) showed the highest mean value of FAW ear damage (Table 4.1.20b).

4.1.1.7.3. Kernel damage by FAW (1-9 scale)

Table 4.1.20 depicts the impact of various fertilizer levels and cropping systems on the kernel damage caused by FAW (2020, 2021 and mean data). The cropping system and different levels of fertilizers had a significant impact on the kernel damage caused by the FAW. FAW damage to the kernel was demonstrated

to be higher in plots where maize was produced as the sole crop in the two growing years and the mean data, while lesser ear damage was reported in plots where maize was planted in combination with mungbean (Table 4.1.20). The lowest infestation of fall armyworm in maize kernels, observed through intercropping with mungbean instead of sole cropping, was due to a combination of factors. Diversifying the crop environment disrupted the preferred habitat of the pest, reducing its population around maize kernels. Additionally, mungbean may have acted as a natural deterrent, and the increased biological diversity attracted natural enemies of fall armyworm, collectively contributing to the effective pest management in the intercropped system. Gao *et al.* (2014) also reported a significant reduction in disease incidence and severity index through intercropping, particularly noting a substantial decrease in disease severity when soybean was grown in close proximity to maize. Maitra *et al.* (2019) observed an expansion in the population of beneficial insects, contributing to pest control and reducing the reliance on harmful chemicals. Lulie *et al.* (2016) highlighted that intercropping different crops on the same piece of land alters environmental conditions, influencing the host plant's quality and, consequently, the insect pest's ability to identify and recognize it. In line with existing research, Blessing *et al.* (2022) concluded that intercropping maize and soybean enhances resource utilization, lodging resistance, and control over pests and weeds. Other research has documented the contribution of intercrops in reducing the population of plant-eating insects by promoting the presence of natural predators (Asiry, 2013; Parthiban *et al.* 2018).

The impact of various fertilizer levels on plant damage caused by FAW kernel damage varied considerably between treatments. FAW infestation in the kernel of maize was significantly less on maize crops treated with 50% RDF and 50% Nano NPK fertilizers, followed by the plot treated with 100% RDF and then the plot where 100 % Nano NPK fertilizers were applied. Yet, the plot where no fertilizer was applied had a considerably larger FAW infestation in the kernel (control). After pooling the data, the outcomes were comparable for both growth seasons (Table 4.1.20). The limited damage inflicted by fall armyworm on maize kernels, a result of combining 50% NPK fertilizers and 50% Nano NPK fertilizers, can be attributed to distinct factors separate from those influencing grain and straw yield. Nanofertilizers, with their nano-sized particles, played a pivotal role

in enhancing the resistance of maize kernels against fall armyworm infestation. This heightened kernel resistance was a significant contributor to the observed reduction in damage. Moreover, the collaborative use of NPK fertilizers and nanofertilizers optimized the nutrient composition within maize kernels, fostering healthier kernels with attributes that deterred fall armyworm feeding, leading to diminished damage. Nanofertilizers likely contributed to reinforcing natural protective mechanisms within maize kernels, involving the activation of defense mechanisms or the enhancement of physical barriers that limited fall armyworm damage in the kernel region. The efficient and targeted delivery of nutrients to maize kernels facilitated by nanofertilizers also played a role in overall kernel health and resilience, reducing vulnerability to fall armyworm damage. Furthermore, nanofertilizers induced changes in the biochemical environment within maize kernels, creating conditions less favorable for fall armyworm infestation. These alterations included shifts in the composition of biochemicals or signals that discouraged pest feeding. In summary, the collaborative impact of NPK fertilizers and nanofertilizers significantly contributed to minimizing fall armyworm damage specifically in the critical kernel region of maize, encompassing enhanced kernel resistance, optimized nutrient composition, reinforced protective mechanisms, efficient nutrient delivery, and alterations in the biochemical environment. According to Pittarate *et al.* 2021, nanoparticles will be a useful component of integrated pest management regimens. In addition, Javed *et al.* 2022 also suggested that the effective application of nano pesticides and nanofertilizers can boost the efficacy of fertilizers in agricultural production. Likewise, Sahar *et al.* (2020) stated that the application of NPK nano-fertilizers led to a reduction in the occurrence and intensity of plant diseases and pests in both greenhouse and field experiments.

In the two growing seasons (2020 and 2021) as well as when data were mean, the interaction between the cropping system and various fertilizer levels was determined to be significant. The plot where maize was cultivated as sole crop in conjunction with control showed the highest mean value of FAW kernel damage, whereas the plots where maize was grown as an intercrop with mung-bean in conjunction with 50% RDF + 50% Nano NPK fertilizers showed the lowest mean value of FAW kernel damage (Table 4.1.20c).

Table 4.1.20.: Effect of cropping systems and different levels of fertilizers on leaf, ear and kernel damage due to fall armyworm in maize during *kharif* season (2020 and 2021) and mean data.

Treatments	2020	2020	2020	2021	2021	2021	Mean data	Mean data	Mean data
	Leaf damage rating (1-9 scale)	Ear damage rating (1-9 scale)	Kernel damage rating (1-9 scale)	Leaf damage rating (1-9 scale)	Ear damage rating (1-9 scale)	Kernel damage rating (1-9 scale)	Leaf damage rating (1-9 scale)	Ear damage rating (1-9 scale)	Kernel damage rating (1-9 scale)
A-Cropping system									
M ₁	3.50 ^a	3.99 ^a	2.82 ^a	3.41 ^a	3.89 ^a	2.77 ^a	3.46 ^b	3.94 ^a	2.80 ^a
M ₃	3.18 ^b	2.90 ^b	2.37 ^b	3.10 ^b	2.82 ^b	2.32 ^b	3.14 ^a	2.86 ^b	2.35 ^b
SEm (±)	0.05	0.06	0.05	0.04	0.06	0.05	0.04	0.06	0.05
CD (P=0.05)	0.33	0.36	0.32	0.31	0.34	0.33	0.32	0.35	0.32
B-Different levels of fertilizer									
S ₁	4.24 ^a	4.59 ^a	3.32 ^a	4.06 ^a	4.45 ^a	3.29 ^a	4.15 ^a	4.52 ^a	3.31 ^a
S ₂	2.94 ^c	3.21 ^c	2.41 ^c	2.89 ^c	3.14 ^c	2.36 ^c	2.92 ^c	3.18 ^c	2.39 ^c
S ₃	3.61 ^b	3.98 ^b	2.64 ^b	3.54 ^b	3.90 ^b	2.59 ^b	3.58 ^b	3.94 ^b	2.62 ^b
S ₄	2.58 ^d	2.00 ^d	2.02 ^d	2.53 ^d	1.94 ^d	1.95 ^d	2.56 ^d	1.97 ^d	1.99 ^d
SEm (±)	0.08	0.08	0.06	0.07	0.09	0.05	0.07	0.08	0.06
CD (P=0.05)	0.24	0.25	0.18	0.22	0.27	0.16	0.23	0.25	0.17
Interaction (A x B)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.20a: Interaction between cropping systems and different fertilizers levels on the damage caused by the fall armyworm on sole and intercrop maize in the year 2020.

Leaf damage	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	4.30 ^a	3.22 ^c	3.87 ^c	2.75 ^d	3.99 ^a	3.16 ^c	3.79 ^b	2.70 ^d	4.15 ^a	3.19 ^c	3.83 ^b	2.73 ^d
M ₃	4.14 ^{ab}	2.66 ^d	3.35 ^b	2.41 ^d	4.12 ^a	2.61 ^d	3.28 ^b	2.36 ^e	4.13 ^a	2.64 ^d	3.32 ^b	2.39 ^e
SEm (±)	0.11				0.10				0.11			
CD(P=0.05)	0.34				0.32				0.33			

Table 4.1.120b: Interaction between cropping systems and different fertilizers levels on the damage caused by the fall armyworm on sole and intercrop maize in the year 2021.

Ear damage	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	5.29 ^a	3.66 ^b	4.98 ^a	2.04 ^d	5.09 ^a	3.58 ^b	4.87 ^a	1.96 ^d	5.19 ^a	3.62 ^b	4.93 ^a	2.00 ^d
M ₃	3.89 ^b	2.75 ^c	2.99 ^c	1.95 ^d	3.76 ^b	2.69 ^c	2.92 ^c	1.91 ^d	3.83 ^b	2.72 ^c	2.96 ^c	1.93 ^d
SEm (±)	0.11				0.12				0.11			
CD(P=0.05)	0.35				0.38				0.36			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.20c: Interaction between cropping system and different fertilizer levels on the damage cause by the fall armyworm on sole and intercrop maize (Mean data).

Kernel damage	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	3.39 ^a	2.64 ^{bc}	2.87 ^b	2.38 ^d	3.31 ^a	2.59 ^{bc}	2.81 ^b	2.33 ^d	3.35 ^a	2.62 ^{bc}	2.84 ^b	2.35 ^d
M₃	3.25 ^a	2.17 ^f	2.41 ^{cd}	1.66 ^e	3.20 ^a	2.13 ^f	2.36 ^{cd}	1.63 ^e	3.22 ^a	2.15 ^f	2.38 ^{cd}	1.65 ^e
SEm (±)	0.08				0.07				0.07			
CD(P=0.05)	0.25				0.23				0.24			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.1.21: Classification of maize hybrids against fall armyworm based on leaf damage rating (1-9 scale).

Treatments	2020		2021		Mean data	
	Rating scale	Classification	Rating scale	Classification	Rating scale	Classification
A. Cropping system						
M₁	3.50	Least susceptible	3.41	Least susceptible	3.46	Least susceptible
M₃	3.18	Least susceptible	3.10	Least susceptible	3.14	Least susceptible
B. Different levels of fertilizers						
S₁	4.24	Moderately susceptible	4.08	Moderately susceptible	4.15	Moderately susceptible
S₂	2.94	Least susceptible	2.89	Least susceptible	2.92	Least susceptible
S₃	3.61	Moderately susceptible	3.54	Least susceptible	3.58	Moderately susceptible
S₄	2.58	Least susceptible	2.53	Least susceptible	2.56	Least susceptible

M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers. RDF=Recommended dose of fertilizers.

Table 4.1.22: Classification of maize hybrids against fall armyworm based on ear damage rating (1-9 scale).

Treatments	2020		2021		Mean data	
	Rating scale	Classification	Rating scale	Classification	Rating scale	Classification
A. Cropping system						
M₁	2.90	Least susceptible	2.82	Least susceptible	2.86	Least susceptible
M₃	3.99	Least susceptible	3.89	Least susceptible	3.94	Least susceptible
B. Different levels of fertilizers						
S₁	4.59	Moderately susceptible	4.45	Moderately susceptible	4.52	Moderately susceptible
S₂	3.21	Least susceptible	3.14	Least susceptible	3.18	Least susceptible
S₃	3.98	Least susceptible	3.90	Least susceptible	3.94	Least susceptible
S₄	2.00	Least susceptible	1.94	Least susceptible	1.97	Least susceptible

M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁=Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers. RDF=Recommended dose of fertilizers.

Table 4.1.23: Classification of maize hybrids against fall armyworm based on Kernel damage rating (1-9 scale).

Treatments	2020		2021		Mean data	
	Rating scale	Classification	Rating scale	Classification	Rating scale	Classification
A. Cropping system						
M₁	2.37	Least susceptible	2.32	Least susceptible	2.35	Least susceptible
M₃	2.82	Least susceptible	2.77	Least susceptible	2.80	Least susceptible
B. Different levels of fertilizers						
S₁	3.32	Least susceptible	3.29	Least susceptible	3.31	Least susceptible
S₂	2.41	Least susceptible	2.36	Least susceptible	2.39	Least susceptible
S₃	2.64	Least susceptible	2.59	Least susceptible	2.62	Least susceptible
S₄	2.02	Least susceptible	1.95	Least susceptible	1.99	Least susceptible

M₁=Maize (sole), M₃=Maize+Mungbean (intercropping), S₁= Control, S₂=100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+50% Nano NPK fertilizers. RDF=Recommended dose of fertilizers.

4.1.1.8. Post-harvest soil analysis

Specifics of the physical and chemical study of soil following the harvest of the maize and mungbean crop in the years 2020 and 2021, as well as the mean data, are presented in Table 4.1.24 and 4.1.25.

4.1.1.8.1. pH

The impact of various fertilizer levels and cropping system on the pH of the soil when maize and mungbean were grown earlier in both seasons, i.e., 2020 and 2021, and in the mean statistics, was found to be significant. The plot where maize was planted as the sole crop had the highest pH, which was statistically comparable to the plot where maize and mungbean were intercropped. The plot where mungbean was cultivated as a sole crop with mungbean had the lowest pH in both 2020 and 2021. A similar pattern was seen in the mean data. The reason for the lowest soil pH in sole mungbean cropping, in contrast to maize and mungbean intercropping and maize intercropping, can be attributed to root exudation from mungbean, when cultivated alone, contributes to soil acidification by releasing organic acids into the rhizosphere. The symbiotic relationship between mungbean and nitrogen-fixing bacteria in root nodules might have been added to soil acidification through the production of acidic compounds. Mungbean specific nutrient uptake patterns might have influenced the release of acidic ions into the soil, impacting pH levels. The decomposition of mungbean residues, including roots and aboveground plant parts, releases organic acids during the breakdown process, contributing to the accumulation of acidic substances in the soil. In contrast, the absence of alkaline residues, such as those from maize, in sole mungbean cropping may contribute to a lower soil pH. Maize residues, upon decomposition, might produce different decomposition products that are less acidic or even alkaline. These factors collectively explain why sole mungbean cropping tends to result in the lowest soil pH when compared to intercropping scenarios involving maize or sole maize cropping. Lukin *et al.* (2019) documented that legumes alter soil pH by releasing hydrogen ions through their root system. According to Dugga, (2023), legume crops have the capability to modify the soil pH in the rhizosphere, thereby enhancing nutrient availability for cereals. The cultivation of legumes induces soil acidity due to the release of protons from the roots. This process results in the accumulation of organic anions in plants, and when these

anions are returned and degraded in the soil, they can neutralize soil acidity. This also may be due to the fact that legumes can acidify their rhizosphere for as long as they take up more cations than anions from the soil solution which fallouts in the proclamation of H ions from plant roots to maintain the electrochemical balance within their tissues, which nets out to the acidity of the soil. Furthermore, on soils with a pH above the range for ideal crop growth and development, legumes could lower the pH and encourage an increase in plant-soil microbial activity. Inoculated, modulated legumes have the overall effect of lowering the pH of the soil. This finding is confirmed by Yuvaraj *et al.* (2020), who also noted that alfalfa and soybeans in greenhouse trials decreased the pH of the soil.

In the case of different levels of fertilizer treatment, in the years 2020 and 2021, the control plot had the highest pH which was statistically similar to the plot treated with 100% Nano NPK fertilizers and 100% RDF. Statically lowest pH was recorded in the plot where 50% RDF + 50% Nano NPK fertilizers were applied. The mean statistics revealed a comparable pattern (Table 4.1.24). The attainment of the lowest pH in the harvested soil of maize, resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, can be attributed to distinct factors separate from those influencing grain and straw yield. The combined application of NPK fertilizers and nanofertilizers likely enhanced nutrient availability in the soil, providing a more accessible form for plants and contributing to changes in soil pH. Also, the nano-sized particles in nanofertilizers may have interacted with soil components, influencing chemical reactions and ion exchange processes, thus playing a role in pH modulation. The combination of NPK fertilizers and nanofertilizers may have influenced microbial activity in the soil, impacting processes such as nutrient cycling and organic matter decomposition, which can affect pH levels and contribute to a decrease in soil pH. Moreover, the optimized nutrient supply facilitated by nanofertilizers might have influenced nutrient leaching and uptake by plants, potentially altering the release of ions and contributing to a decrease in soil pH. The chemical reactions facilitated by the combination of NPK fertilizers and nanofertilizers, involving the breakdown of fertilizers and the release of ions, could have directly influenced soil acidity. Similarly, Pide *et al.* (2023) observed that the application of nanofertilizer resulted in a significant decrease in soil pH, while having no impact on total nitrogen (N) and available phosphorus (P). Najm and Al-Juthery (2023) similarly

observed that the lowest soil pH was attained through the application of the combination of NPK nano-fertilizers with NPK, in comparison to other treatment methods. Esmaeil *et al.* (2020) reported a minor reduction in soil pH resulting from the application of nanofertilizers. El-Ghamry *et al.* (2018) found a similar finding, stating that the use of nanofertilizers improved soil pH, which represented the presence of organic matter and biological activity.

The interaction between the cropping system and different fertilizer levels on pH was shown to be significant in both (2020 and 2021) as well as in the mean data.

4.1.1.8.2. Electric conductivity (EC)

When maize and mungbean were cultivated in both seasons, (2020 and 2021) and in the mean data, the effects of varied levels of fertilizers and cropping system considerably impacted the EC of the soil (Table 4.1.24). The plot with mungbean as the sole crop had the highest EC, followed by the plot with maize and mungbean intercropped, which was statistically similar to the plot with maize as sole crop. The plot where maize was planted as the sole crop in 2020, 2021 had the lowest EC. A similar pattern was seen in the mean data. The elevated EC in soil resulting from sole mungbean cultivation as opposed to intercropping with maize or sole maize cropping can be attributed to various factors. One significant factor may be the distinct nutrient uptake patterns of different crops. Mungbean, when grown alone, may have specific nutrient requirements or accumulate particular ions, impacting the overall EC in the soil. Root exudation, the release of substances by plant roots, may be another contributing factor. Mungbean, in isolation, might release compounds that more significantly increase the EC compared to when intercropped with maize. Additionally, the decomposition of crop residues plays a role. The type and quantity of residues left by mungbean, and maize could differ, leading to variations in EC levels. The competitive interactions between mungbean and maize in intercropping scenarios also influence nutrient availability and ion concentrations in the soil, affecting EC. Moreover, disparities in water uptake patterns between mungbean and maize may have contributed to variations in the concentration of ions in the soil solution, influencing soil EC. Kabirinejad *et al.* (2014) mentioned that the elevated EC in legumes could be attributed to heightened concentrations of nutrients released during biomass decomposition. This correlation may be associated with the more pronounced

influence of soil moisture, compared to soil EC, on N₂O emissions, as indicated by Kandel *et al.* (2019). According to Wang *et al.* (2023), the decline in pH can be attributed to the legume-potato rotation, which substantially decreased EC and pH. Ajithkumar *et al.* (2021) also documented a marginal decrease in soil pH and a slight increase in EC, percentage of organic carbon, and the availability of NPK in maize crops through the application of nanofertilizers. Moriri *et al.* (2015) observed similar findings and noted that sole mungbean had a lower pH and higher percent of organic carbon when compared to sole maize and interop maize with mungbean.

The plot treated with 50% RDF + 50% Nano NPK fertilizers in the year 2020 and 2021 had the highest EC and was statistically equivalent to the plot treated with 100% RDF and 100% Nano NPK fertilizers. This was true for all levels of fertilizer treatment. On the control plot, the lowest EC was statistically observed. According to mean data, the plot treated with 50% RDF and 50% Nano NPK fertilizers had the highest EC value, which was statistically comparable to the plot treated with 100% RDF and 100% Nano NPK fertilizers. Nonetheless, the control plot had the lowest EC (Table 4.1.24). The attainment of the highest EC in the harvested soil of maize, resulting from the combination of 50% NPK fertilizers and 50% Nano NPK fertilizers, can be attributed the collaborative application of NPK fertilizers and nanofertilizers which may have led to an increase in ion concentrations in the soil. The presence of nano-sized particles in nanofertilizers likely played a role in interacting with soil components, influencing the movement of ions and, consequently, impacting the electrical conductivity of the soil. Furthermore, the optimized nutrient supply facilitated by nanofertilizers might have influenced both nutrient uptake and leaching in the soil, contributing to changes in ion concentration and, subsequently, in the overall EC of the harvested soil. The chemical reactions facilitated by the combination of NPK fertilizers and nanofertilizers could have directly influenced the release of ions and, consequently, the soil's electrical conductivity. Additionally, the combined impact of NPK fertilizers and nanofertilizers may have influenced soil structure, potentially affecting water movement and ion distribution, thus contributing to variations in EC levels in the harvested soil. According to Zheng *et al.* (2023), the cultivation of legumes resulted in decreased soil salinity and an increase in total carbon and total nitrogen. Within the soil microbiota, certain nitrogen-fixing

bacteria, such as *Azotobacter*, showed enrichment in the presence of legumes, suggesting a potential role in soil nitrogen accumulation. Ajithkumar *et al.* (2021) slight increase in EC.

In both 2020 and 2021, the correlation between the cropping system and various fertilizer levels was shown to be non-significant. Similar tendencies were observed when the data was mean.

4.1.1.8.3. Organic carbon (%)

The fertilizer levels and cropping systems had a non-significant impact on the organic carbon (OC) of the soil where maize and mungbean were grown earlier in both seasons, i.e., 2020, 2021 and in the mean statistics (Table 4.1.24).

The interaction between the cropping system and various fertilizer levels was revealed to be non-significant ($P=0.05$) in both 2020 and 2021 and in the mean data.

Table 4.1.24.: Effect of cropping system and different levels of fertilizers on the chemical properties of soil (2020 and 2021 and mean data).

Treatments	2020			2021			Mean data		
	pH	EC (dsm ⁻¹)	Organic Carbon (%)	pH	EC (dsm ⁻¹)	Organic Carbon (%)	pH	EC (dsm ⁻¹)	Organic Carbon (%)
A - Cropping System									
M₁	8.04 ^a	0.496 ^b	0.529	7.96 ^a	0.508 ^c	0.535	8.07 ^a	0.503 ^b	0.532
M₂	7.83 ^b	0.589 ^a	0.542	7.70 ^b	0.602 ^a	0.548	7.73 ^b	0.596 ^a	0.545
M₃	8.01 ^a	0.537 ^b	0.535	7.92 ^a	0.550 ^b	0.541	7.94 ^a	0.544 ^b	0.538
SEm (±)	0.06	0.009	0.006	0.04	0.011	0.007	0.04	0.010	0.007
CD(P=0.05)	0.17	0.036	NS	0.15	0.043	NS	0.15	0.039	NS
B- Different levels of fertilizer									
S₁	8.11 ^a	0.478 ^b	0.519	8.01 ^a	0.492 ^b	0.525	8.06 ^a	0.486 ^c	0.522
S₂	7.98 ^b	0.559 ^a	0.543	7.88 ^a	0.571 ^a	0.549	7.93 ^b	0.565 ^{ab}	0.546
S₃	8.02 ^{ab}	0.545 ^a	0.529	7.92 ^a	0.557 ^a	0.535	7.97 ^{ab}	0.552 ^b	0.532
S₄	7.73 ^c	0.581 ^a	0.550	7.64 ^b	0.594 ^a	0.556	7.68 ^c	0.588 ^a	0.553
SEm (±)	0.04	0.017	0.015	0.03	0.018	0.017	0.04	0.018	0.016
CD(P=0.05)	0.16	0.052	NS	0.13	0.054	NS	0.15	0.053	NS
Interaction (Ax B)	S	NS	NS	S	NS	NS	S	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.8.4. Available Nitrogen (kg/ha)

When maize and mungbean were cultivated in both seasons, i.e., 2020 and 2021, and in the mean data, the effects of varying levels of fertilizers and cropping systems significantly impacted the available N content of the soil (Table 4.1.25). The plot where mungbean was cultivated as the sole crop in 2020 and 2021 recorded the highest mean value of N that was accessible, followed by the plot where maize and mungbean were intercropped, which was statistically comparable to the plot where maize was planted as the sole crop. The lowest mean value of N that was accessible was reported on the plot where maize was grown as sole crop in the 2020 and 2021 growing years. Sole mungbean cropping leads to the highest soil N content compared to maize and mungbean intercropping and maize cropping due to the symbiotic relationship between mungbean and N-fixing bacteria which might have allowed the efficient conversion of atmospheric nitrogen into a usable form. Decomposition of mungbean root nodules and residues also might have contributed to the additional nitrogen to the soil. The absence of competing crops in sole mungbean cultivation may have enhanced the N accumulation. Additionally, mungbean N-rich root exudation further may have augments the soil N levels. The reduced N competition in sole mungbean cropping might have allowed efficient N absorption. This could also be because during the growth stage, mungbean release N through the root, nodule, or fallen leaf turnover and supplied the soil with varied amounts of nutrients and may be to blame for the increase in the amount of readily available N, P, and K. Similar to this, Kebede (2020a) also noted that cereals grown with legume crops benefit from nitrogen in comparison to cereal monoculture. Murphy-Bokern *et al.* (2017) stated that the N-rich root, shoot, and leaf biomass of legumes, made possible by beneficial nitrogen fixation (BNF), increase the availability of N to following non-legume crop plants as exudates and that both living and senescent biomasses contribute additional below-ground N-enriched input to the soil. Also, according to Matse *et al.* (2020), the improved BNF achieved through the application of rhizobia inoculants aids in improving the amount of N and P that is accessible in the soil after the crop is harvested so that it may be used by the subsequent crop. Latati *et al.* (2016) noted that intercropping corn with peanuts leads to a rise in soil microorganism numbers. This, in turn, boosts the availability of N and P in the soil by elevating the activity of soil urease and phosphate monoesterase. The

substitution of nitrogen fertilizer can be achieved entirely or partially through biological nitrogen fixation, and the utilization of legumes in intercropping enhances soil fertility by fixing atmospheric N and contributing to soil conservation (Ananthi *et al.* 2017). Kumari *et al.* (2020) documented that the introduction of legume-based cropping systems into existing agricultural practices has positively impacted all soil properties, including the availability of NPK. Ro *et al.* (2023) noted that the highest concentration of available N in the soil was observed in the intercropping system of maize with ground nuts.

The plot treated with 50% RDF + 50% Nano NPK fertilizers recorded the maximum available N in the case of different levels of fertilizer treatment in the years 2020 and 2021, followed by the plot supplied with 100% Nano NPK fertilizers and 100% RDF. On the control plot, the statically lowest available N was noted. A similar pattern was seen in the mean data (Table 4.1.25). The accomplishment of the highest N content in harvested maize soil, resulting from the synergy of 50% NPK fertilizers and 50% Nano NPK fertilizers, can be attributed to the combined application's fine-tuning of N supply. This collaboration balances the use of N-rich fertilizers and enhances nanofertilizers' efficiency in nutrient delivery. Nano-sized particles within the fertilizers engage with soil components, influencing N availability and retention. The optimized nutrient supply facilitated by nanofertilizers influences both plant and soil nitrogen levels, playing a crucial role in mitigating nitrogen loss and contributing to higher retention in harvested soil. Studies by Esmaeil *et al.* (2020) and Abdel-Hakim *et al.* (2023) support the impact of nanofertilizers on soil nutrient concentrations, emphasizing characteristics like slow release, precise targeting, rapid absorption, membrane penetration, and protection against adsorption reactions. Research by Al-Juthery and Saadoun (2018), Mahgoub *et al.* (2017), and Subramanian and Thirunavukkarasu (2017) align with these outcomes. Rajonee *et al.* (2016) note higher available N in nano fertilizer treatments, with the nano counterpart retaining more inorganic N than conventional fertilizers. Azarpour *et al.* (2013) highlight improved nutrient availability with nanofertilizers. Nanoparticles' limited travel near the root, as suggested by Rajonee *et al.* (2017), contributes to increased soil physiochemical characteristics. Nanofertilizers, with distinct chemical and physical properties, release gradually, minimize external influences, and reduce N losses due to nitrification linked with temperature variations. This aligns with findings by Jyothi and

Hebsur (2017), Qureshi *et al.* (2018), and Kalwani *et al.* (2022), emphasizing the unique benefits of NPK nanofertilizers in enhancing soil nutrient concentrations.

It was determined that there was significant interaction between the cropping system and the various fertilizer levels in 2020, 2021, as well as when the data were mean. The sole mungbean in combination with 50% RDF + 50% Nano NPK fertilizers had the highest mean value of N. While the sole maize in combination with the control had the lowest mean value of N. However, when the data were mean, the pattern remained the same (Table 4.1.25a).

4.1.1.8.5. Available phosphorous (kg/ha)

Table 4.1.25 depicts the impact of various fertilizer levels and cropping systems on the available phosphorous (2020, 2021 and mean data) The plot with mungbean as the sole crop had the highest percentage of available phosphorous followed by the plot with maize and mungbean intercropped in both years. Moreover, the plot with maize as the sole crop in the growing years of 2020 and 2021 had the lowest available P content in the soil. Similarly, the mean data was comparable to that observation recorded like that in 2020 and 2021. Sole mungbean cropping have results in the highest soil P content compared to maize and mungbean intercropping and maize cropping due to mungbean ability to formed beneficial associations with mycorrhizal fungi and enhancing the P solubilization through root exudation and organic acid release. Additionally, mungbean nitrogen-fixing process and the release of phosphatase enzymes during nodulation may have contributed to the mobilization of P in the soil. Moreover, in sole mungbean cropping, reduced P competition might have allowed for more efficient P absorption and the decomposition of mungbean residues further might have added to the P availability in the soil. Moreover, mungbean also increases soil microbial activity, which improves the soil physical atmosphere by solubilizing the insoluble P in the soil through substances secreted by roots and due to their relatively high nitrogen contents and relatively low C: N ratio in mungbean residue in comparison to maize residues, the residues of mungbean can be a source of more mineral nitrogen to succeeding wheat crops than the residues of maize. This explanation is supported by Louarn *et al.* (2015). Stagnari *et al.* (2017) also noted that the inclusion of legumes in cropping systems increased P availability at the rhizosphere level. Similarly, according to Jensen *et al.* (2012), legume-based systems enhance the availability of N and P and organic carbon among other

characteristics of soil fertility.

The plot treated with 50% RDF + 50% Nano NPK fertilizers in the year 2020 and 2021 had the highest available P followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. This was true for all levels of fertilizer treatment. On the control plot, the lowest percentage of available P was observed in both years (2020 and 2021). The results from the mean data are comparable to those from 2020 (Table 4.1.25). The attainment of the highest available P in the harvested soil of maize, resulting from the synergy of 50% NPK fertilizers and 50% Nano NPK fertilizers, can be attributed through the cooperative application of NPK fertilizers and nanofertilizers, the phosphorus supply in the soil was likely finely tuned, benefiting from a harmonious use of P-rich fertilizers and the heightened efficiency of nanofertilizers in nutrient delivery. The nano-sized particles within the nanofertilizers may have interacted with soil components, impacting both the availability and retention of P, thereby contributing to an improvement in P levels within the harvested soil. Moreover, the optimized nutrient supply facilitated by nanofertilizers could have influenced the plant's uptake of P, leading to increased P levels in both the plants and the soil after harvest. The combined influence of NPK fertilizers and nanofertilizers may have played a pivotal role in mitigating P loss from the soil, whether through leaching or other processes, thereby contributing to the retention of higher available P levels in the harvested soil. Soliman *et al.* (2016) affirmed that the foliar application of nano P, along with traditional P fertilizer, met the P needs of plants at various stages in the soil cycle. Furthermore, they noted that the application of nanofertilizers through spraying enhanced the nutrient status in the soil following crop harvesting. According to Sahar *et al.* (2020), nano-NPK fertilizers have been found to substantially increase the NPK content in wheat. The use of nano-fertilizers promotes a gradual and controlled release of nutrients, consequently minimizing nutrient loss and improving overall nutrient utilization efficiency.

It was shown that there was significant interaction between the cropping system and the various fertilizer levels in 2020, 2021 and when the data were mean. The sole mungbean had the highest mean value of P when combined with 50% RDF + 50% Nano NPK fertilizers. The sole maize combined with the control had the lowest mean value of P. The pattern persisted, nevertheless, when the data were mean (Table 4.1.25b).

4.1.1.8.6. Available potassium (kg/ha)

When maize and mungbean were grown in both seasons, i.e., 2020 and 2021, or when the data was mean, the influence of different fertilizer levels and cropping techniques had a significant impact on the accessible K in the soil (Table 4.1.25). The effects of various fertilizer levels and cropping systems had a significant impact on the available K of soil when maize and mungbean were grown earlier in both seasons, i.e., 2020 and 2021, or when the data was mean (Table 4.1.25). Sole mungbean cropping results in the highest soil K content compared to maize and mungbean intercropping and maize cropping due to the mungbean ability to release organic acids through root exudation, facilitating the release of K from soil particles. The symbiotic relationship with N-fixing bacteria and reduced competition for potassium in sole mungbean cropping may have contributed to efficient potassium absorption. Additionally, the decomposition of mungbean residues adds potassium to the soil. According to Kakraliya *et al.* (2018); Bedoussac *et al.* (2015) the increasing significance of legume crops is apparent in their ability to improve crop productivity while simultaneously preserving soil fertility and environmental quality. As per Layek *et al.* (2018), pulses have the potential to counteract the declining production trend observed in continuous cereal-cereal systems by improving the chemical, biological, and physical conditions of the soil. Ghassan *et al.* (2017) noted that the enduring impacts of mungbean residue play a significant role in shaping the nutrient content of the soil. The findings suggest that mungbean residue is an effective means of enhancing soil fertility.

The plot where mungbean was cultivated as the sole crop in 2020 recorded the highest mean value of K that was accessible, followed by the plot where maize and mungbean were intercropped. In the year 2021, the highest available K was recorded in the plot where mungbean was grown as the sole crop followed by the plot where maize and mungbean were intercrops which were statistically at par with the plot where maize was cultivated as the sole crop. The least mean value of available K was found on the plot where maize was the only crop grown. A similar trend to that of data recorded in 2020 was observed when the data were mean. Attaining the peak levels of available K in harvested maize soil, arising from the amalgamation of 50% NPK fertilizers and 50% Nano NPK fertilizers can be attributed to the collaborative application of NPK fertilizers and

nanofertilizers, the finely tuned provision of K in the soil is a result of the balanced use of K-rich fertilizers and the heightened efficacy of nanofertilizers in nutrient delivery. Nano-sized particles within the nanofertilizers may have engaged with soil components, influencing the availability and retention of K, contributing to the enhancement of K levels in the harvested soil. Moreover, the optimized nutrient supply facilitated by nanofertilizers could have influenced the plants' uptake of K, leading to increased potassium levels in both plants and, subsequently, in the soil. The combination of NPK fertilizers and nanofertilizers may have played a role in diminishing K loss from the soil, reducing loss through leaching or other processes and contributing to higher available K levels in the harvested soil. The collaborative impact of NPK fertilizers and nanofertilizers might have enhanced the overall dynamics of K in the soil, encompassing improved retention, cycling, and availability, contributing to elevated available K content in the harvested soil. Rajonee *et al.* (2017) also observed increased accumulation of P and K in plants cultivated with nano fertilizer. The considerable and beneficial impact on available K resulting from the application of nanofertilizers may be attributed to the gradual release of nutrients over the course of crop growth. Nano fertilizer particles are coated with nano membranes that facilitate a slow and steady release of nutrients. These findings are consistent with the prior research of Pawar *et al.* (2017), who similarly reported a significant influence on soil available K. Sharma *et al.* (2022) also conveyed that nanofertilizers enhance soil fertility, creating a more favorable environment for crop growth. Similarly, Rahim *et al.* (2019), also reported that spraying nano fertilizer provided the best physicochemical properties of soil. Additionally, Azarpour *et al.* (2013) also informed that the usage of NPK nanofertilizers led to a substantial raise in available N, P and K content when compared to fertilizer levels without nano-fertilizer.

It was determined that in 2020 and 2021, as well as when the data were mean, there was no significant interaction between the cropping system and the different fertilizer levels on the available potassium.

Table 4.1.25.: Effect of cropping system and different levels of fertilizers on the available nitrogen, phosphorous, and potassium content of soil (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
A - Cropping System									
M₁	241.94 ^c	25.62 ^c	268.04 ^b	246.85 ^c	28.04 ^b	280.25 ^b	244.39 ^c	26.83 ^b	274.14 ^b
M₂	351.30 ^a	30.45 ^a	300.44 ^a	358.45 ^a	33.17 ^a	314.43 ^a	354.88 ^a	31.81 ^a	307.43 ^a
M₃	318.56 ^b	27.10 ^b	279.89 ^{ab}	325.03 ^b	29.55 ^b	292.89 ^b	321.80 ^b	28.33 ^b	286.39 ^{ab}
SEm (±)	5.05	0.43	5.91	5.81	0.46	4.94	5.43	0.45	5.59
CD(P=0.05)	19.82	1.70	23.20	22.82	1.82	19.38	21.32	1.75	21.93
B- Different levels of fertilizer									
S₁	242.35 ^d	18.63 ^d	193.97 ^c	247.27 ^d	18.52 ^d	200.31 ^d	244.81 ^c	18.58 ^c	197.14 ^c
S₂	316.21 ^b	31.04 ^b	319.51 ^a	322.63 ^b	34.49 ^b	335.49 ^{bc}	319.42 ^{ab}	32.77 ^b	327.50 ^b
S₃	290.99 ^c	27.35 ^c	292.49 ^b	296.90 ^c	30.39 ^c	307.11 ^c	293.95 ^{bc}	28.87 ^c	299.80 ^b
S₄	366.19 ^a	33.86 ^a	325.18 ^a	373.64 ^a	37.63 ^a	340.11 ^a	369.91 ^a	35.75 ^a	332.85 ^a
SEm (±)	5.06	0.51	5.47	5.17	0.52	10.27	5.12	0.51	7.92
CD(P=0.05)	15.03	1.52	16.25	15.37	1.54	30.51	15.20	1.52	23.54
Interaction (A x B)	S	S	NS	S	S	NS	S	S	NS

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.12.5a: Interaction between cropping system and different levels of fertilizers on the available nitrogen (kg/ha) of soil.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	208.82 ^h	238.65 ^g	221.65 ^g	298.31 ^e	213.06 ^h	243.49 ^g	226.48 ^g	304.37 ^e	210.94 ^h	241.07 ^g	224.22 ^g	301.34 ^e
M₂	259.86 ^f	375.87 ^{bc}	359.29 ^{cd}	410.20 ^a	265.14 ^f	383.50 ^{bc}	366.58 ^{cd}	418.59 ^a	262.50 ^f	379.69 ^{bc}	362.93 ^{cd}	414.39 ^e
M₃	245.22 ^g	334.11 ^d	304.88 ^e	390.05 ^{ab}	250.19 ^g	340.89 ^d	311.07 ^e	397.97 ^{ab}	247.71 ^g	337.50 ^d	307.97 ^e	394.01 ^{ab}
SEm (±)	8.76				8.96				8.86			
CD(P=0.05)	26.04				26.62				26.33			

Table 4.12.5b: Interaction between cropping system and different levels of fertilizers on the available phosphorous (kg/ha) of soil.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	15.02 ^g	29.08 ^{cd}	25.40 ^e	32.96 ^b	15.02 ^g	32.31 ^{cd}	28.22 ^e	36.62 ^b	15.02 ^g	30.70 ^{cd}	26.81 ^e	34.79 ^b
M₂	20.88 ^f	33.00 ^b	29.23 ^c	38.71 ^a	20.55 ^f	36.66 ^b	32.47 ^c	43.01 ^a	20.72 ^f	34.83 ^b	30.85 ^c	40.86 ^a
M₃	19.99 ^{fg}	31.05 ^c	27.43 ^{de}	29.92 ^c	19.99 ^{fg}	34.50 ^c	30.48 ^{de}	33.25 ^c	19.99 ^{fg}	32.77 ^c	28.96 ^{de}	31.59 ^c
SEm (±)	0.89				0.90				0.89			
CD(P=0.05)	2.64				2.67				2.64			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Maize (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2 MUNGBEAN

4.1.2.1 Growth Components

4.1.2.1.1 Plant height (cm)

The focus of the current study was on the impact of the cropping system and various fertilizer levels on the height of sole and intercrop mungbean plants during the *kharif* seasons of 2020 and 2021, as well as the mean data. As the plant approaches maturity in both the 2020 and 2021 growing seasons, the tallness of the plant gradually rises to the end of the study period. Maximum mungbean plant height was recorded with mungbean as the sole crop while minimum plant height was recorded when mungbean was intercropped with maize at all sampling periods (20 DAS, 40 DAS, 60 DAS, and at harvest) in both the years (2020 and 2021). When the statistics were mean, a comparable pattern was seen. This phenomenon may be attributed to the sole cropping system, where mungbean plants likely have unrestricted access to sunlight, facilitating optimal photosynthetic activity and resulting in increased height. In contrast, during intercropping with maize, the taller maize plants may cast shade on the mungbean, leading to reduced light availability and subsequently impeding growth. Moreover, heightened competition for nutrients in the soil occurs in intercropping with maize, as both crops may share similar nutrient requirements. This competition may limit the availability of essential nutrients for mungbean, impacting its overall growth and height. The release of allelopathic compounds by maize plants may further hinder the growth of neighboring mungbean plants, potentially contributing to the observed reduction in height in the intercropping scenario. Alterations in microclimate, including changes in wind patterns and humidity due to the presence of taller maize plants, could also adversely affect the conducive environment for mungbean growth, resulting in diminished plant height. Additionally, resource partitioning, where water, nutrients, and space are shared among different crops in intercropping systems, may create a suboptimal environment for mungbean, further influencing its reduced height compared to sole cropping. Likewise, various researchers have reported analogous findings, affirming that the efficient absorption and utilization of nutrients and soil water play a pivotal role in the enlargement of root systems, consequently leading to improved crop growth. These observations are particularly notable in the domain of legume and cereal intercropping, as highlighted in

studies conducted by Mao *et al.* (2012), Chen *et al.* (2017), and Li *et al.* (2020). Arshad *et al.* (2020) also observed that the height of mungbean was greater in a sole cropping system compared to its intercropping with maize.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the maximum plant height among different fertilizer levels at all sampling periods in both the years (2020 and 2021), followed by 100% RDF application and 100 % Nano NPK fertilizers. The lowest plant height was observed in control at all sampling periods in both the years. When the data were mean, similar data to those obtained in 2020 and 2021 were noted. The plot treated with combination of 50% RDF and 50% Nano NPK fertilizers consistently exhibited the highest plant height across various fertilizer levels during all sampling periods in both 2020 and 2021. This phenomenon can be ascribed to Nano NPK fertilizers characterized by their nanoscale size, which has the potential to augment nutrient absorption by plant roots. This enhancement may have contributed to improved nutrient availability, fostering optimal plant growth, and height augmentation. Furthermore, the controlled or slow-release attributes of Nano NPK fertilizers likely ensured a sustained nutrient supply to the plants, fostering continuous and steady growth. The combination of Nano NPK fertilizers with a reduced amount of conventional RDF (50%) may enhance overall nutrient use efficiency. This implies that a higher percentage of applied nutrients is efficiently utilized by the plants, thereby promoting robust growth. The observed synergistic effects resulting from the combination of Nano NPK fertilizers with conventional ones may have additionally contributed to improved plant performance and increased height. Similar significant conclusions were also stated by Rathore *et al.* (2022) they noted that, by using NPK nanofertilizers to the plant height and leaf area were raised. Shende *et al.* (2017) recounted similar outcomes in pigeon pea. Similarly, as documented by Sekhon (2014), the utilization of recommended dose of fertilizer (RDF) in combination with nano NPK fertilizers resulted in elevated values for plant height. Additionally, Sahar *et al.* (2020) also presented findings indicating that the increase in plant height was influenced by the foliar application of NPK nanofertilizers in conjunction with mineral NPK fertilizers. Additionally, Benzon *et al.* (2015) reported that the application of nano fertilizer resulted in a greater increase in plant height compared to the control. Furthermore, the combination of nano fertilizer with traditional methods, even at lower rates, exhibited a more

pronounced enhancement in plant height. These findings suggest that nano fertilizer can contribute to nutrient provision for the plants or facilitate the absorption of available nutrients, ultimately leading to improved crop growth. Noaema *et al.* (2019) recorded that the increase in plant height of broad bean could be ascribed to the positive influence of nano-fertilizers on the transfer of carbohydrates from source to sink. These nanofertilizers are proposed to impact the process of photosynthesis, induce chlorophyll production, and improve enzymatic efficiency, ultimately fostering vegetative growth, including an augmentation in plant height. Liang *et al.* (2013) reported similar results in tobacco plants through the use of nanofertilizers, corroborating the consistency of the findings presented.

In the years 2020 and 2021 as well as in the mean data, it was determined that the interaction between the cropping system and various fertilizer levels on plant height was found to be significant in 20 DAS and 60 DAS while in case of 60 DAS and at harvest it was found to be non-significant.

Table 4.2.1.: Effect of cropping system and different levels of fertilizers on the plant height (cm) of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A –Cropping system												
M ₂	25.46 ^a	49.10 ^a	57.45 ^a	58.63 ^a	26.56 ^a	51.07 ^a	59.13 ^a	60.67 ^a	26.01 ^a	50.09 ^a	58.41 ^a	59.65 ^a
M ₃	22.83 ^b	41.87 ^b	50.12 ^b	50.45 ^b	23.29 ^b	45.47 ^b	51.54 ^b	51.87 ^b	23.06 ^a	43.71 ^b	50.83 ^b	51.16 ^b
SEm (±)	0.14	0.63	0.87	1.07	0.41	0.77	0.90	1.07	0.41	0.70	0.88	1.07
CD (P=0.05)	2.49	3.83	5.28	6.51	2.48	4.68	5.47	6.48	2.48	4.26	5.37	6.50
B-Different levels of fertilizer												
S ₁	19.91 ^d	34.69 ^d	49.04 ^c	49.88 ^c	20.41 ^d	35.10 ^d	50.13 ^d	50.97 ^d	20.16 ^d	34.90 ^d	49.59 ^d	50.42 ^d
S ₂	26.14 ^b	49.52 ^b	55.48 ^a	56.40 ^a	26.80 ^b	52.57 ^b	57.21 ^b	57.63 ^b	26.47 ^b	51.05 ^b	56.35 ^b	57.02 ^b
S ₃	20.70 ^c	45.68 ^c	53.02 ^b	53.88 ^b	21.39 ^c	49.59 ^c	55.51 ^c	56.37 ^c	21.05 ^c	47.64 ^c	54.26 ^c	55.13 ^c
S ₄	29.83 ^a	52.05 ^a	57.57 ^a	58.00 ^a	31.09 ^a	56.03 ^a	59.00 ^a	60.10 ^a	30.46 ^a	54.04 ^a	58.29 ^a	59.05 ^a
SEm (±)	0.63	1.82	1.65	1.67	0.63	1.02	1.79	1.72	0.63	1.42	1.72	1.69
CD (P=0.05)	1.93	5.60	5.09	5.13	1.95	3.15	5.50	5.30	1.94	4.38	5.29	5.21
Interaction (Ax B)	S	S	NS	NS	S	S	NS	NS	S	S	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.2 Number of leaves

Table 4.2.2 shows the impact of the cropping system and different fertilizers levels on sole mungbean and intercrop mungbean no. of leaves during the 2020 and 2021 *kharif* seasons as well as the mean data. The mungbean grown as a sole crop produced the most leaves per plant during all sample periods. While the intercropping of mungbean with maize produced the fewest leaves per plant in both 2020 and 2021. A similar trend was observed when the data were mean. This difference can be attributed to the taller stature of maize in the intercropping system potentially resulted in shading, diminishing the amount of sunlight accessible to mungbean plants. Since leaves serve as primary sites for photosynthesis, reduced sunlight may have led to a decrease in leaf production in intercropped mungbean plants. Furthermore, the intercropping arrangement introduced resource competition, as different crops shared resources such as water, nutrients, and space. The presence of maize plants may have intensified this competition, limited the availability of essential resources and impeded leaf development in the mungbean. Additionally, potential allelopathic effects from maize plants and interactions between root systems could have influenced nutrient uptake and overall plant growth, contributing to the observed disparity in leaf production. Similarly, Onuh *et al.* (2011) reported a decrease in growth parameters in pure mungbean cultivation compared to the mungbean intercropping system. Furthermore, Khan *et al.* (2012) and Islam *et al.* (2018) stated comparable outcomes, indicating that maize intercropped with legumes had higher increases in growth metrics than sole mungbean.

Application of 50 % RDF + 50 % Nano NPK fertilizers to mungbean has produced the most no. of leaves at all sampling periods in both the growing years (2020 and 2021) followed by plot treated 100 % RDF and 100 % Nano NPK fertilizers while the least was noted in control plot at all sampling periods during 2020 and 2021 as well as when the data was mean. The application of a combined 50% recommended dose of fertilizer (RDF) and 50% Nano NPK fertilizers to mungbean, resulting in the highest number of leaves at all sampling periods in both growing years (2020 and 2021), can be attributed to the nanoscale size of Nano NPK fertilizers which may have enhance the absorption of nutrients by mungbean plants, promoting overall health and vigor and contributing to the

development of a greater number of leaves. Moreover, Nano NPK fertilizers often exhibit controlled or slow-release characteristics, ensuring a sustained and steady supply of nutrients to mungbean plants. This continuous nutrient availability may have supported prolonged and robust leaf production throughout the growing seasons. The combination of Nano NPK fertilizers with a reduced amount (50%) of conventional RDF may also improve the overall nutrient use efficiency, allowing a higher proportion of applied nutrients to be effectively utilized by the mungbean plants and fostering increased leaf development. The synergy between Nano NPK fertilizers and conventional ones in the 50% RDF + 50% Nano NPK combination may further enhance plant performance, positively influencing nutrient absorption, utilization, and, consequently, leaf production in the mungbean. Zaky *et al.* (2022) similarly reported that the combined application of NPK and Nano NPK significantly increased the number of leaves per plant in onions. These findings align with the results reported by Liu and Lal (2014), Aryanpour *et al.* (2017), Gosavi *et al.* (2017). Their studies highlighted the positive effects of foliar-applied nitrogen, phosphorus, and potassium in sustaining proper leaf nutrition, maintaining carbon balance, and enhancing photosynthetic capacity. Alyasari *et al.*, 2019 observed a comparable increase in plant height, leaf number, LA, and LAI by the application of nanofertilizers whereas control plants showed minimal growth characteristics. In cucumber cultivation, as reported by Merghany *et al.* (2019), the nano fertilizer NPK exhibited optimal growth characteristics. Significant enhancements in plant height, the number of leaves, and the percentage of nitrogen, phosphorus, and potassium (NPK) in leaves were observed.

The interaction between cropping system and various fertilizer levels on the number of leaves of sole and intercrop mungbean were recorded to be non-significant.

Table 4.2.2.: Effect of cropping system and different levels of fertilizers on the number of leaves of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A –Cropping system												
M ₂	25.18 ^a	37.22 ^a	48.45 ^a	44.58 ^a	27.33 ^a	39.41 ^a	49.51 ^a	46.54 ^a	26.63 ^a	38.31 ^a	48.98 ^a	48.03 ^a
M ₃	22.50 ^b	33.42 ^b	38.81 ^b	35.70 ^b	24.23 ^b	35.95 ^b	40.97 ^b	38.51 ^b	23.37 ^b	34.68 ^b	39.89 ^b	39.74 ^b
SEm (±)	0.38	0.52	1.14	0.69	0.51	0.56	0.80	0.77	0.39	0.54	0.97	0.73
CD (P=0.05)	2.32	3.14	6.94	4.21	3.08	3.38	4.86	4.68	2.36	3.26	5.90	4.45
B-Different levels of fertilizer												
S ₁	19.30 ^c	24.65 ^d	31.05 ^d	28.56 ^d	19.35 ^d	24.73 ^d	31.13 ^d	29.26 ^d	19.32 ^d	24.69 ^d	31.09 ^d	30.20 ^d
S ₂	25.72 ^b	38.33 ^b	50.91 ^b	46.83 ^b	28.69 ^b	41.46 ^b	52.56 ^b	49.40 ^b	27.20 ^b	39.89 ^b	51.73 ^b	50.98 ^b
S ₃	19.97 ^c	35.27 ^c	37.18 ^c	34.21 ^c	23.96 ^c	38.31 ^c	40.93 ^c	38.47 ^c	21.96 ^c	36.79 ^c	39.05 ^c	39.70 ^c
S ₄	30.37 ^a	43.02 ^a	55.38 ^a	50.95 ^a	31.13 ^a	46.22 ^a	56.34 ^a	52.96 ^a	30.75 ^a	44.62 ^a	55.86 ^a	54.65 ^a
SEm (±)	0.81	1.07	1.17	1.48	0.78	0.81	1.60	1.50	0.72	0.94	1.39	0.88
CD (P=0.05)	2.48	3.30	3.61	4.57	2.40	2.50	4.94	4.62	2.20	2.90	4.27	2.69
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.3. Number of branches/plant

Table 4.2.3 illustrates the impact of the cropping system and various fertilizer rates on the no. of branches/plant during the *kharif* seasons of 2020 and 2021 as well as the mean data. The no. of branches/plant of the mungbean is significantly impacted by the cropping system in both the years (2020 and 2021) and when data were mean. When mungbean was planted as the sole crop in 2020, a larger no. of branches/plant was seen, however a lower no. of branches/plant was observed when mungbean and maize were intercropped. A similar pattern was also seen in 2021 and in the mean statistics. Intercropping introduces competition for essential resources such as sunlight, water, and nutrients, where the taller maize plants have the potential to shade mungbean, leading to diminished sunlight availability. Consequently, mungbean reallocates its resources, resulting in a reduction in the no. of branches in response to the competitive environment. Additionally, resource partitioning in intercropping systems may induce a shift in resource allocation, with the presence of maize influencing mungbean to allocate fewer resources to branch development, prioritizing other aspects of growth. The release of allelopathic compounds by maize plants might further influence the branching pattern of mungbean in intercropping scenarios. The intrinsic growth dynamics specific to mungbean, favorable for branching when grown as a sole crop, may undergo alterations due to the presence of maize in an intercropping arrangement. Ro *et al.* (2023) similarly reported that the no. of branches per plant in mungbean was significantly influenced by the cropping systems. Likewise, Amanu *et al.* (2022) reported a significant impact of the cropping system on the no. of primary branches per plant, with a notable 46.9% reduction observed in the intercropping scenario. They explained that this reduction might be attributed to the presence of adverse shading effects and intense inter and intra-species competition for growth resources. Consistent with these findings, Onuh *et al.* (2011) also observed a higher no. of branches in mungbean plants grown in a sole cropping system compared to intercropping.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the most branches per plant out of all the levels of fertilizer treatments, followed by 100% RDF and 100% Nano NPK fertilizers, while the control plot had the fewest branches per plant. The outcomes were the same for the growth seasons of 2020 and 2021 as well as when the data were mean (Table 4.2.3). This observed pattern

can be attributed to the 50% RDF + 50% Nano NPK combination which likely might have provided a balanced and optimal supply of essential nutrients, promoted overall plant health and encouraged increased branching. The combination of conventional RDF and Nano NPK fertilizers may have synergized, improving nutrient uptake and utilization by the plants, contributing to enhanced branching. Moreover, Nano NPK fertilizers, known for their controlled release characteristics might have provided a sustained nutrient supply to the plants, supporting continuous growth and branching. The 50% RDF + 50% Nano NPK combination may have also enhanced nutrient use efficiency, meaning a higher proportion of applied nutrients was effectively utilized, promoting robust growth and branching. Similarly, Sahar *et al.* (2020) also presented data revealing that the augmentation of number of branches were influenced by foliar application of NPK nanofertilizers in combination with mineral NPK fertilizers. As reported by Sathyan in 2022, nanofertilizers exhibited substantial benefits in terms of the no. of branches and dry weight per plant at maturity compared to the control. The application of Zn also contributed to improved growth attributes over the control, primarily attributed to its direct and indirect roles in various physiological activities within the plant. Meena *et al.* (2023) similarly discovered that the application of a combination of recommended dose of nitrogen + recommended dose of phosphorus and potassium + nano nitrogen at 30 and 60 DAS resulted in the maximum consequential impact on all the growth and yield parameters of maize. Similarly, Mahewish *et al.* (2021) observed that Nano NPK application in Rosemary plants resulted in superior outcomes in terms of plant height and the no. of branches. Khater (2016) reported that the application of nanofertilizers in fennel plants resulted in the highest no. of branches. Hassani *et al.* (2015) additionally noted that in peppermint, the use of K nanofertilizers led to the highest no. of branches and leaves on the branches. Marimuthu and Surendran (2015) reported that the foliar spraying of nano formulations containing NPK, and a mixture of micronutrients increased both plant height and the no. of branches in black gram.

The interaction between cropping system and various fertilizer levels on the no. of branches/plant of sole and intercrop mungbean were recorded to be non-significant.

Table 4.2.3.: Effect of cropping system and different levels of fertilizers on the no. of branches/plant of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A –Cropping system												
M₂	1.72 ^a	2.73 ^a	3.71 ^a	3.74 ^a	2.02 ^a	2.79 ^a	3.88 ^a	3.99 ^a	1.87 ^a	2.75 ^a	3.76 ^a	3.80 ^a
M₃	1.51 ^b	2.43 ^b	3.37 ^b	3.40 ^b	1.81 ^b	2.45 ^b	3.49 ^a	3.57 ^a	1.66 ^a	2.44 ^a	3.43 ^b	3.48 ^b
SEm (±)	0.02	0.04	0.05	0.05	0.03	0.05	0.06	0.07	0.02	0.05	0.06	0.06
CD (P=0.05)	0.11	0.25	0.32	0.33	0.19	0.32	0.35	0.40	0.15	0.28	0.34	0.36
B-Different levels of fertilizer												
S₁	1.32 ^d	2.10 ^d	3.04 ^d	3.07 ^c	1.32 ^d	2.11 ^c	3.04 ^c	3.17 ^c	1.32 ^c	2.11 ^d	3.04 ^c	3.07 ^d
S₂	1.65 ^b	2.80 ^b	3.61 ^b	3.65 ^b	2.05 ^b	2.85 ^b	3.83 ^b	3.97 ^b	1.85 ^b	2.83 ^b	3.72 ^b	3.76 ^b
S₃	1.39 ^c	2.34 ^c	3.44 ^c	3.48 ^b	1.79 ^c	2.37 ^b	3.67 ^b	3.73 ^b	1.59 ^b	2.35 ^c	3.55 ^b	3.59 ^c
S₄	2.08 ^a	3.08 ^a	4.06 ^a	4.10 ^a	2.48 ^a	3.12 ^a	4.19 ^a	4.26 ^a	2.28 ^a	3.10 ^a	4.12 ^a	4.13 ^a
SEm (±)	0.05	0.15	0.08	0.11	0.07	0.15	0.10	0.13	0.06	0.15	0.09	0.12
CD (P=0.05)	0.15	0.48	0.25	0.35	0.23	0.46	0.32	0.42	0.19	0.47	0.28	0.38
Interaction (Ax B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.4 Leaf area (cm²)

Table 4.2.4 depicts the impact of the cropping system and various fertilizer levels on the Leaf Area (LA) of sole and intercrop mungbean during the *kharif* seasons of 2020 and 2021 along with the mean data. At all the sampling periods, the effect of the cropping system on sole and intercrop mungbean LA was noted to be significant in both years i.e., 2020 and 2021 and when data were mean. In the years 2020 and 2021, the maximum LA was recorded when mungbean was grown as the sole crop, while the minimum LA was noted when mungbean was intercropped with mungbean in all the sampling periods. A comparable pattern was noted when both the data were mean. The noteworthy influence of the cropping system on the leaf area of both sole cropped and intercropped mungbean, observed at all sampling periods in both 2020 and 2021, and when data were mean, can be attributed to the intercropping systems, competition for essential resources such as sunlight, water, and nutrients are heightened, impacting the development of mungbean leaf area. Resource partitioning among different crops in intercropping scenarios may have led to a redistribution of resources, affecting the allocation to leaf area development in mungbean. Additionally, the release of allelopathic compounds by certain crops, like maize, could have influence the growth of mungbean, including leaf area. The microclimate variations created by the presence of taller crops in the intercrop might also contribute to suboptimal conditions for leaf area development in mungbean. Increased competition for nutrients in the soil, as well as the consistent impact observed across two consecutive years, underscores the persistent influence of the cropping system on mungbean leaf area. The possible explanations could be associated with the augmentation in both the number and size of individual leaves, facilitated by sufficient moisture and space. Consistent with this finding, Lulie *et al.* (2016) and Assefa *et al.* (2018) reported significantly higher Leaf Area in sole haricot bean cultivation compared to intercropped haricot bean in maize/haricot bean intercropping.

The application of 50% RDF + 50% Nano NPK fertilizers produced the maximum leaf area followed by 100% RDF and 100% Nano NPK fertilizers, while the control consistently recorded the lowest LA during all sampling times and during all growth seasons, as well as when the data were mean. The application of a fertilizer combination comprising 50% RDF and 50% Nano NPK may result in the maximum leaf area due to the balanced nutrient supply from RDF

and Nano NPK, including essential elements like NPK, is conducive to overall plant growth, facilitating the expansion of leaves. Additionally, the smaller particle size of Nano NPK fertilizers can enhance nutrient availability and uptake efficiency, contributing to improved plant development and larger leaf area. The interaction between RDF and Nano NPK may create synergistic effects, optimizing nutrient utilization and promoting physiological processes such as photosynthesis. This synergistic action can lead to increased leaf area. The combination of fertilizers might also alleviate nutrient stress on plants, ensuring optimal growth conditions. Moreover, the overall improvement in soil health resulting from these fertilizers can create a favorable environment for plant growth, supporting root development and, consequently, an increase in leaf area. Sekhon *et al.* 2014 suggested that this effect could be attributed to the unique properties of nano-fertilizer, characterized by a larger surface area facilitating high absorption. This, in turn, leads to an increase in photosynthesis and expanded leaf area. These outcomes align with the observations made by Mohasedat *et al.* (2018) in apples. Verma *et al.* (2023) recorded that the application of NPK nano fertilizer augmented nutrient absorption and plant growth, evident in increased leaf count, expanded leaf area, and improved photosynthetic gas exchange in the leaves. Nofal *et al.* (2021) documented a 31% increase in leaf area when applying NPK nanofertilizers at half the recommended dose in lettuce. El-Rahman *et al.* (2022) documented that nitrogen fertilization in nano form had a substantial impact on leaf area as well as leaf nitrogen and potassium contents in both seasons. Moreover, El-Metwally *et al.* (2013) determined that pea growth components were considerably impacted by nano-fertilizers. Similar significant conclusions were also stated by Rathore *et al.* (2022) they noted that, by using NPK nanofertilizers to the plant height and leaf area were raised. Shende *et al.* (2017) recounted similar outcomes in pigeon pea.

At all sampling periods throughout the years (2020 and 2021) and when data were mean, the interaction between the cropping system and various fertilizer levels was found to be significant.

Table 4.2.4.: Effect of cropping system and different levels of fertilizers on the leaf area (cm²) of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A-Cropping system												
M₂	192.90 ^a	425.07 ^a	386.74 ^a	284.42 ^a	196.72 ^a	439.47 ^a	400.77 ^a	293.11 ^a	194.82 ^a	432.27 ^a	393.75 ^a	288.77 ^a
M₃	150.84 ^b	372.79 ^b	333.95 ^b	247.44 ^b	174.32 ^b	379.49 ^b	346.12 ^b	255.04 ^b	162.58 ^b	376.14 ^b	340.03 ^b	251.24 ^b
SEm (±)	3.14	7.27	8.36	4.84	3.23	6.09	6.33	3.98	3.28	6.68	7.34	4.41
CD (P=0.05)	19.10	44.21	50.87	29.42	20.85	37.06	38.51	24.24	19.98	40.64	44.69	26.83
B-Different levels of fertilizer												
S₁	124.25 ^c	268.16 ^d	240.21 ^d	189.76 ^d	126.42 ^c	272.96 ^d	249.06 ^d	195.57 ^d	125.34 ^d	270.56 ^d	244.63 ^d	192.66 ^d
S₂	206.24 ^b	441.65 ^b	395.61 ^b	286.47 ^b	209.77 ^b	449.55 ^b	410.07 ^b	295.24 ^b	208.06 ^b	445.60 ^b	402.84 ^b	290.85 ^b
S₃	126.89 ^c	398.44 ^c	356.97 ^c	264.71 ^c	129.66 ^c	405.65 ^c	369.93 ^c	272.81 ^c	149.32 ^c	402.04 ^c	363.45 ^c	268.76 ^c
S₄	230.11 ^a	487.47 ^a	448.60 ^a	322.79 ^a	234.06 ^a	509.77 ^a	464.73 ^a	332.68 ^a	232.08 ^a	498.62 ^a	456.66 ^a	327.73 ^a
SEm (±)	4.16	10.78	10.35	8.06	8.40	12.09	15.58	5.71	6.28	11.44	12.97	6.89
CD (P=0.05)	12.82	33.22	31.88	24.83	25.88	37.25	48.02	17.60	19.35	35.23	39.94	21.22
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.5 Leaf Area Index (LAI)

Table 4.2.5 displays the effects of the cropping pattern and various fertilizer levels on the LAI of sole and intercrop mungbean during the *kharif* seasons of 2020 and 2021 as well as the mean data. When mungbean was cultivated as the only crop during all sample periods, the maximum LAI was recorded; however, when mungbean was intercropped with mungbean in 2020 and 2021, as well as when data were mean, the least LAI was reported. When mungbean was intercropped with maize, the variations observed in LAI in comparison to the period when mungbean was grown as a sole crop throughout all sample periods can be ascribed to the intercropping practice. This intercropping method might have resulted in heightened competition between the two crops for essential resources such as sunlight, water, and nutrients. This heightened competition had the potential to impact the overall growth and development of both maize and mungbean, particularly in terms of their respective leaf area index. Additionally, the intercropped crops may have demonstrated complementary resource utilization, showcasing distinct requirements or utilization patterns that contributed to alterations in overall land-use efficiency. The presence of allelopathic effects from maize, where certain compounds released by maize had the potential to influence mungbean growth, could have also played a significant role in shaping the observed changes in leaf area index. Moreover, distinctions in crop management practices, encompassing factors like planting density, nutrient application, and irrigation, between the systems of sole cropping and intercropping, may have been pivotal contributors to the variations witnessed in leaf area index. Aydin *et al.* (2021) also noted that the LAI of sole soybean systems surpassed that of the maize-soybean intercropping system. The greater LAI observed in sole cropping situations may be attributed to the absence of inter-specific competition for growth resources. Zahed *et al.* (2015) reported divergent outcomes in the maize and crotalaria intercrop. They noted that during the R₁ maize growth stage, when the LAI was measured, crotalaria plants had recently exceeded the height of maize plants. This led the authors to infer an increased competition for light interception, potentially influencing the biomass partitioning process in maize crops and, consequently, impacting the grain yield in the maize/crotalaria intercrops. The factors contributing to this outcome could be associated with an augmentation in both the number and size of individual leaves, potentially stemming from sufficient

moisture and space. Consistent with this finding, Lulie *et al.* (2016) and Assefa *et al.* (2018) documented a markedly elevated LAI in exclusive haricot bean and common bean cultivation when contrasted with the intercropping of haricot bean and common bean with maize.

Regarding different fertilizer treatments, the control consistently noted the lowest LAI throughout the sampling period, in 2020 and 2021, as well as when the data were mean. The highest LAI was produced by the treatment of 50% RDF + 50% Nano NPK fertilizers, which was followed by 100% RDF and 100% Nano NPK fertilizers. The treatment combining 50% RDF with 50% Nano NPK fertilizers resulted in the highest LAI due to the combined treatment offered by the balanced nutrient supply, including essential elements like nitrogen, phosphorus, and potassium, fostering overall plant growth, particularly in leaf development. The smaller particle size of Nano NPK fertilizers may have enhanced nutrient availability and uptake efficiency, ensuring optimal nutrient supply for healthy plant growth and the expansion of the leaf area index. Synergistic effects between RDF and Nano NPK might have further optimized nutrient utilization, positively influencing physiological processes such as photosynthesis and, consequently, increasing leaf area index. Additionally, the treatment's potential to reduce nutrient stress on plants and improve nutrient use efficiency played roles in promoting larger leaf area index. As per the findings of Rajaseker *et al.* in 2017, the rise in leaf area index resulting from nanofertilizers application may be attributed to the swift delivery of nutrients introduced through foliar spraying. This process, involving stomata or leaf damage, facilitates rapid nutrient transport to cells. Consequently, it enhances the speed and consistency of nutrient supply crucial for various plant metabolic processes. The maximum LAI value was noted in the treatment involving Recommended Dose of Fertilizers (RDF) of NPK, along with foliar application of nano-N and nano-Zn, at all observation dates. This outcome aligns with comparable findings reported by Seleiman *et al.* (2020), Moghaddasi *et al.* (2017), Tarafdar *et al.* (2014), and Monreal *et al.* (2016).

At all sampling periods throughout the years (2020 and 2021) and when data were mean, the interaction between the cropping system and various fertilizer levels was found to be significant.

Table 4.2.5.: Effect of cropping system and different levels of fertilizers on the leaf area index of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A –Cropping system												
M ₂	1.29 ^a	2.83 ^a	2.58 ^a	1.90 ^a	1.31 ^a	2.93 ^a	2.67 ^a	1.95 ^a	1.30 ^a	2.90 ^a	2.63 ^a	1.93 ^a
M ₃	1.01 ^b	2.49 ^b	2.23 ^b	1.65 ^b	1.16 ^b	2.53 ^b	2.31 ^b	1.70 ^b	1.08 ^b	2.51 ^b	2.27 ^b	1.67 ^b
SEm (±)	0.02	0.05	0.06	0.03	0.02	0.04	0.04	0.03	0.03	0.05	0.04	0.03
CD (P=0.05)	0.13	0.31	0.18	0.20	0.16	0.27	0.23	0.17	0.19	0.29	0.19	0.17
B-Different levels of fertilizer												
S ₁	0.83 ^c	1.79 ^d	1.60 ^d	1.27 ^d	0.84 ^c	1.82 ^d	1.66 ^d	1.30 ^c	0.84 ^d	1.80 ^d	1.63 ^d	1.28 ^d
S ₂	1.37 ^b	2.94 ^b	2.64 ^b	1.91 ^b	1.40 ^b	3.00 ^b	2.73 ^b	1.97 ^b	1.39 ^b	2.97 ^b	2.69 ^b	1.94 ^b
S ₃	0.85 ^c	2.66 ^c	2.38 ^c	1.76 ^c	1.15 ^b	2.70 ^c	2.47 ^c	1.82 ^b	1.00 ^c	2.68 ^c	2.42 ^c	1.79 ^c
S ₄	1.53 ^a	3.25 ^a	2.99 ^a	2.15 ^a	1.56 ^a	3.40 ^a	3.10 ^a	2.22 ^a	1.55 ^a	3.37 ^a	3.04 ^a	2.18 ^a
SEm (±)	0.02	0.06	0.04	0.06	0.06	0.07	0.05	0.06	0.05	0.07	0.06	0.05
CD (P=0.05)	0.11	0.18	0.15	0.17	0.19	0.22	0.17	0.18	0.15	0.22	0.18	0.17
Interaction (Ax B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, DAS= Days after sowing, RDF= Recommended dose of fertilizers, M₂= Mungbean (sole), M₃= Maize + Mungbean (inter-cropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.6 Shoot dry weight (g)

Table 4.2.6 illustrates the impact of the cropping system and various fertilizer levels on the shoot dry weight of sole and intercrop mungbean. The cropping system had a significant effect on the shoot dry weight of mungbean at all sampling intervals in both growing years, as well as in the mean data analysis. The maximum shoot dry weight was observed when mungbean was grown as the sole crop across all sampling periods. Conversely, the lowest shoot dry weight was recorded when mungbean was intercropped with maize in both the 2020 and 2021 sampling seasons, as well as in the mean data. This difference can be attributed to intercropping, a practice that often introduces heightened competition among crops for essential resources such as sunlight, water, and nutrients. This heightened competition has the potential to limit the growth and shoot dry weight of individual plants. Furthermore, the dynamics of complementary resource utilization in intercropping systems might not have sufficiently offset the negative impacts of resource competition, leading to a reduction in shoot dry weight. The presence of allelopathic effects from other crops in the intercropping system could also have negatively influenced the shoot dry weight of mungbean. The effective absorption and utilization of nutrients and soil water contributes to the expansion of root systems, resulting in enhanced crop growth. This improvement is evident in increased growth and yield parameters, particularly in the context of legume and cereal intercropping (Mao *et al.* 2012; Chen *et al.* 2017; Li *et al.* 2020).

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest shoot dry weight across all sample periods, followed by 100% RDF + 100% Nano NPK fertilizers in both the 2020 and 2021 growing seasons. In both the year 2020 and 2021, i.e., during all sample intervals, the least shoot dry weight was noted in the control. When both seasons' data were mean, the trend was similar. The plot treated with 50% RDF + 50% Nano NPK fertilizers exhibited the highest shoot dry weight across all sample periods due to the combination of RDF and Nano NPK which provided a balanced and efficient nutrient supply, including essential elements like N, P, and K, which promoted optimal plant growth and contributed to the increased shoot dry weight. The smaller particle size of Nano NPK fertilizers may have enhanced nutrient availability and uptake efficiency, ensuring that plants receive an optimal supply of nutrients for healthy growth and development. Additionally, the synergistic effects between RDF and Nano NPK

optimized nutrient utilization, positively influencing physiological processes such as photosynthesis, ultimately might have led to a higher shoot dry weight. The improved nutrient use efficiency and reduced nutrient stress on plants in the combined treatment further might have contributed to the observed increase in shoot dry weight. Vadlamudi *et al.* (2022) found that the highest values dry matter production of sunflower at 90 DAS were recorded in both years and on average when conventional fertilizers were applied at the recommended dose along with foliar application of nano NPK at 0.2% at 30 DAS and 60 DAS. Alhasan *et al.* (2021) reported that the utilization of NPK nano-fertilizer resulted in a substantial increase in plant height, dry weight of vegetative biomass, and essential oil production in sweet basil. Sharaf-Eldin *et al.* (2022) documented that the application of a nano nitrogen fertilizer, alongside a conventional fertilizer, in two crop cycles resulted in an increased plant weight for lettuce. Seleiman *et al.* (2020) documented that the utilization of nanofertilizers exerted a notable impact on dry matter production. Across all treatments, plants exhibited a consistent increasing trend in dry matter production up to the harvesting stage. Similarly, in Peppermint (*Mentha piperita* L.), the utilization of nanofertilizers led to the highest recorded values for both the number of wet and dry weights of the plant, as reported by Hassani *et al.* (2015).

In all the sampling periods in 2020 and 2021, as well as when the data from both seasons were mean, the interaction between the cropping system and different fertilizer levels was significant (Table 4.1.6a, 4.1.6b, 4.1.6c, and 4.1.6d). The sole mungbean coupled with 50% RDF + 50% Nano NPK fertilizers had the highest mean value of shoot dry weight in all sampling periods (20 DAS, 40 DAS, 60 DAS, and at harvest), but the intercrop mungbean coupled with control had the lowest mean value throughout the growing years and when data were mean.

Table 4.2.6.: Effect of cropping system and different levels of fertilizers on the shoot dry weight(g/plant) of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A –Cropping system												
M ₂	2.55 ^a	7.16 ^a	14.57 ^a	18.79 ^a	2.67 ^a	7.52 ^a	15.37 ^a	20.17 ^a	2.61 ^a	7.34 ^a	14.97 ^a	19.48 ^a
M ₃	2.17 ^b	6.35 ^b	13.28 ^b	16.60 ^b	2.26 ^b	6.67 ^b	14.01 ^b	17.81 ^b	2.22 ^b	6.51 ^b	13.65 ^b	17.21 ^b
SEm (±)	0.05	0.07	0.11	0.95	0.06	0.09	0.12	0.98	0.06	0.08	0.11	0.97
CD (P=0.05)	0.17	0.43	0.68	1.65	0.20	0.45	0.72	1.69	0.19	0.44	0.70	1.67
B-Different levels of fertilizer												
S ₁	1.81 ^d	4.24 ^d	8.23 ^c	9.87 ^d	1.85 ^d	4.45 ^d	8.68 ^c	10.59 ^d	1.83 ^d	4.34 ^d	8.45 ^c	10.23 ^d
S ₂	2.76 ^b	8.05 ^b	16.61 ^a	21.12 ^b	2.82 ^b	8.45 ^b	17.52 ^a	22.66 ^b	2.79 ^b	8.25 ^b	17.06 ^a	21.89 ^b
S ₃	1.84 ^c	6.06 ^c	13.25 ^b	17.45 ^c	2.11 ^c	6.36 ^c	13.98 ^b	18.72 ^c	1.98 ^c	6.21 ^c	13.61 ^b	18.09 ^c
S ₄	3.03 ^a	8.68 ^a	17.62 ^a	22.35 ^a	3.09 ^a	9.11 ^a	18.59 ^a	23.98 ^a	3.06 ^a	8.89 ^a	18.11 ^a	23.17 ^a
SEm (±)	0.03	0.06	0.53	0.60	0.05	0.09	0.80	0.91	0.06	0.08	0.66	0.76
CD (P=0.05)	0.15	0.18	1.16	1.29	0.17	0.21	1.27	1.31	0.18	0.20	1.22	1.30
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.6a: Interaction between cropping systems and different fertilizer levels on the shoot dry weight (g/plant) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

20DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	1.84 ^d	3.24 ^a	1.86 ^c	3.27 ^a	1.88 ^d	3.30 ^a	2.15 ^c	3.34 ^a	1.86 ^d	3.27 ^a	2.01 ^c	3.30 ^a
M ₃	1.77 ^d	2.29 ^c	1.82 ^d	2.78 ^b	1.81 ^d	2.34 ^c	2.06 ^{cd}	2.84 ^b	1.79 ^d	2.32 ^c	1.94 ^{cd}	2.81 ^b
SEm (±)	0.08				0.09				0.08			
CD(P=0.05)	0.24				0.29				0.27			

Table 4.2.6b: Interaction between cropping systems and different fertilizer levels on the shoot dry weight (g/plant) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

40DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	4.49 ^e	8.24 ^a	6.46 ^c	8.99 ^a	4.72 ^e	8.58 ^a	6.78 ^c	9.44 ^a	4.61 ^e	8.41 ^a	6.62 ^c	9.21 ^a
M ₃	3.98 ^e	7.47 ^b	5.66 ^d	8.36 ^a	4.18 ^e	7.77 ^b	5.94 ^d	8.78 ^a	4.08 ^e	7.62 ^b	5.80 ^d	8.57 ^b
SEm (±)	0.18				0.24				0.21			
CD(P=0.05)	0.73				0.90				0.82			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.6c: Interaction between cropping systems and different fertilizer levels on the shoot dry weight (g/plant) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

60DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	8.60 ^e	14.40 ^c	13.93 ^c	18.32 ^a	9.07 ^e	15.11 ^c	14.69 ^c	19.33 ^a	8.84 ^e	14.76 ^c	14.31 ^c	18.82 ^a
M ₃	7.85 ^e	13.28 ^{cd}	12.57 ^d	16.92 ^b	8.28 ^e	13.92 ^d	13.26 ^d	17.85 ^b	8.07 ^e	13.60 ^d	12.92 ^d	17.38 ^b
SEm (±)	0.74				0.80				0.77			
CD(P=0.05)	1.23				1.34				1.29			

Table 4.2.6d: Interaction between cropping systems and different fertilizer levels on the shoot dry weight (g/plant) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

At harvest	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	10.47 ^f	17.20 ^{cd}	18.49 ^{bc}	23.69 ^a	11.23 ^f	18.35 ^{cd}	19.85 ^{bc}	25.42 ^a	10.85 ^f	17.78 ^{cd}	19.17 ^{bc}	24.55 ^a
M ₃	9.27 ^g	15.40 ^e	16.40 ^{de}	21.01 ^b	9.94 ^g	16.42 ^e	17.60 ^{de}	22.55 ^b	9.61 ^g	15.91 ^e	17.00 ^{de}	21.77 ^b
SEm (±)	0.88				0.94				0.91			
CD(P=0.05)	1.73				1.90				1.82			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.7 Days to 50% flowering

The impact of the cropping system and various levels of fertilizers on the days to 50% flowering of sole and intercrop mungbean during the 2020 and 2021 *kharif* seasons and when data was mean are shown in Table 4.2.7. The cropping system exhibited no statistically significant impact on the number of days to reach 50% flowering in both the years 2020 and 2021. When the data were mean and analyzed collectively, no notable differences were observed.

Application of different levels of fertilizer to mungbean significantly affected the days to 50% flowering in both seasons (2020 and 2021). Plots treated with 50 % RDF + 50 % Nano NPK fertilizers took most days to attain 50% flowering followed by 100 % NPK fertilizers and 100 % Nano NPK fertilizers in both seasons (2020 and 2021) and when data was mean. In both seasons (2020 and 2021) and when data were mean, the control plot took the least days to reach 50% flowering. The application of different levels of fertilizer to mungbean had a significant impact on the days to 50% flowering in both seasons (2020 and 2021). The plots treated with 50% RDF + 50% Nano NPK fertilizers took the most days to attain 50% flowering, followed by those treated with 100% NPK fertilizers and 100% Nano NPK fertilizers in both seasons. This variation in flowering time can be explained by the different nutrient compositions and release patterns of the fertilizers. The 50% RDF + 50% Nano NPK treatment, despite containing a recommended dose of fertilizers, may have exhibited a slower release of nutrients due to the presence of Nano NPK, leading to a delayed onset of flowering. The combination of RDF and Nano NPK may have influenced nutrient availability and uptake efficiency, affected the plant's physiological processes and ultimately delayed the flowering stage. In contrast, the plots treated with 100% NPK and 100% Nano NPK fertilizers likely provided a more readily available and abundant supply of nutrients, promoting faster growth and development. This resulted in an earlier attainment of the 50% flowering stage compared to the 50% RDF + 50% Nano NPK treatment. According to findings by Sharma *et al.* (2023), a prolonged duration to reach 50% flowering was observed with the application of fertilizers along with a single combined spray of nanofertilizers during both years. Similarly, in the study conducted by Amirnia *et al.* (2014), it was reported that applying nanofertilizers containing P and K to Saffron had a beneficial impact on both flowering and yield. Similarly, Sabaghnia and Janmohammadi (2023)

reported that the treatment combinations involving nano-chelated fertilizers exhibited superior performance in terms of the number of days required to reach 50% flowering in chickpea.

The interaction between the cropping system and different levels of fertilizers in both the years (2020 and 2021) and mean data was significant. In the year, 2021 and when data were mean, the highest mean value of 50% flowering was recorded in sole mungbean combined with 50 % RDF + 50 % Nano NPK fertilizers whereas, the lowest mean value was recorded when intercrop mungbean combined with control (Table 4.2.7a).

4.1.2.1.8 Days to 90 % maturity

The influence of the cropping system and different levels of fertilizers on the days to 90% maturity of sole and intercrop mungbean during the 2020 and 2021 *kharif* seasons and when data was mean are shown in Table 4.2.7. The cropping system exhibited no statistically significant impact on the number of days to reach 90% maturity in both the years 2020 and 2021. When the data were average and analyzed collectively, no notable differences were observed.

In both seasons (2020 and 2021) fertilizer levels had a significant impact. The application of 50% RDF + 50% Nano NPK fertilizers required more days to reach 90% maturity, followed by 100% RDF and 100% Nano NPK fertilizers, and so forth in both the years (2020 and 2021) and when the data were mean. The lowest no. of days taken for 90% maturity was noted in the control plot in both seasons (2020 and 2021) and when the data were mean (Table 4.2.7).

The extended duration for reaching 90% maturity with the application of 50% RDF + 50% Nano NPK fertilizers, followed by 100% RDF and 100% Nano NPK fertilizers in both years, and when the data were mean, can be ascribed to the Nano NPK fertilizers, known for their controlled nutrient release due to smaller particle size, might result in a gradual nutrient availability, impacting the growth and maturation rate. The balanced nutrient uptake from the combined 50% RDF and 50% Nano NPK treatment, while beneficial for overall plant health, might prolong the time needed for the plant to attain maturity compared to treatments with higher percentages of readily available nutrients. Synergistic effects between RDF and Nano NPK could optimize nutrient utilization but may take more time to manifest in terms of plant maturation. Specific physiological responses of plants to the 50% RDF + 50% Nano NPK treatment, influencing factors such as

root development and nutrient assimilation, may contribute to a slower maturation process. Additionally, environmental conditions during the growing seasons, including temperature, sunlight, and moisture availability, might have played a role in influencing the rate of maturation. In a similar vein, Ashenafi *et al.* (2023) asserted that, in contrast to the conventional recommendation, the use of nanofertilizers reduces the number of days required to reach 90% physiological maturity in maize. The results of this study align with the findings of Redda and Abay in 2015. Their research indicated that the application of a larger fertilizer dose was associated with an extended duration to reach physiological maturity. This result contradicts the findings of Hailu *et al.* in 2016 and Tekulu *et al.* in 2019, who asserted that maturity is significantly influenced by the application of nanofertilizers. In direct opposition to the control group, which took the longest time to reach maturity, shorter maturity days were observed with the use of nanofertilizers-blended fertilizer.

In 2020 and 2021 and in the mean data, there was a significant interaction between the cropping system and various fertilizer levels. The plot where sole mungbean was treated with 50% RDF and 50% Nano NPK fertilizers took the longest to reach 90% maturity. However, the intercropped mungbean plot in combination with the control took the shortest day taken for 90% maturity (Table 4.2.7b).

Table 4.2.7: Effect of cropping system and different levels of fertilizers on the days to 50% flowering and days to 90% maturity of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Days to 50% flowering	Days to 90% maturity	Days to 50% flowering	Days to 90% maturity	Days to 50% flowering	Days to 90% maturity
A –Cropping system						
M₂	53.24	73.71	54.04	74.31	53.64	74.03
M₃	52.69	73.45	53.48	74.29	53.09	73.89
SEm (±)	0.84	0.86	0.86	0.96	0.85	0.91
CD (P=0.05)	NS	NS	NS	NS	NS	NS
B-Different levels of fertilizer						
S₁	50.41 ^c	70.23 ^d	51.17 ^c	71.12 ^c	50.79 ^c	70.69 ^d
S₂	54.40 ^a	75.39 ^b	55.22 ^a	76.07 ^a	54.81 ^a	75.75 ^b
S₃	51.93 ^b	71.75 ^c	52.70 ^b	72.27 ^b	52.32 ^b	72.03 ^c
S₄	55.13 ^a	76.96 ^a	55.96 ^a	77.72 ^a	55.54 ^a	77.36 ^a
SEm (±)	0.41	0.47	0.61	0.70	0.51	0.58
CD (P=0.05)	1.27	1.30	1.87	2.13	1.57	1.71
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.7a: Interaction between cropping systems and different fertilizer levels on the days to 50 % flowering of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₂	50.82 ^e	54.87 ^b	52.23 ^d	55.05 ^a	51.58 ^e	55.69 ^b	53.01 ^d	55.88 ^a	51.20 ^e	55.28 ^b	52.62 ^d	55.46 ^a
M₃	50.01 ^f	53.94 ^b	51.62 ^c	55.21 ^a	50.76 ^f	54.75 ^b	52.40 ^c	56.03 ^a	50.38 ^f	54.35 ^b	52.01 ^c	55.62 ^a
SEm (±)	0.27				0.44				0.36			
CD(P=0.05)	1.30				1.53				1.51			

Table 4.2.7b: Interaction between cropping systems and different fertilizer levels on the days to 90 % flowering of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₂	70.71 ^e	75.38 ^c	71.78 ^d	76.97 ^a	71.16 ^c	76.06 ^b	72.28 ^c	77.72 ^a	70.95 ^c	75.74 ^b	72.05 ^c	77.36 ^a
M₃	69.74 ^f	75.40 ^c	71.72 ^d	76.94 ^b	71.09 ^c	76.08 ^b	72.26 ^c	77.71 ^a	70.44 ^d	75.76 ^b	72.01 ^c	77.1 ^a
SEm (±)	0.35				0.56				0.45			
CD(P=0.05)	1.41				1.72				1.57			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.9. Crop growth rate (g/m²/day)

The impact of the cropping system and different fertilizers levels on the Crop Growth Rate (CGR) of sole and intercrop mungbean is given in Table 4.2.8. In 2020, at all the sampling periods, a higher CGR was recorded when mungbean was grown as the sole crop, while a lower CGR was recorded when mungbean was intercropped with mungbean. A similar result was also observed in the year 2021 and when the data were mean. The higher CGR consistently recorded when mungbean was cultivated as a sole crop, in contrast to the lower CGR observed when mungbean was intercropped with mungbean, can be attributed to the intercropping systems, competition for essential resources such as sunlight, water, and nutrients intensifies, resulting in a reduction in CGR when mungbean is grown in close proximity to itself. The spatial arrangement of plants in intercropping scenarios may limit individual plants' access to sunlight, influencing their growth and CGR. Additionally, allelopathic effects, where compounds released by mungbean plants inhibit the growth of neighboring mungbean plants, could contribute to the observed lower CGR in intercropping situations. Resource partitioning among the same crop species and differences in plant density in intercropping systems may further impact the overall efficiency of resource utilization and CGR. Exploring adjustments in planting arrangements, resource management, or considering alternative intercropping combinations could be essential for optimizing CGR in such scenarios. Likewise, as reported by Kebede in 2021, the highest CGR for faba bean was observed in both sole faba bean cultivation and in faba bean intercropped with wheat. Similarly, in the study conducted by Amanullah *et al.* in 2021, it was observed that sole cultivation of mungbean and pigeon pea resulted in higher CGR. Conversely, the intercropping of mungbean and pigeon pea with cereals, specifically millet and sorghum, led to a suppression of their respective CGR.

In the case of different levels of fertilizer treatments, the plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the maximum CGR at all sampling periods followed by 100 % RDF and 100 % Nano NPK fertilizers in both seasons 2020 and 2021 while, the least CGR was observed in control at all sampling periods in both the years and when the data were mean. Conversely, the control group consistently showed the least CGR at all sampling periods in both years (2020 and 2021) and when the data were mean. The reasons for these observations

can be explained by factors such as the optimal nutrient supply facilitated by the 50% RDF + 50% Nano NPK treatment proved effective in providing an optimal and balanced nutrient supply, fostering robust plant growth across different developmental stages. The synergistic effects between RDF and Nano NPK fertilizers in the 50% treatment potentially might have enhanced nutrient utilization and physiological processes, contributing to the observed maximum CGR. In contrast, the 100% RDF and 100% Nano NPK treatments, while supplying sufficient nutrients, may not have optimized nutrient release as efficiently as the 50% RDF + 50% Nano NPK combination, resulting in slightly lower CGR. Conversely, the control group's consistently lower CGR was attributed to the absence of external fertilizer inputs, leading to nutrient deficiencies that restricted overall plant growth potential. The lack of supplemental nutrients in the control group underscored the importance of external fertilization in influencing crop growth rates. Sathyan in 2022, also documented that the highest crop growth rate in field peas was observed in treatments where nano nutrients were administered. Likewise, as indicated by Choudhary *et al.* in 2023, the application of foliar spray containing combination of chemical and nanofertilizers led to an enhancement of the crop growth rate during both years. This improvement is suggested to be associated with elevated levels of growth-promoting chemicals and naturally occurring phytohormones, facilitated by the increased supply of nitrogen. These positive effects may be linked to the early and abundant availability of nitrogen, substantiated by the improved nutritional status of plants at different growth stages. Consequently, this created a superior nutritional environment conducive to the growth and development of the root zone. In addition, Salama *et al.* (2022), determined that the use of nanofertilizers increased pea growth parameters, CGR, and RGR.

The interaction with cropping systems and various levels of fertilizers are reported to be significant in both the growing years as well as when the data were mean. In all the sampling periods, the highest value of crop growth rate was acquired in sole mungbean combined with 50 % RDF + 50 % Nano NPK fertilizers while the lowest mean value of crop growth rate was acquired in intercrop mungbean coupled with control in both the 2020 and 2021 growing seasons as well as when the data were mean (Table 4.2.8a, 4.2.8b and 4.2.8c).

Table 4.2.8.: Effect of cropping system and different levels of fertilizers on the crop growth rate (g/m²/day) of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	20-40 DAS	40-60 DAS	60DAS-at harvest	20-40 DAS	40-60 DAS	60DAS-at harvest	20-40 DAS	40-60 DAS	60DAS-at harvest
A –Cropping system									
M ₂	0.767 ^a	1.235 ^a	0.704 ^a	0.808 ^a	1.309 ^a	0.799 ^a	0.787 ^a	1.272 ^a	0.752 ^a
M ₃	0.697 ^b	1.155 ^b	0.553 ^b	0.734 ^b	1.224 ^b	0.633 ^b	0.715 ^b	1.189 ^b	0.593 ^b
SEm (±)	0.011	0.010	0.010	0.019	0.011	0.016	0.018	0.010	0.014
CD (P=0.05)	0.067	0.060	0.053	0.069	0.070	0.064	0.068	0.065	0.059
B-Different levels of fertilizer									
S ₁	0.405 ^d	0.665 ^c	0.274 ^d	0.434 ^d	0.705 ^c	0.318 ^c	0.419 ^d	0.685 ^c	0.296 ^d
S ₂	0.880 ^b	1.427 ^a	0.752 ^b	0.938 ^b	1.512 ^a	0.857 ^a	0.909 ^b	1.469 ^a	0.804 ^b
S ₃	0.702 ^c	1.198 ^b	0.700 ^c	0.709 ^c	1.269 ^b	0.791 ^b	0.705 ^c	1.234 ^b	0.746 ^c
S ₄	0.942 ^a	1.491 ^a	0.788 ^a	1.003 ^a	1.580 ^a	0.899 ^a	0.972 ^a	1.536 ^a	0.844 ^a
SEm (±)	0.014	0.035	0.009	0.013	0.039	0.012	0.012	0.037	0.011
CD (P=0.05)	0.042	0.116	0.035	0.060	0.119	0.037	0.058	0.118	0.036
Interaction (A x B)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.8a: Interaction between cropping systems and different fertilizer levels on the crop growth rate (g/m²/day) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

20-40DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	0.442 ^f	0.909 ^b	0.766 ^d	0.953 ^a	0.473 ^f	0.970 ^b	0.772 ^d	1.017 ^a	0.457 ^f	0.938 ^b	0.769 ^d	0.985 ^a
M ₃	0.368 ^g	0.852 ^c	0.639 ^e	0.930 ^a	0.395 ^g	0.905 ^c	0.646 ^e	0.990	0.381 ^g	0.878 ^c	0.642 ^e	0.960 ^a
SEm (±)	0.016				0.017				0.016			
CD(P=0.05)	0.050				0.054				0.053			

Table 4.2.8b: Interaction between cropping systems and different fertilizer levels on the crop growth rate (g/m²/day) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

40-60DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	0.685 ^e	1.456 ^b	1.244 ^c	1.555 ^a	0.726 ^e	1.544 ^b	1.318 ^c	1.649 ^a	0.705 ^e	1.500 ^b	1.281 ^c	1.602 ^a
M ₃	0.645 ^e	1.397 ^b	1.152 ^d	1.426 ^b	0.684 ^e	1.480 ^b	1.220 ^d	1.512 ^b	0.664 ^e	1.438 ^b	1.186 ^d	1.496 ^b
SEm (±)	0.017				0.020				0.019			
CD(P=0.05)	0.062				0.074				0.068			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.8c: Interaction between cropping systems and different fertilizer levels on the crop growth rate (g/m²/day) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

60DAS-At harvest	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	0.311 ^f	0.848 ^b	0.762 ^c	0.895 ^a	0.360 ^f	0.963 ^b	0.859 ^d	1.015 ^a	0.336 ^f	0.906 ^b	0.810 ^c	0.955 ^a
M ₃	0.236 ^g	0.655 ^e	0.639 ^e	0.682 ^d	0.277 ^g	0.751 ^e	0.724 ^e	0.783 ^c	0.256 ^g	0.703 ^e	0.681 ^e	0.732 ^d
SEm (±)	0.010				0.014				0.012			
CD(P=0.05)	0.041				0.047				0.044			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.1.10 Relative growth rate (g/g/day)

Table 4.2.9 displays the influence of cropping systems and various fertilizer levels on the Relative Growth Rate (RGR) of sole and intercrop mungbean. The results indicate that, in both the 2020 and 2021 seasons, the cropping system did not have a statistically significant impact on the RGR of either sole or intercrop mungbean during all sampling intervals.

In the case of different levels of fertilizer treatments, the plot treated with 100% Nano NPK had the maximum RGR at all sampling periods (20-40 DAS, 40-60 DAS, and 60 DAS-harvest) while the control showed the lowest RGR in all the sampling periods. The result obtained was true for both the growing years (2020 and 2021) as well as when the data were mean. This observation can be attributed to several factors associated with the specific characteristics of the Nano NPK treatment. The 100% Nano NPK treatment provided a concentrated and readily available source of essential nutrients, including N, P and K. This immediate and targeted nutrient supply likely facilitated optimal plant growth and development throughout the various growth stages, resulting in a consistently higher RGR compared to other treatments. Conversely, the control group, devoid of external fertilizer inputs, experienced a lack of essential nutrients, leading to suboptimal plant growth and the lowest RGR across all sampling periods. The absence of supplemental nutrients in the control treatment limited the overall growth potential, emphasizing the importance of external fertilization in influencing the relative growth rates of plants. Similarly, Sathyan in 2022, stated that the highest relative growth rate in field peas was observed in the plot treated with nano nutrients, demonstrating a significant difference compared to other treatments. Likewise, as proposed by Hassnein *et al.* (2019), the observed increase in the RGR in sugar beet plants treated with nano nitrogen can be linked to the promotion of growth and an augmentation in the total plant weight during the 60–90-day period from the sowing date. This phenomenon ultimately contributed to the upsurge in the relative growth rate. These conclusions are consistent with the findings reported by El-Azizy and colleagues (2021) who reported a parallel outcome in broad beans, noting that the application of nano-fertilizer resulted in improved nutrient accumulation and increased growth activity, attributed to the smart delivery system of the fertilizers.

The interaction between the cropping system and various fertilizer levels was significant in all sampling periods except 60 DAS to harvest in both growing years (2020 and 2021) and in the case of mean data. In the sampling period of 20-40 DAS, the highest RGR value was obtained in intercrop mungbean combined with 100 % Nano NPK fertilizer in the year 2020, while the lowest mean value was obtained in sole mungbean coupled with control. In 2021, the highest RGR was obtained in sole mungbean coupled with 100 % RDF. However, the maximum RGR was recorded in the intercrop mungbean mixed with 100% Nano NPK fertilizer in the Mean data. In both 2021 and Mean data, the lowest RGR was seen in the sole mungbean coupled with control (Table 4.2.9a). In the sampling period of 40-60 DAS, the highest value of RGR was acquired in sole mungbean combined with 100% Nano NPK fertilizers while the lowest mean value was acquired in intercrop mungbean coupled with control in both the growing seasons as well as when the data were mean (Table 4.2.9b).

Table 4.2.9.: Effect of cropping system and different levels of fertilizers on the relative growth rate (g/g/day) of the sole and intercrop mungbean at all observation stages during the growing years (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	20-40 DAS	40-60 DAS	60DAS-at harvest	20-40 DAS	40-60 DAS	60DAS-at harvest	20-40 DAS	40-60 DAS	60DAS-at harvest
A –Cropping system									
M₂	0.0516	0.0354	0.0124	0.0515	0.0356	0.0133	0.0515	0.0355	0.0128
M₃	0.0527	0.0367	0.0109	0.0528	0.0370	0.0117	0.0527	0.0369	0.0113
SEm (±)	0.0006	0.0012	0.0008	0.0019	0.0015	0.0009	0.0005	0.0015	0.0009
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
B-Different levels of fertilizer									
S₁	0.0424 ^c	0.0333 ^c	0.0090 ^c	0.0438 ^b	0.0335 ^c	0.0099 ^c	0.0431 ^b	0.0334 ^c	0.0095 ^c
S₂	0.0540 ^b	0.0363 ^b	0.0120 ^b	0.0554 ^a	0.0366 ^b	0.0128 ^b	0.0547 ^a	0.0364 ^b	0.0124 ^b
S₃	0.0594 ^a	0.0392 ^a	0.0138 ^a	0.0552 ^a	0.0394 ^a	0.0146 ^a	0.0573 ^a	0.0393 ^a	0.0142 ^a
S₄	0.0528 ^b	0.0354 ^b	0.0118 ^b	0.0542 ^a	0.0357 ^b	0.0127 ^b	0.0535 ^a	0.0355 ^b	0.0123 ^b
SEm (±)	0.0016	0.0011	0.0006	0.0018	0.0013	0.0007	0.0017	0.0012	0.0007
CD (P=0.05)	0.0020	0.0018	0.0010	0.0023	0.0021	0.0017	0.0022	0.0020	0.0014
Interaction (A x B)	S	S	NS	S	S	NS	S	S	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.9a: Interaction between cropping systems and different fertilizer levels on the relative growth rate (g/m²/day) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

20-40DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	0.0405 ^d	0.0586 ^a	0.0566 ^a	0.0550 ^b	0.0419 ^c	0.0600 ^a	0.0529 ^b	0.0564 ^a	0.0412 ^d	0.0593 ^a	0.0547 ^b	0.0557 ^b
M ₃	0.0444 ^c	0.0494 ^c	0.0622 ^a	0.0506 ^b	0.0458 ^b	0.0508 ^b	0.0574 ^a	0.0520 ^b	0.0451 ^c	0.0501 ^c	0.0598 ^a	0.0513 ^c
SEm (±)	0.0009				0.0011				0.0010			
CD(P=0.05)	0.0028				0.0033				0.0030			

Table 4.2.9b: Interaction between cropping systems and different fertilizer levels on the relative growth rate (g/m²/day) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

40-60DAS	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₂	0.0339 ^{de}	0.0379 ^b	0.0399 ^a	0.0352 ^c	0.0342 ^{de}	0.0381 ^b	0.0402 ^a	0.0355 ^c	0.0341 ^{de}	0.0380 ^b	0.0400 ^a	0.0354 ^c
M ₃	0.0326 ^e	0.0348 ^{cd}	0.0384 ^b	0.0356 ^c	0.0328 ^e	0.0350 ^{cd}	0.0386 ^b	0.0358 ^c	0.0327 ^e	0.0349 ^{cd}	0.0385 ^b	0.0357 ^c
SEm (±)	0.0004				0.0008				0.0006			
CD(P=0.05)	0.0014				0.0019				0.0017			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.2. Yield components and Yield

4.1.2.2.1. Number of pods/plant

The data presented in Table 4.2.10 illustrates the statistics regarding the number of pods/plant for both sole mungbean and intercrop mungbean, spanning the years 2020 and 2021, along with the mean values. It is evident that the cropping system had a significant impact on the no. of pods/ plant in both years as well as in the mean data. In both seasons, mungbean intercropped with maize resulted in a lower no. of pods/plant and a higher no. of pods/ plant when mungbean was the monocrop (2020 and 2021). The data recorded in the years 2020 and 2021 was comparable to the data recorded in the mean data (Fig 4.2.10a). This observed difference in pod production can be explained by the dynamics of intercropping and competition for resources. In the past seasons, when mungbean was intercropped with maize, the presence of the larger maize plants might have led to increased competition for essential resources such as sunlight, water, and nutrients. The competitive interactions between mungbean and maize likely constrained the available resources for mungbean plants, affecting their reproductive development and resulting in a reduced number of pods per plant. Conversely, when mungbean was cultivated as a monocrop, it had uninterrupted access to resources without competition from other crops. This advantageous growth environment allowed mungbean plants to allocate more resources towards reproductive structures, leading to a higher number of pods per plant. Afshar and colleagues (2014) documented a rise in the seed count per plant attributed to the utilization of nanofertilizers. Khan *et al.* (2012) also reported that mungbean monocropping displayed heavier grains and more pods/plant compared to intercropping with maize. Conversely, plots where maize was intercropped with mungbean showed a lower no. of pods/plant. The authors suggested that the higher no. of pods/plant in sole mungbean plots might be attributed to the absence of interspecific competition and the better utilization of nitrogen applied as a starter dose, which was fixed by root nodules. Additionally, considering mungbean as a drought-resistant crop, it may not tolerate excess water when grown as an intercrop with maize, where more water is typically applied. These findings also align with previous research by Onuh *et al.* (2011) and Tohura *et al.* (2014) who reported significantly greater no. of pod/plant in sole-cropped mung bean compared to maize/mung bean intercropping and stated that this decline is likely

attributed to the unfavorable shading effect induced by taller plants and the presence of inter and intra-species competition for shared growth resources.

The no. of mungbean pods/plant was significantly affected by fertilizer treatment at different levels in both the 2020 and 2021 growing seasons and in the mean data. In the year 2020, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest no. of pods/plant, which was similar to the plot supplied with 100% RDF followed by 100% Nano NPK fertilizers, while the control plot had the lowest pods/plant. A similar pattern was seen in 2021 and in mean statistics. This could be attributed to the balanced combination of nutrients provided by the mixture, promoting optimal plant growth and pod development. The synergistic effect of the specific proportions of RDF and Nano NPK fertilizers likely created favorable conditions for increased pod production in comparison to other treatments or the control plot. Similarly, Hassan and Lehmoed (2019) reported an augmentation in the number of pods per plant through the application of nanofertilizers. They indicated that the heightened effectiveness of a concentrated nano fertilizer could be linked to the increased leaf area, particularly at elevated concentrations. This expansion renders the leaf surface more receptive to fertilizer spraying, thereby promoting enhanced element absorption by the leaves. The consequence of this effect is evident in the increased number of pods per plant, playing a crucial role in amplifying flower nodes and supporting the fertilization process. Furthermore, Mondal and Sengupta (2020) also documented that the combined use of nano fertilizer along with 50% of the recommended full dose of fertilizers demonstrated the highest effectiveness. This approach exhibited superior performance compared to all other treatments, particularly in terms of the pod count per unit area of black gram. The observed correlation aligns with the research outcomes of Drostkar *et al.* (2016) in chickpea and Gomma *et al.* (2022) in faba bean. Both studies yielded similar results in terms of the number of pods per plant, attributing this consistency to the utilization of nanofertilizers.

The interaction between the cropping system and various fertilizer levels was significant in both the years (2020 and 2021) as well as when the data were mean. In 2020, intercrop mungbean coupled with control had the least overall no. of pods/plant, whereas sole mungbean mixed with 50% RDF + 50%, Nano NPK fertilizers had the highest value of no. of pods/plant. Similar results to those of 2020 were noted in 2021 and mean statistics (Table 4.2.10a).

4.1.2.2.2. Number of seeds/pod

The effect of the cropping system and various fertilizer levels on the no. of seeds/pod of sole mungbean and intercrop mungbean during the 2020 and 2021 *kharif* seasons are shown in Table 4.2.10 along with the mean data. In plots where mungbean was cultivated as the sole crop in the year 2020, a larger no. of seeds/pod was seen, while a lower no. of seeds/pod was noted in plots where mungbean and maize were intercropped in both seasons. Similar outcomes were also observed in 2021, and when the data were mean (Fig 4.2.10b). This difference in seed production can be attributed to the competition for resources between mungbean and maize when intercropped. The intercropping system led to increased competition for nutrients, water, and sunlight, which may have adversely affected the reproductive development of mungbean, resulting in a reduced no. of seeds/pod compared to the sole-cropped scenario. In contrast, the sole cultivation of mungbean allowed for more optimal resource utilization, contributing to a higher no. of seeds/pod. In alignment with these findings, Tohura *et al.* (2014) observed a higher no. of seeds/pod in mung bean when grown in sole cropping compared to intercropping in maize/mung bean intercropping. Likewise, Khan *et al.* (2012) reported a significantly greater no. of seeds/pod for mung bean in sole cropping than in intercropping within maize/mung bean intercropping. They attributed the reduction in seed/pod to the shading effect caused by the tall maize plants, resulting in a lower intake of solar radiation. This, in turn, adversely affected the rate of net photosynthesis, leading to poor translocation of photosynthates from source to sink, ultimately resulting in the formation of fewer seeds/pod in intercropping. A similar outcome was documented by Assefa *et al.* (2016) in the case of both sole common bean and intercrop common bean with maize.

In both the 2020 and 2021 growing seasons as well as when the data were mean, the treatment of various fertilizer levels significantly impacts the number of seeds per mungbean pod. In the years 2020 and 2021, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest no. of seeds per pod followed by 100% RDF and 100% Nano NPK fertilizers, whereas the control plot had the lowest. Similar patterns were revealed in the mean statistics. This observed pattern can be attributed to the balanced nutrient composition provided by the combination of 50% RDF and 50% Nano NPK fertilizers, creating optimal conditions

for seed development. The controlled release of nutrients from the nano-fertilizers, along with the supplementary dose from RDF, likely contributed to enhanced seed formation. In comparison, the control plot, lacking such targeted nutrient supplementation, experienced less favorable conditions for seed development, resulting in a lower number of seeds per pod. Sathyan in 2022 revealed comparable outcomes, indicating that the highest number of seeds per pod in field peas occurred with nanofertilizers treatment. Similarly, Abd Alqader *et al.* in 2020 reported analogous findings in broad beans. They highlighted that the combined use of chemical fertilizer and nanofertilizers resulted in a positive impact on nitrogen and nano-nitrogen, increasing the percentage of pod fertilization and subsequently leading to an augmentation in the number of seeds/pod. The outcomes were constant with the outcomes of Gomaa *et al.* (2017), Gomaa *et al.* (2018) and Khalil *et al.* (2019), and who stated that the application of a combination of 50% chemical fertilizers and 50% nanofertilizers enhanced the yield components of cereal crops in both growing seasons. In addition to that, El-Metwally *et al.* (2013) also found that the nano-fertilizers significantly affected the yield components of pea.

The interaction between the cropping system and various fertilizer levels was significant throughout the growing years (2020 and 2021) and in the mean data. In the year 2020, sole mungbean coupled with 50% RDF+50% Nano NPK produced the largest no. of seeds/pod, whereas intercrop mungbean + control plot produced the least no. of seeds/ pod. When data were mean and in 2021, a comparable pattern was seen (Table 4.2.10b).

4.1.2.2.3. Pod length (cm)

Table 4.2.10 illustrates the impact of the cropping system and various fertilizer rates on the mungbean pod length during the *kharif* season of 2020 and 2021 along with mean data. In both years the effect of cropping system has a significant effect on the pod length of mungbean. In the year 2020, pod length was found to be longer when mungbean was grown as the sole crop, while the shorter pod length was reported when mungbean was cultivated with maize. A similar tendency was also seen in 2021, and when the data was mean (Fig.4.2.10c). This difference in pod length can be attributed to the competition for resources, particularly nutrients and water, between mungbean and maize when grown together. The presence of maize as a companion crop may have led

to resource limitations, affecting the overall growth and development of mungbean pods, resulting in a reduced pod length compared to when mungbean was grown alone. Li *et al.* (2020) indicated that the efficient absorption and utilization of nutrients and soil water play a vital role in expanding root systems, thereby promoting enhanced crop growth when cultivated as sole legumes. This positive effect is noticeable in the amplified growth and improved yield parameters, particularly in the scenario of legume and cereal intercropping. Mao *et al.* (2012) observed such enhancement in sole pea rather than pea intercropped with maize, while Chen *et al.* (2017) reported similar effects in sole soybean compared to soybean intercropped with maize.

In the case of different levels of fertilizer treatments, throughout the growing years (i.e., 2020 and 2021) the longest pod length was observed in the plot applied with 50% RDF +50% Nano NPK fertilizers followed by 100 % RDF and 100 % Nano NPK fertilizers whereas, the shortest pod length was recorded in the control plot in both years i.e., 2020 and 2021, and when both the year's data were mean. This difference in pod length can be attributed to the enhanced nutrient availability and balanced nutrition provided by the combination of 50% RDF and 50% Nano NPK fertilizers. The synergistic effect of these fertilizers likely facilitated optimal growth conditions, resulting in longer pods. On the other hand, the control plot, which did not receive additional fertilizers, experienced nutrient deficiencies, leading to stunted growth and the shortest pod length observed in both years (2020 and 2021). Mirji *et al.* (2023) asserted that the observed increase in sapota fruit length might be attributed to the distinctive characteristics and behavior of nano-fertilizers, which effectively deliver nutrients throughout the plant's growth stages. Notably, potassium, with its positive impact on cell division and expansion, stimulates cell wall expansion, consequently leading to an augmentation in both fruit length and width. These findings align with similar results reported by Sabir *et al.* (2014) in blueberries, Kamiab and Zamanibahramabadi (2016) in almonds, and Gad *et al.* (2021) in mangoes. Likewise, in Abd Alqader *et al.*'s study conducted in 2020, it was documented that employing nano fertilizer concentration resulted in the highest Mean pod length. The authors suggested that this particular outcome could be ascribed to the heightened leaf area and chlorophyll content within the leaves. Consequently, this phenomenon contributed to an enhancement in both cell division and elongation, ultimately leading to an

observed increase in pod length.

In both the years (2020 and 2021) and when the data were mean, the interaction between the cropping system and different fertilizer levels was significant (Table 4.2.10c). The intercrop mungbean plot treated with no fertilizers had the shortest pod length, while the sole mungbean plot treated with 50% RDF + 50% Nano NPK fertilizers had the longest pod length. These findings were recorded in both the seasons (2020 and 2021) and when the data were mean (Table 4.2.10c).

4.1.2.2.4. Test weight (g)

The test weight was significantly affected by the cropping system, various fertilizers levels in both 2020 and 2021 and in mean data (Table 4.2.10). A higher test weight was recorded with mungbean as the sole crop while a lower test weight was noted when mungbean was intercropped with mungbean in both the seasons 2020 and 2021 and when data were mean (Table 4.2.10 and Fig 4.2.10d). The decrease in test weight in the intercropping system can be attributed to the competition for resources, such as nutrients, water, and sunlight, between mungbean and maize. The shared resources likely led to resource limitations for mungbean, affecting its overall growth and development. As a result, the individual grains of mungbean in the intercropped system may not have reached their full potential size and weight, contributing to the observed lower test weight compared to when mungbean was grown as a sole crop. Corroborating these results, Temesgen *et al.* (2015) recorded a substantial decrease in the hundred seed weight of common bean when cultivated in maize-bean intercropping. In a parallel manner, Solomon *et al.* (2012) noted a pronounced reduction in the hundred seed weight of soybean in maize-soybean intercropping. Furthermore, Alemayehu *et al.* (2018) reported that the cropping system had a significant impact on the hundred seed weight of various common bean varieties. This reduction in hundred grains weight could also be attributed to the adverse shading effects and interspecies competition, leading to inhibited growth and a lower rate of assimilate translocation to grain filling. Consequently, this condition resulted in the formation of shriveled and smaller-sized seeds. Consistent with this finding, Arshad *et al.* (2020) reported the highest thousand grain weight of mung bean in sole cropping compared to intercropping with maize.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest test weight in the case of varying levels of fertilizer treatment in 2020, followed by 100% RDF and 100% Nano NPK nanofertilizers. The control plot had the lowest test weight on a statistical basis. Similar trends were seen in 2021 and when data was mean. This observed trend can be attributed to the synergistic effect of the combined application of 50% RDF and 50% Nano NPK fertilizers. The balanced and optimal nutrient composition provided by this treatment likely supported enhanced physiological processes in the plants, leading to better grain development and increased test weight. The combination of conventional fertilization (RDF) with nano-fertilizers possibly facilitated improved nutrient absorption and utilization efficiency, contributing to the observed higher test weight. The subsequent rankings of 100% RDF and 100% Nano NPK nanofertilizers in descending order could be linked to differences in nutrient availability and uptake, emphasizing the significance of the specific fertilizer treatment on test weight outcomes. The result corresponds with those presented by El-Metwally *et al.* in 2018, indicating that nano-fertilizers have a considerable influence on various aspects of plant growth. The research revealed significant effects on seed weight per plant. The researchers postulated that these favorable results could be linked to the improved nutrient availability facilitated by the application of nano-fertilizers. Likewise, Safaei *et al.* (2014) observed that nano-fertilizers had a substantial impact on the seed weight of black cumin.

Throughout the growing years (2020 and 2021) and the mean statistics showed significant interactions between the cropping system and various fertilizer levels (Table 4.2.10d). The sole mungbean treated with 50% RDF + 50% Nano NPK fertilizers had the superior mean test weight value, whereas the intercrop mungbean treated with control had the least mean test weight value. These results were recorded during both the growth seasons (2020 and 2021), as well as in the mean data (Table 4.2.10d).

Table 4.2.10.: Effect of cropping system and different levels of fertilizers on the yield attributes of sole and intercrop mungbean during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	No. of pods plant ⁻¹	No. of seeds pod ⁻¹	Pod length(cm)	Test weight(g)	No. of pods plant ⁻¹	No. of seeds pod ⁻¹	Pod length (cm)	Test weight(g)	No. of pods plant ⁻¹	No. of seeds pod ⁻¹	Pod length(cm)	Test weight(g)
A –Cropping system												
M₂	26.27 ^a	9.84 ^a	8.70 ^a	34.34 ^a	29.41 ^a	11.39 ^a	9.30 ^a	34.51 ^a	27.82 ^a	10.61 ^a	9.00 ^a	34.42 ^a
M₃	22.06 ^b	9.21 ^b	8.31 ^a	28.69 ^b	24.29 ^b	10.58 ^b	8.75 ^a	28.77 ^b	23.17 ^b	9.90 ^b	8.53 ^a	28.73 ^b
SEm (±)	0.55	0.10	0.06	0.25	0.60	0.11	0.09	0.27	0.58	0.11	0.08	0.26
CD (P=0.05)	3.56	0.62	0.38	1.51	3.68	0.69	0.55	1.67	3.52	0.65	0.46	1.59
B-Different levels of fertilizer												
S₁	20.13 ^c	6.94 ^d	7.60 ^d	24.08 ^d	20.18 ^c	7.12 ^d	8.00 ^c	24.11 ^d	20.16 ^c	7.02 ^d	7.80 ^c	24.10 ^d
S₂	26.18 ^a	10.70 ^b	8.86 ^b	34.77 ^b	29.88 ^a	12.59 ^b	9.38 ^a	34.92 ^b	28.03 ^a	11.64 ^b	9.12 ^a	34.84 ^b
S₃	23.22 ^b	8.96 ^c	8.46 ^c	30.34 ^c	26.49 ^b	10.55 ^c	8.94 ^b	30.49 ^c	24.85 ^b	9.75 ^c	8.70 ^b	30.41 ^c
S₄	27.12 ^a	11.52 ^a	9.10 ^a	36.88 ^a	30.85 ^a	13.68 ^a	9.76 ^a	37.03 ^a	28.94 ^a	12.60 ^a	9.43 ^a	36.96 ^a
SEm (±)	0.69	0.16	0.11	0.47	0.47	0.20	0.12	0.49	0.73	0.18	0.12	0.48
CD (P=0.05)	2.12	0.49	0.35	1.44	1.44	0.63	0.38	1.52	2.24	0.56	0.37	1.48
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

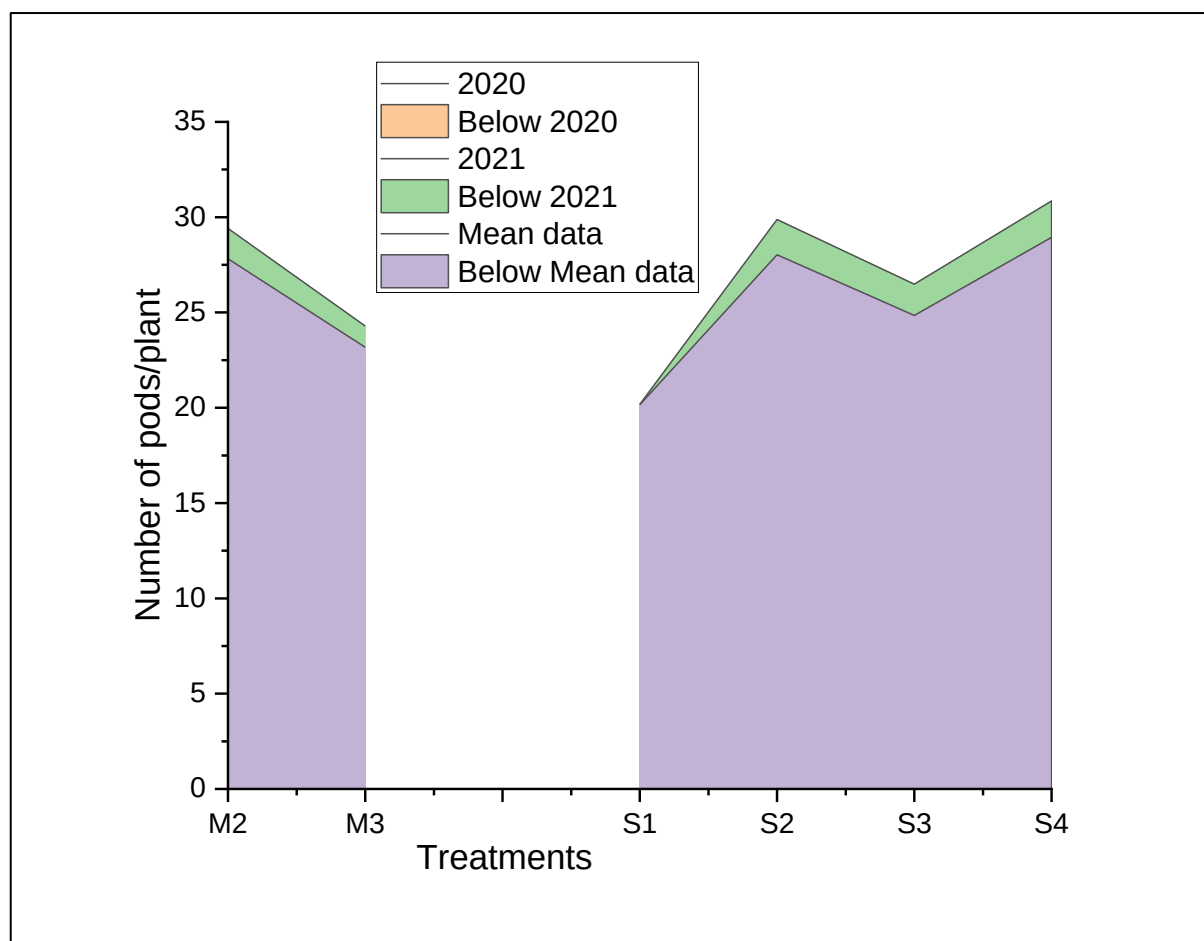


Fig 4.2.10a: Effect of cropping system and different levels of fertilizers on the no. of pods/ plant of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

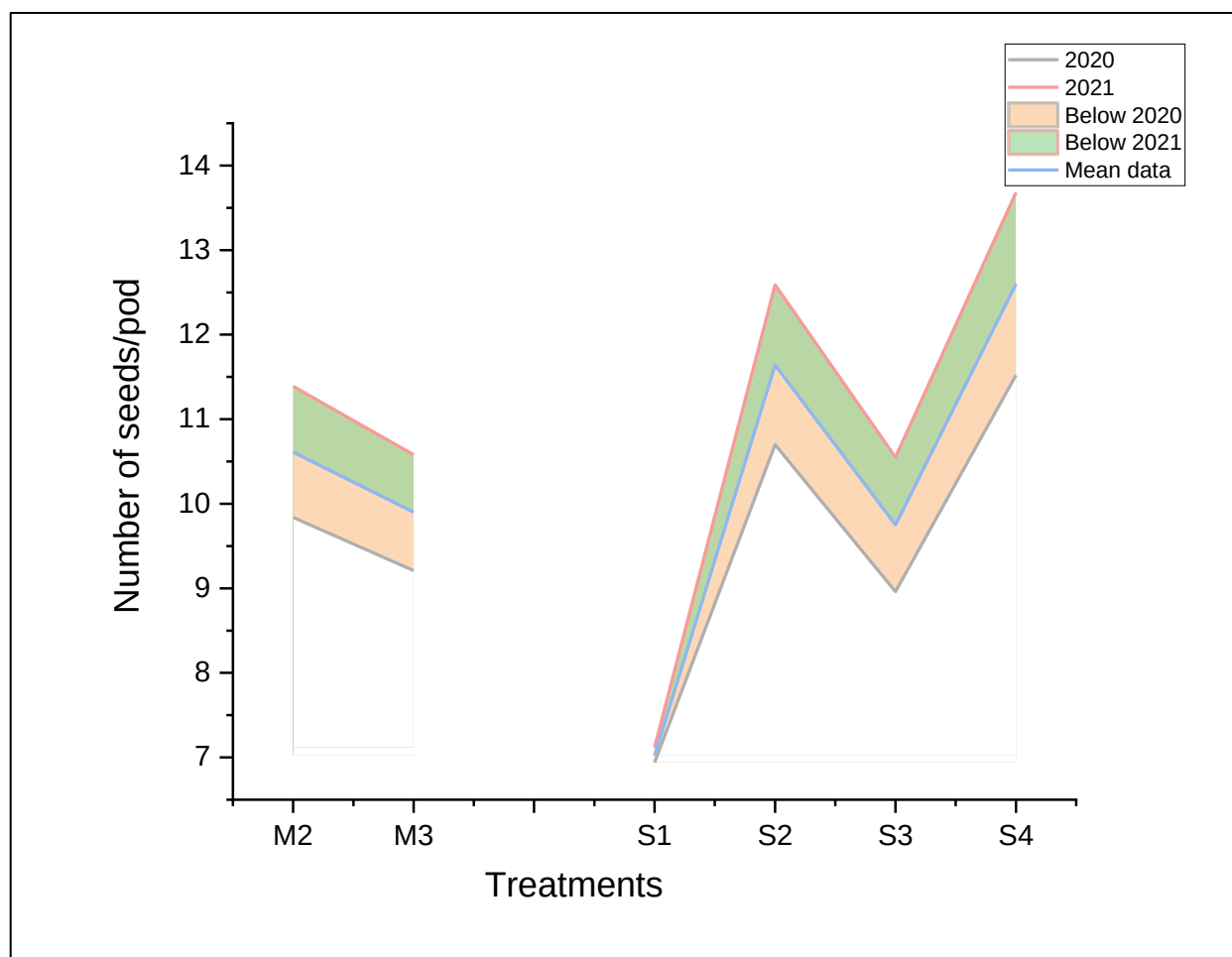


Fig 4.2.10b: Effect of cropping system and different levels of fertilizers on the number of seeds/ pod of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

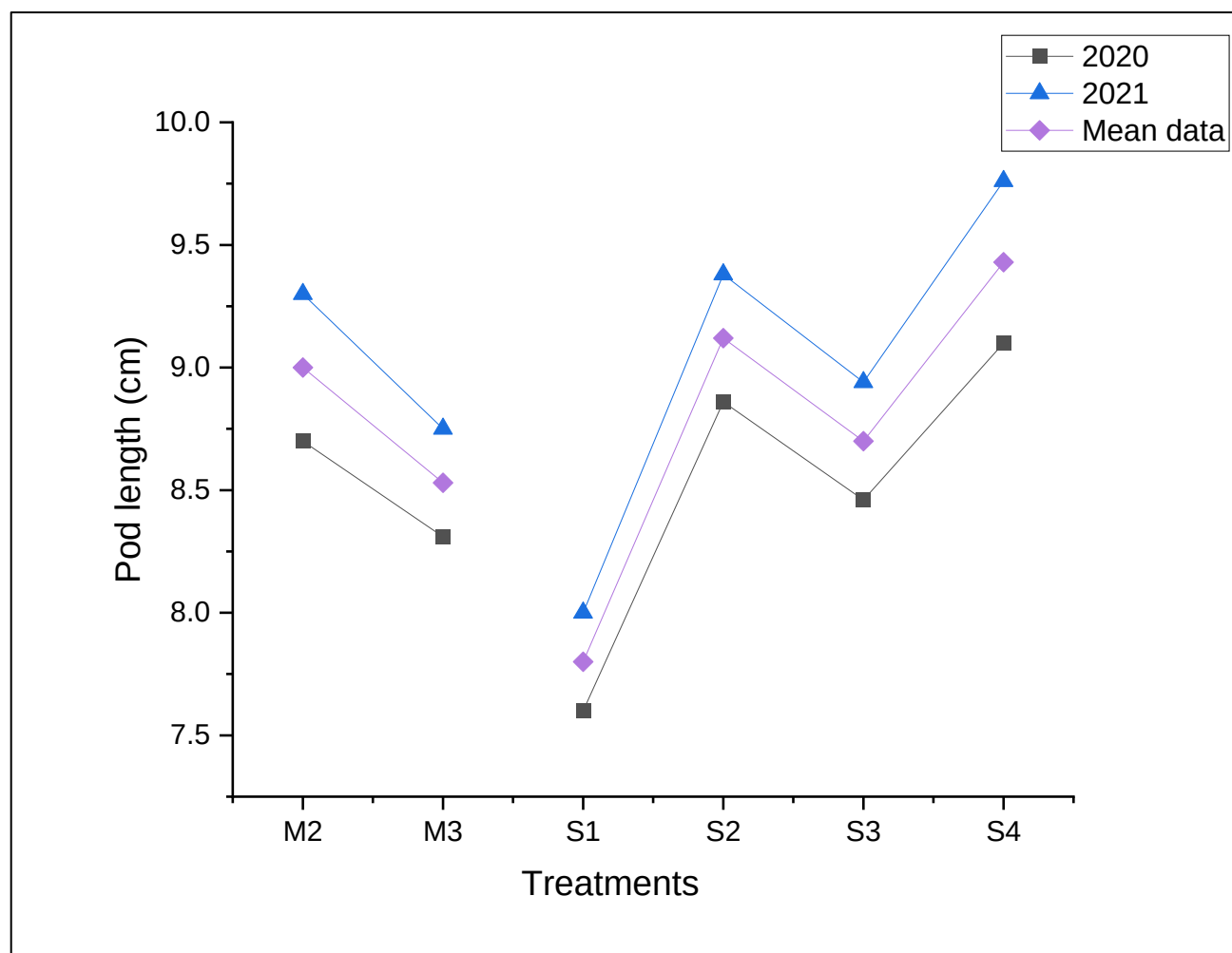


Fig 4.2.10c: Effect of cropping system and different levels of fertilizers on the pod length (cm) of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

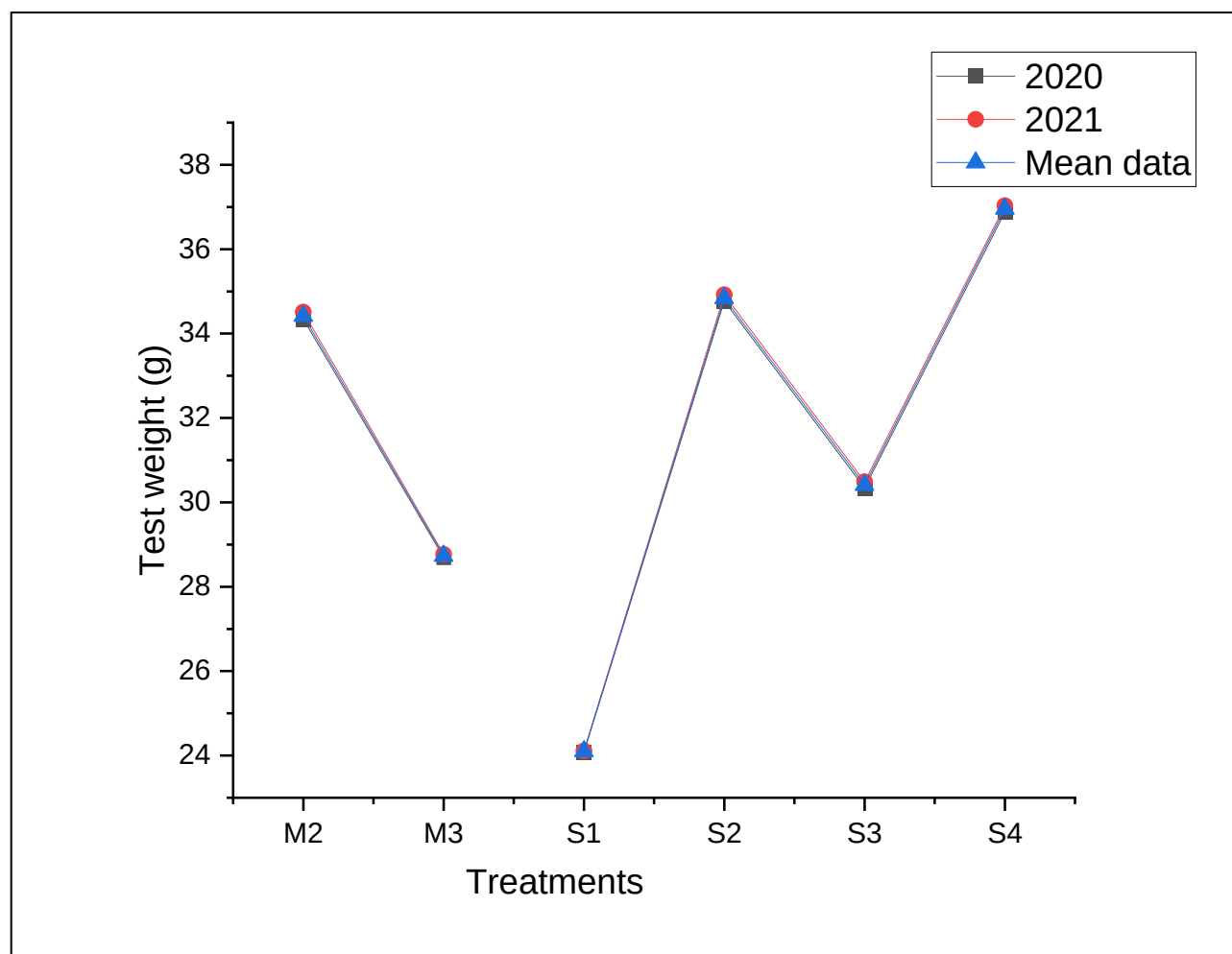


Fig 4.2.10d: Effect of cropping system and different levels of fertilizers on the test weight (%) of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

Table 4.2.10a: Interaction between cropping systems and different fertilizer levels on the no. of pods/plant of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	20.60 ^{de}	29.21 ^a	24.87 ^b	30.39 ^a	20.70 ^d	33.60 ^a	28.60 ^b	34.75 ^a	20.65 ^{de}	31.40 ^a	26.73 ^b	32.57 ^a
M₃	19.66 ^e	23.15 ^c	21.57 ^{cd}	23.85 ^{bc}	19.66 ^d	26.16 ^c	24.38 ^c	26.95 ^{bc}	19.66 ^e	24.65 ^{bc}	22.97 ^{cd}	25.40 ^b
SEm (±)	0.97				1.09				1.03			
CD(P=0.05)	3.00				3.35				3.17			

Table 4.2.10b: Interaction between cropping systems and different fertilizer levels on the no. of seeds/pod of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	6.99 ^d	10.94 ^b	9.03 ^c	12.45 ^a	7.19 ^d	13.00 ^b	10.61 ^c	14.75 ^a	7.11 ^d	11.97 ^b	9.77 ^c	13.60 ^a
M₃	6.81 ^d	10.45 ^b	8.92 ^c	10.67 ^b	7.05 ^d	12.19 ^b	10.48 ^c	12.62 ^b	6.93 ^d	11.32 ^b	9.73 ^c	11.61 ^b
SEm (±)	0.22				0.29				0.26			
CD(P=0.05)	0.69				0.89				0.79`			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.10c: Interaction between cropping systems and different fertilizer levels on the pod length (cm) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	8.06 ^b	8.84 ^a	8.74 ^a	9.16 ^a	8.58 ^c	9.48 ^a	9.27 ^b	9.87 ^a	8.32 ^b	9.16 ^a	9.01 ^a	9.51 ^a
M₃	7.13 ^c	8.88 ^a	8.19 ^b	9.04 ^a	7.42 ^d	9.28 ^b	8.62 ^c	9.66 ^a	7.28 ^c	9.08 ^a	8.40 ^b	9.35 ^a
SEm (±)	0.16				0.17				0.16			
CD(P=0.05)	0.50				0.54				0.52			

Table 4.2.10d: Interaction between cropping systems and different fertilizer levels on the test weight (g) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	26.90 ^e	39.11 ^a	33.60 ^c	37.76 ^{ab}	26.96 ^e	39.31 ^a	33.80 ^c	37.96 ^{ab}	26.93 ^e	39.21 ^a	33.70 ^c	37.86 ^{ab}
M₃	21.26 ^f	30.42 ^d	27.08 ^e	36.01 ^b	21.26 ^f	30.52 ^d	27.18 ^e	36.11 ^b	21.26 ^f	30.47 ^d	27.13 ^e	36.06 ^b
SEm (±)	0.69				0.70				0.69			
CD(P=0.05)	2.12				2.15				2.13			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.1.2.5. Seed yield (kg/ha)

Table 4.2.11, shows how various fertilizer levels and cropping systems affected mungbean seed yields in the *kharif* seasons of 2020 and 2021 and mean data. The mungbean seed yield was significantly impacted by the cropping system. Throughout the growing years (2020 and 2021), and in the mean statistics, a higher yield of seed was observed in the plot where mungbean was cultivated as the sole crop and a lower seed yield was observed in the plot where mungbean was intercropped with maize (Fig.4.2.11a). In the intercropping, maize and mungbean faced heightened competition for crucial resources such as sunlight, water, and nutrients, as the taller and more robust maize plants cast shadows on mungbean, limiting its access to essential sunlight needed for photosynthesis and overall growth. The coexistence of maize in intercropped plots may have led to nutrient competition, hindering mungbean nutrient uptake and affecting its growth and seed development. Additionally, potential allelopathic interactions could have occurred, where substances released by maize negatively impacted mungbean growth, contributing to a decline in seed yield. The dynamics of growth and the microclimate in intercropped systems, differing from those in sole cropping, may have played a role in influencing mungbean overall productivity. Moreover, distinct crop management practices between sole cropping and intercropping, including variations in irrigation, fertilization, and pest control, likely contributed to the observed differences in mungbean seed yield. Liu *et al.* (2023) also documented a higher yield in monoculture soybean compared to soybean grown in intercropped conditions. Saleem *et al.* (2015) asserted that the yield of mung bean was reduced by 28% in intercropping compared to the sole cultivation of mung bean in the context of maize/mung bean intercropping. Legwaila *et al.* (2012) recorded a notable alteration in grain yield, noting higher yields in sole cowpea cultivation compared to intercropping. The study attributed this observed change to factors like competition for water and nutrients, along with shading. Similarly, Worku (2020) reported a reduction in mungbean yield in intercropping compared to monocropping. Comparable outcomes were documented by Arshad *et al.* (2020) in the context of mungbean, as well as by Tohura *et al.* (2014) and Wang *et al.* (2022) in separate studies involving mungbean. In line with these findings, Alemayehu *et al.* (2018) identified substantial variations in seed yields among different common bean varieties in the context of maize/common bean

intercropping. A comparable trend was stated by Yosuf and Rahman (2022), they observed cereal crops as stronger competitors to legumes when grown in intercropping environments which leads to lower yield in the interop mungbean. Similar findings were made by Negash (2018), who noted a decrease in grain yield in cowpea when maize and cowpea were intercropped.

In the year 2020, the plot applied with 50% RDF + 50% Nano NPK fertilizers had the highest yield of seed, followed by the plot applied with 100% RDF and 100% Nano NPK fertilizers, which was statistically better than the other treatments. According to statistics, the control plots yielded the least seed yield in 2020. A similar tendency was seen in the year 2021 as well as in the mean statistics (Table 4.1.11 and Fig.4.1.11a). This observed trend in seed yield can be attributed to the enhanced nutrient availability and balanced nutrition provided by the combination of 50% RDF and 50% Nano NPK fertilizers. This optimized nutrient composition likely supported improved plant growth, flowering, and ultimately, seed development. Similarly, the plots treated with 100% RDF and 100% Nano NPK fertilizers also benefited from adequate nutrient supply, contributing to their high seed yields. On the other hand, the control plots, lacking additional fertilization, experienced nutrient deficiencies, which could have hindered plant development and, consequently, resulted in the lowest seed yield. Hassani *et al.* (2015) reported that the application of nano-fertilizer yielded superior values for various agronomic traits in mint plants compared to the utilization of conventional chemical fertilizers. According to Sadhukhan *et al.* (2021), nanofertilizers enhance the yield of multiple field crops, including pearl millet, wheat, soybean, and others. The results align with the observations of Mahmoodi *et al.* (2017) in Borage plant. Astaneh *et al.* (2021) stated that nanofertilizers have the potential to increase crop yield, enhance soil fertility, reduce pollution, and create a favorable environment for soil microorganisms. Additionally, they help prevent nutrient loss in the soil through processes like leaching, evaporation, or volatilization, ensuring essential nutrients are available for plant growth. The total tuber yield of potatoes was significantly impacted by the utilization of nanofertilizers. Notably, the foliar application of nanofertilizers proved to be more effective than their individual application in augmenting the overall tuber yield of potatoes, as observed by Das and Chakraborty (2018). Similar findings were also reported by Lenka and Das (2019). Delfani *et al.* (2014) observed that the highest yield in black-

eyed pea was achieved through the combination of regular fertilizer and nanofertilizers. This supports the findings of [Liu and Lal (2015); Salama *et al.* (2022)], who reported a synergistic effect between conventional fertilizers and nano fertilizers for higher nutrient uptake in the cells of the plant which led to increased photosynthesis, accumulation of higher levels of photosynthates, and transportation of nutrients to the economically important parts of the plant that correlate to a final seed yield. Lemraski *et al.* (2017) suggest that the explanation for the rise in yield and yield components could be related to the nutrients uptake that sped up photosynthesis, which was positively reflected in the rise in dry matter weight.

It was determined that there was a significant interaction between the cropping system and fertilizer levels in both seasons (2020 and 2021) as well as in the case of mean statistics. The sole mungbean plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the highest mean value of seed yield; conversely, the intercrop mungbean plot treated with the no fertilizer in both seasons and in the of mean statistics had the lowest mean value of seed.

4.1.2.2.6. Straw yield (kg/ha)

Table 4.2.11 shows the straw yield per hectare as influenced by varying levels of fertilizer and cropping system during the 2020 and 2021 *kharif* seasons, along with mean statistics. Straw yield significantly responded to different fertilizer levels and different cropping systems treatments. In both the 2020 and 2021 and in the mean statistics, plots with mungbean as the sole crop produced higher straw yields than those with mungbean intercropped with maize. The observed trend can be attributed to the practice of cultivating mungbean as a sole crop which allows for optimized resource allocation. When mungbean is the exclusive focus of cultivation in a plot, resources such as water, nutrients, and sunlight are dedicated solely to its growth and development. This targeted allocation can lead to a more efficient utilization of these resources, fostering optimal conditions for mungbean to thrive and produce higher yields, including an increased amount of straw. Additionally, the competition for resources between mungbean and maize in intercropped plots may impact the overall productivity of both crops. Maize and mungbean could have varying requirements in terms of nutrients, water, and space. Interplant competition may lead to a suboptimal distribution of these essential resources, potentially limiting the growth potential of mungbean and subsequently affecting its straw yield. Moreover, the intricate interplay between the

two crops in intercropped plots may introduce complexities in terms of pest and disease management. Mungbean and maize could be susceptible to different pests and diseases, and their proximity in intercropped settings may facilitate the spread of such issues. In contrast, cultivating mungbean as a sole crop may allow for more targeted pest and disease control measures, contributing to a healthier crop and higher straw yields. Temeche *et al.* (2022) similarly reported that cultivating beans as a sole crop resulted in the highest yield compared to intercropping beans with sorghum. Doutaniya *et al.* (2023) also observed an increase in straw yield when mungbean was cultivated as a sole crop compared to intercropping.

In the case of different levels of fertilizer treatment, the plot treated with 50% RDF + 50% Nano NPK fertilizers recorded the highest straw yield during 2020 and 2021 and in mean statistics. It was followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. The control plot has consistently had the lowest straw yield in the year 2020. Nonetheless, a comparable pattern was seen in 2021 and mean data (Fig.4.2.11b). The rationale behind this observation lies in the synergistic effect of the specific fertilizer combination employed. The application of 50% RDF ensured that the mungbean plants received a balanced and essential dose of conventional fertilizers according to established recommendations. This addressed the basic nutritional needs of the crops, fostering healthy growth and development. The addition of 50% Nano NPK fertilizers further might have enhanced the nutrient supply to the mungbean plants. Nano fertilizers, owing to their reduced particle size, exhibit improved nutrient absorption efficiency. This increased efficiency in nutrient uptake could have played a pivotal role in maximizing the utilization of the applied fertilizers, contributing to enhanced mungbean growth and, consequently, higher straw yields. Furthermore, the balanced combination of conventional and nano-scale fertilizers likely provided a comprehensive spectrum of nutrients, including nitrogen, phosphorus, and potassium, essential for the different stages of mungbean growth. This optimal nutrient supply throughout the growing season would have positively influenced various physiological processes, such as photosynthesis and nutrient assimilation, leading to increased straw yield. Similarly, in a study by El Karamity *et al.* (2020), it was observed that substituting 50% of the recommended nitrogen dose with nano N led to the highest straw yield in sesame. Hong *et al.* (2021) indicated that the utilization of nanoparticles through foliar spray can lead to an

increase in total biomass. Likewise, in 2018, El-Metwally *et al.* observed that the use of nano-fertilizers had a notable influence on both the fresh and dry weights of straw of peanut plant.

In both 2020 and 2021 and in the mean statistics, it was determined that the interaction between the cropping system and various fertilizer levels was significant. In all seasons (2020 and 2021), as well as when data were mean data, the maximum mean value of straw yield was found in sole mungbean combined with 50% RDF+50% Nano NPK fertilizers, whereas the minimum was recorded in intercrop mungbean combined with the control (Table 4.2.11b).

4.1.2.2.7. Biological yield (kg/ha)

Table 4.2.11 illustrates the biological yield/hectare affected by various fertilizer rates and cropping system during the *kharif* seasons of 2020 and 2021. Biological yield significantly responded to different fertilizer levels and different cropping systems treatments. Plots, where mungbean was grown as a sole crop, produced higher biological yield compared to the plot where mungbean was intercropped with maize in both seasons i.e., 2020 and 2021 as well as when the data were mean. The reason for this can be attributed to mungbean when cultivated as a sole crop, might have benefits from the absence of interspecific competition with maize for essential resources such as sunlight, water, and nutrients. In intercropped settings, the shared resources and potential competition between mungbean and maize plants might have led to suboptimal conditions for both crops, limiting their individual growth and overall productivity. Additionally, mungbean as a leguminous crop is capable of nitrogen fixation through symbiotic relationships with nitrogen-fixing bacteria in its root nodules. When grown as a sole crop, mungbean can utilize this nitrogen-fixing ability more effectively to meet its own nitrogen requirements. However, in intercropped scenarios with maize, the nitrogen-fixing capacity of mungbean may be constrained due to competition for resources, and this could potentially limit nitrogen availability for both crops. Moreover, the distinct growth patterns and requirements of mungbean and maize might have contributed to the observed differences in biological yield. Mungbean is a relatively shorter-duration crop, and its growth cycle may not align perfectly with that of maize. The asynchronous growth patterns could result in inefficient resource utilization in intercropped plots, affecting the overall yield potential. Khan *et al.* (2012) reported that the sole cultivation of mungbean

demonstrated superior performance compared to intercropped mungbean, resulting in a higher biological yield. The authors suggested that this outcome could be attributed to reduced photosynthetic activities in the mungbean crop, likely caused by limited exposure to sunlight and the shading effect of maize leaves covering the canopy. Intercropping systems involving maize and mungbean may encounter intricate interactions of inter- and intra-specific competition, with maize predominantly prevailing in such competitions. Tohura *et al.* (2014) reported analogous findings in the context of sole mungbean and mungbean maize intercropping. Consistent with this outcome, Lyngdoh *et al.* (2020) reported a significant decrease in the biological yield of intercropped mung beans when compared to the sole crop.

The plot treated with 50% RDF + 50% Nano NPK fertilizers provided the maximum biological yield in the case of varying levels of fertilizer treatment in the year 2020, followed by the plot applied with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot's least biological yield occurred in 2020. Yet, a similar pattern was seen when data were mean and in the year 2021. The plot treated with 50% RDF + 50% Nano NPK fertilizers can be attributed to the synergistic effects of the fertilizer combination. The inclusion of Nano NPK fertilizers, characterized by their enhanced nutrient absorption efficiency due to reduced particle size, likely facilitated optimal nutrient uptake by the crops. This efficient utilization of nutrients, combined with the balanced dose provided by 50% RDF, created an environment conducive to robust plant growth and increased biological yield. The plot treated with 100% RDF also performed well, emphasizing the importance of adhering to the recommended dose of conventional fertilizers. This approach ensured an adequate and balanced supply of essential nutrients, supporting the plants' nutritional requirements throughout their growth stages. Similarly, the plot receiving 100% Nano NPK fertilizers demonstrated a positive outcome, indicating the potential benefits of nano-scale fertilizers in enhancing nutrient availability and absorption efficiency. According to Jasim *et al.* (2014), the application of nano fertilizer had a positive impact on various traits, including the number of pods per plant, the number of seeds per pod, and seed yield. This led to an overall increase in biological yield of broad beans. The highest biomass yield for gerbera plants was achieved by Mohammadhagheri and Naderi (2017) when treated with nano-fertilizer. Additionally,

Ostadi *et al.* (2020) found that treating peppermint with nano-fertilizer resulted in the highest biomass yield. In a similar vein, Safaei *et al.* (2014) observed that the application of nano fertilizers resulted in increased yield and yield components for black cumin (*Nigella sativa*). Additionally, these nano fertilizers exhibited a significant impact on both biological yield and harvest index. Spruogis (2013) also found that fertilizing the barley plant with nano fertilizer and NPK composite fertilizers significantly increased the biological yield.

The interaction between fertilizer levels and cropping systems was shown to be significant in both growing years (2020 and 2021). Both for the 2020 and 2021 growing seasons, as well as for mean statistics, sole mungbean was found to have the highest mean value of biological yield when combined with 50% RDF + 50% Nano NPK fertilizers, whereas intercrop mungbean was found to have the lowest mean value of biological yield when combined with the control (Table 4.2.11c).

4.1.2.2.8 Harvest index (%)

Table 4.2.11 shows the effects of various fertilizer rates and cropping systems on the mungbean Harvest Index (HI) for the *kharif* seasons of 2020 and 2021 with mean data. The cropping system significantly affected the mungbean harvest index in 2020, 2021 and in mean statistics. In the year 2020, a better percentage of HI was noted in the plot where mungbean was grown as the sole crop while lower percentage of HI was noted in the plot where mungbean was intercrop maize. This can be attributed to the sole crop scenario, where mungbean experienced reduced competition for essential resources such as sunlight, water, and nutrients. This unimpeded access to resources allowed the mungbean plants to allocate a greater proportion of assimilated photosynthates towards reproductive structures, such as seeds or grains, which significantly contributes to the Harvest Index. With fewer constraints on growth and resource utilization, mungbean in the sole crop setting was able to channel more energy into seed production, resulting in a higher HI. Conversely, in the intercropped plots with maize, the shared resources and interspecific competition between mungbean and maize likely led to a less favorable environment for both crops. The differing growth patterns and resource requirements of mungbean and maize may have caused suboptimal conditions, limiting the allocation of assimilates to reproductive structures in mungbean. As a result, the harvest index in the intercropped plots was lower compared

to the sole crop setting. Similarly, Amanu *et al.* (2021) observed a significant difference in the harvest index of mung beans based on the cropping system employed. Sole-cropped mung beans exhibited a higher harvest index compared to intercropped mung beans. This disparity is attributed to the lower grain yield of mung beans in intercropping, primarily due to shading from the tall maize plants, resulting in a reduced harvest index. Consistent with this finding, Saleem *et al.* (2015) also reported a higher harvest index for sole-cropped mung beans compared to intercropped ones in maize-mung bean intercropping. Similarly, Sibhatu *et al.* (2015) documented a higher harvest index for sole cowpea compared to intercropped cowpea in sorghum/cowpea intercropping. Similarly, Lyngdoh *et al.* (2020) illustrated that sole cultivation of legumes (mungbean, soybean, and groundnut) resulted in a higher harvest index over their intercrop.

In the case of different levels of fertilizer treatment, in the year 2020, the plot treated with 100 % Nano NPK fertilizers had the highest harvest index followed by the plot treated 50% RDF +50% Nano NPK fertilizers and 100% RDF. Statically, the least HI was noted in the control plot in 2020. The year 2021 and when data were mean both showed a similar pattern. The superior performance of the plot treated with 100% Nano NPK fertilizers can be attributed to the unique characteristics of nano-scale fertilizers. Nano NPK fertilizers, with their reduced particle size, enhance nutrient absorption efficiency. This increased efficiency likely resulted in improved nutrient uptake by the crops, promoting robust growth and development. The heightened nutrient absorption efficiency facilitated optimal resource allocation, allowing for a greater proportion of assimilates to be directed toward reproductive structures, ultimately leading to a higher harvest index. The plot treated with 50% RDF + 50% Nano NPK fertilizers also demonstrated a notable Harvest Index. The combination of conventional RDF with nano-scale fertilizers contributed to a balanced nutrient supply. This synergistic approach optimized nutrient availability and absorption efficiency, providing a favorable environment for the crops to allocate resources effectively to reproductive organs. In comparison, the plot treated with 100% RDF, although still performing well, exhibited a slightly lower harvest index. This could be attributed to the conventional nature of the fertilizers and the potential limitations in nutrient absorption efficiency compared to nano-scale fertilizers. While the recommended dose of conventional fertilizers supported plant growth, the enhanced efficiency

of nutrient uptake associated with nano-scale fertilizers provided an added advantage in terms of reproductive development and, consequently, a higher harvest index. In the study by Chinnappa *et al.* (2023), a superior harvest index was observed in the treatment group receiving a combination of 75% recommended nitrogen-phosphorus (RNP) as a basal application, along with nano urea and DAP. Furthermore, in comparison to the control plot, Benzon *et al.* (2015) found that the plot treated with 50% recommended dose of nitrogen (RDN) through Urea and 50% through Nano urea exhibited the highest straw yield. This outcome is likely attributed to the controlled release of nutrients, as it releases nutrients based on demand. In the study by Midde *et al.* (2021), the plot treated with nanofertilizers exhibited the highest harvest index. The authors proposed that this outcome might be attributed to the maturation of leaves, which involves numerous functional and anatomical changes leading to a reversal of transport direction from importing to exporting. This reversal potentially triggers enhanced transportation capabilities, specifically in terms of penetration movements within the plant system, ultimately resulting in a higher biological yield and, consequently, the highest harvest index. Abd El-Azeim *et al.* (2019) reported significant and the highest harvest index in their research, particularly in the foliar-applied treatment involving 50% of NPK nanofertilizers at half the recommended level. This result suggests improved yield components for potatoes compared to all other nano or non-nano fertilizer treatments.

Analysis revealed that the interaction between the cropping system and different fertilizer levels showed no statistically significant difference throughout both growing seasons (2020 and 2021), as well as in the overall mean statistics.

Table 4.2.11.: Effect of cropping system and different levels of fertilizers on the yield of sole and intercrop mungbean during the growing years (2020 and 2021) and mean data.

Treatments	2020				2021				Mean data			
	Seed yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological Yield (kg ha ⁻¹)	Harvest Index (%)	Seed yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological Yield (kg ha ⁻¹)	Harvest Index (%)	Seed yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological Yield (kg ha ⁻¹)	Harvest Index (%)
A –Cropping system												
M₂	949.68 ^a	2065.25 ^a	3014.93 ^a	31.03 ^a	1002.84 ^a	2312.59 ^a	3315.42 ^a	30.17 ^a	976.26 ^a	2188.92 ^a	3165.18 ^a	30.60 ^a
M₃	723.40 ^b	1684.72 ^b	2408.12 ^b	29.83 ^b	766.70 ^b	1875.97 ^b	2642.67 ^b	28.83 ^b	745.05 ^b	1780.35 ^b	2525.40 ^b	29.33 ^b
SEm (±)	19.10	40.19	57.79	0.17	19.43	49.07	68.17	0.21	19.27	44.54	62.98	0.19
CD (P=0.05)	116.94	224.53	351.61	1.03	118.21	298.56	414.75	1.30	117.57	271.54	383.18	1.16
B-Different levels of fertilizer												
S₁	474.75 ^d	1324.18 ^d	1799.43 ^d	26.58 ^c	498.63 ^d	1303.70 ^d	1802.30 ^d	27.60 ^c	486.69 ^d	1314.17 ^d	1800.86 ^d	27.09 ^c
S₂	938.50 ^b	2088.20 ^b	3026.71 ^b	30.94 ^b	994.04 ^b	2359.52 ^b	3353.56 ^b	29.59 ^b	966.27 ^b	2223.86 ^b	3190.13 ^b	30.26 ^b
S₃	785.63 ^c	1600.91 ^c	2386.54 ^c	32.85 ^a	827.76 ^c	1809.67 ^c	2637.43 ^c	31.36 ^a	806.70 ^c	1705.29 ^c	2511.98 ^c	32.10 ^a
S₄	1047.28 ^a	2486.16 ^a	3633.44 ^a	31.37 ^b	1218.64 ^a	2904.30 ^a	4122.90 ^a	29.46 ^b	1182.96 ^a	2695.21 ^a	3878.17 ^a	30.41 ^b
SEm (±)	27.38	53.55	74.42	0.41	27.40	64.21	87.54	0.48	27.39	58.88	80.98	0.44
CD (P=0.05)	84.34	164.99	229.27	1.26	84.41	197.83	269.70	1.47	84.37	181.41	249.48	1.37
Interaction (A x B)	S	S	S	NS	S	S	S	NS	S	S	S	NS

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

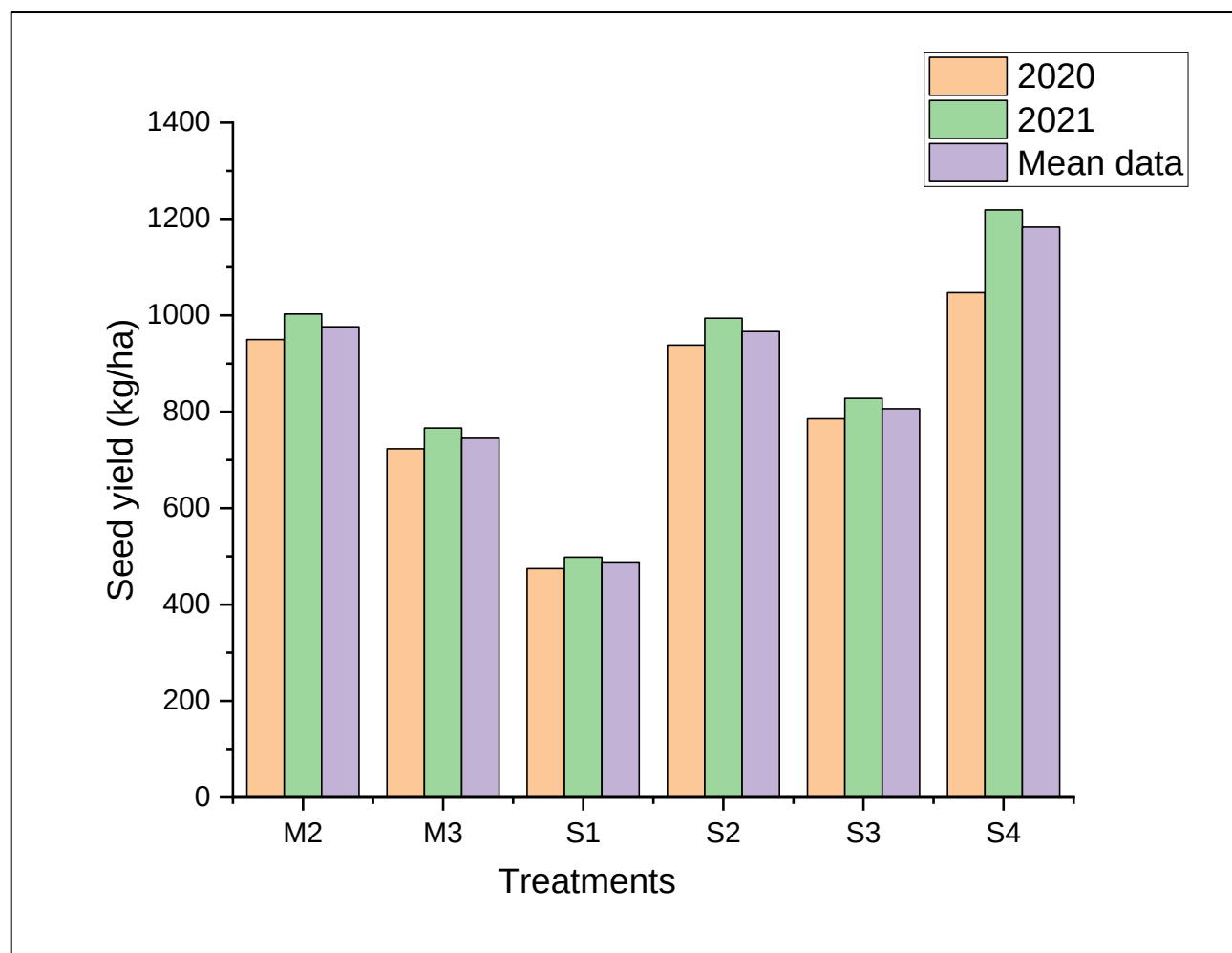


Fig 4.2.11a: Effect of cropping system and different levels of fertilizers on the seed yield (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

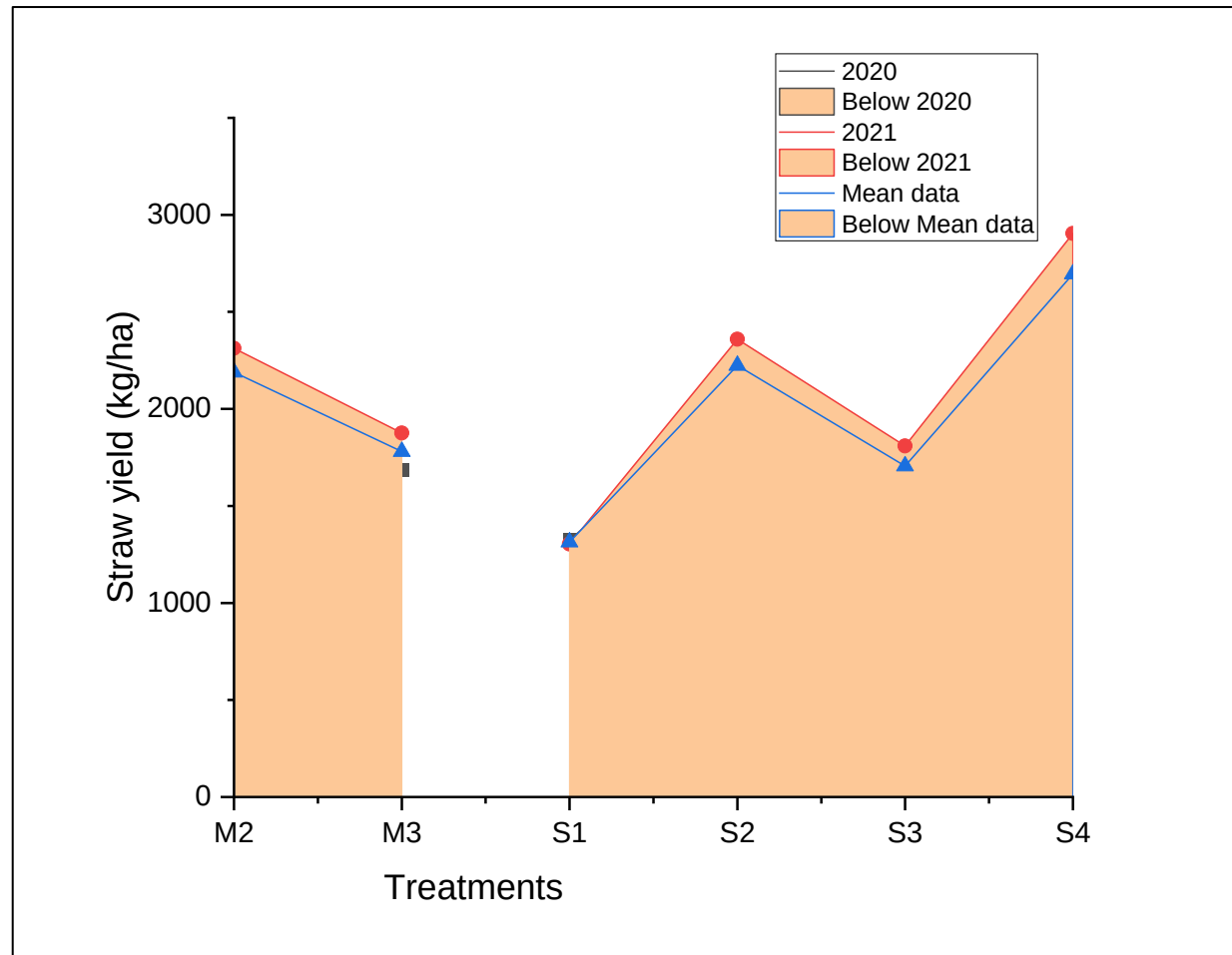


Fig 4.2.11b: Effect of cropping system and different levels of fertilizers on the straw yield (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

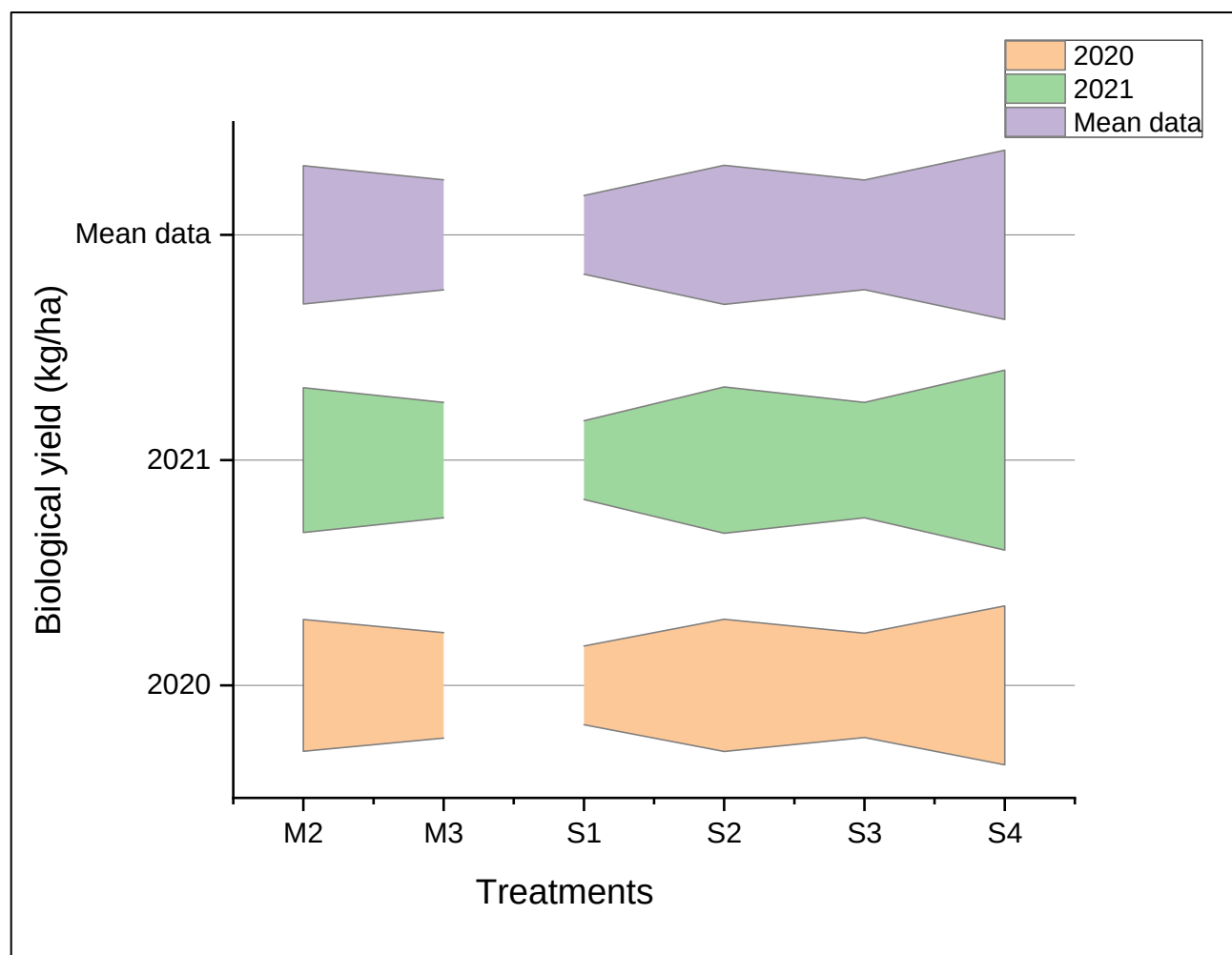


Fig 4.2.11c: Effect of cropping system and different levels of fertilizers on the biological yield (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

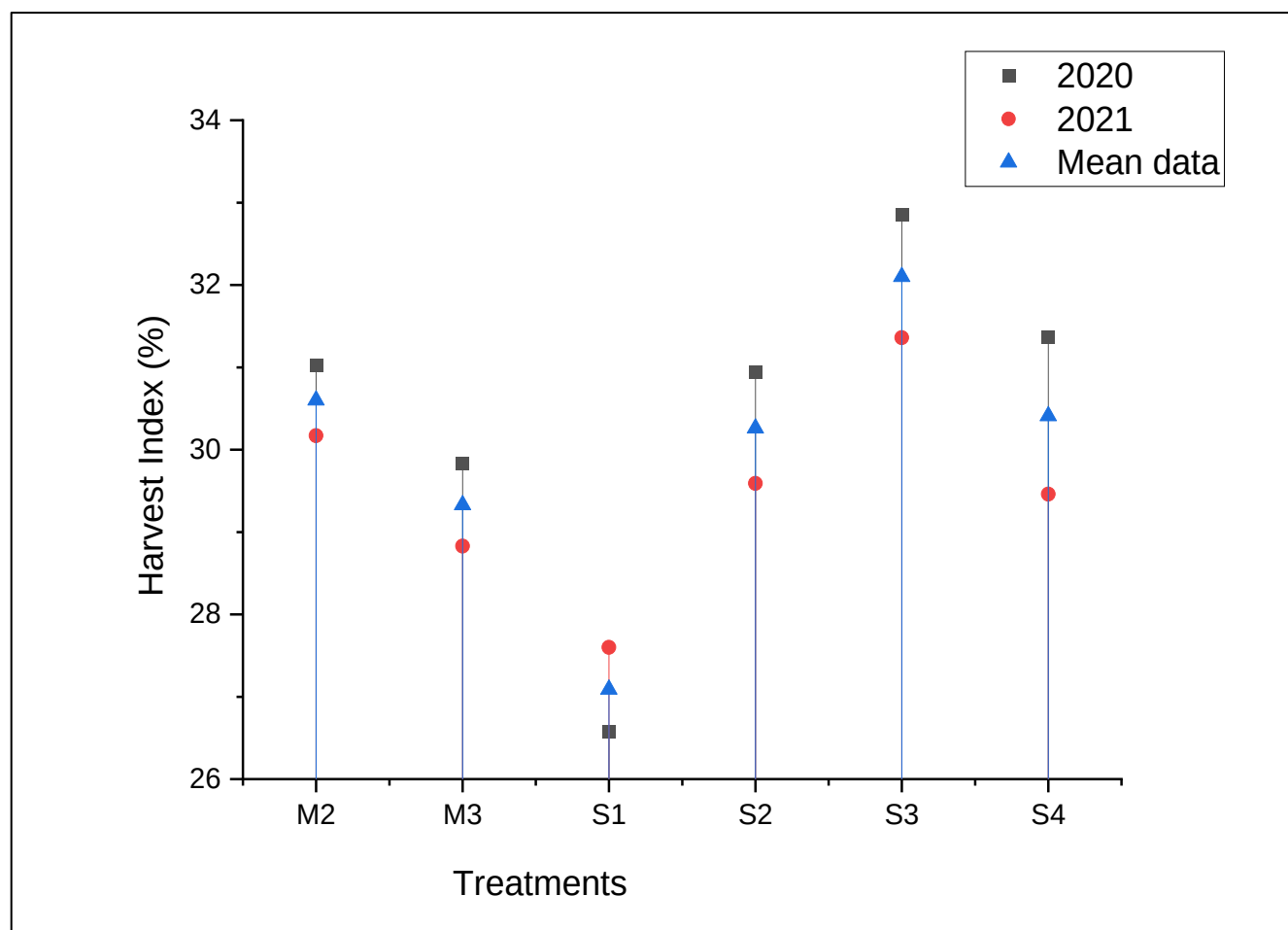


Fig 4.2.11d: Effect of cropping system and different levels of fertilizers on the harvest index (%) of sole and intercrop mungbean during the years (2020 and 2021) and Mean data. M2=Mungbean (sole), M3=Maize + Mungbean (intercropping), S1=Control, S2=100% RDF, S3=100% Nano NPK fertilizers, S4= 50% RDF + 50% Nano NPK fertilizers.

Table 4.2.11a: Interaction between cropping systems and different fertilizer levels on the seed yield (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	557.49 ^e	1026.78 ^b	867.28 ^c	1347.15 ^a	601.39 ^e	1086.54 ^b	903.13 ^c	1420.29 ^a	566.48 ^e	851.22 ^b	848.59 ^c	1284.97 ^a
M₃	392.89 ^f	850.22 ^c	703.98 ^d	947.40 ^{bc}	395.88 ^f	901.54 ^c	752.39 ^d	1017.00 ^{bc}	371.06 ^f	558.09 ^c	646.06 ^d	930.57 ^{bc}
SEm (±)	38.71				38.75				38.73			
CD(P=0.05)	119.26				119.37				119.32			

Table 4.2.11b: Interaction between cropping systems and different fertilizer levels on the straw yield (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	1504.30 ^{cd}	2168.95 ^b	1728.70 ^c	2759.06 ^a	1515.01 ^d	2470.10 ^b	1969.04 ^c	3296.19 ^a	1509.65 ^d	2319.52 ^b	1848.87 ^c	3027.63 ^a
M₃	1045.05 ^e	2007.46 ^b	1473.11 ^d	2213.26 ^b	1092.32 ^e	2248.94 ^b	1650.30 ^d	2512.33 ^b	1068.69 ^e	2128.20 ^b	1561.70 ^d	2362.80 ^b
SEm (±)	75.74				90.81				83.27			
CD(P=0.05)	233.33				279.78				256.55			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.11c: Interaction between cropping systems and different fertilizer levels on the biological yield (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	2061.79 ^e	3195.73 ^b	2595.99 ^d	4106.21 ^a	2116.40 ^e	3556.64 ^b	2872.18 ^d	4716.48 ^a	2089.09 ^e	3376.19 ^b	2734.08 ^d	4411.34 ^a
M₃	1437.07 ^f	2857.68 ^{cd}	2177.09 ^e	3160.66 ^{bc}	1488.19 ^f	3150.47 ^{cd}	2402.69 ^e	3529.33 ^{bc}	1462.63 ^f	3004.07 ^{cd}	2289.89 ^e	3345.00 ^b
SEm (±)	105.24				123.80				114.52			
CD(P=0.05)	324.24				381.41				352.82			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.3 Nutrient uptake (kg/ha)

4.1.2.3.1 Nitrogen uptake in straw (kg/ha)

The cropping system and various fertilizer levels' influences on the mungbean nitrogen uptake in straw during the 2020 and 2021 *kharif* seasons, as well as mean data, are shown in Table 4.2.12. In the year 2020, the plot where mungbean was cultivated as a sole crop showed the maximum uptake of nitrogen in straw, but the plot where mungbean was intercropped with mungbean showed the lowest uptake of nitrogen in straw. Similar patterns were seen in both the 2021 case and the mean statistics. In the sole crop scenario, mungbean experienced reduced competition for essential resources such as nitrogen, sunlight, water, and nutrients. This unimpeded access to resources allowed the mungbean plants to take up a greater amount of nitrogen from the soil. As a result, the nitrogen uptake in the straw of mungbean plants grown as a sole crop was maximized. Conversely, in the intercropped plots with maize, the shared resources and interspecific competition likely led to a less favorable environment for nitrogen uptake by mungbean. The competing presence of maize may have restricted the availability of nitrogen in the soil, reducing the uptake efficiency of mungbean in intercropped settings. The varying growth patterns and nutrient requirements between mungbean and maize could have further contributed to suboptimal nitrogen uptake by mungbean in intercropped plots. Moreover, the potential for nitrogen-fixing abilities of mungbean in the sole crop setting might have been more effectively utilized. Mungbean is known for its capacity to form symbiotic relationships with nitrogen-fixing bacteria in its root nodules, enhancing its ability to acquire nitrogen from the atmosphere. In the presence of maize in intercropped plots, the efficiency of this nitrogen-fixing process may have been compromised due to competition for resources. This also may be owing to enhanced soil essential micro-nutrients availability and improved seed and straw yield in the sole mungbean crop over intercrop mungbean, which likely resulted in greater nutrient uptakes. Xia *et al.* (2013) also reported a notable reduction in the nitrogen (N) uptake per plant of peanut in maize–peanut intercropping in comparison to peanut monoculture. This decline could be attributed to differences in root growth, possibly influenced by the interactive effects between aboveground growth and root proliferation. Ben-chuan *et al.* (2022) presented analogous results, revealing that the nitrogen (N) uptake per plant in the intercropping of peanut with maize exhibited

a significant reduction.

The nitrogen uptake of straw was significantly impacted by varied levels of fertilizers in both the 2020 and 2021 growing seasons as well as in the mean data (Table 4.2.12). The plot treated with 50% RDF + 50% Nano NPK fertilizer had the highest N uptake in straw in 2020, followed by 100% RDF and 100% Nano NPK fertilizer, whereas the control plot had the least nitrogen uptake in straw. In the case of 2021 and mean data, similar outcomes to those of 2020 were observed. This difference can be attributed to the sole crop scenario with 50% RDF, mungbean experienced a favorable environment with reduced competition for essential resources such as nitrogen, sunlight, water, and nutrients. The application of 50% RDF provided a balanced and recommended dose of fertilizers, ensuring optimal nutrient supply. This facilitated efficient nitrogen uptake by mungbean, resulting in the maximum mean value of N uptake in straw. The reduced competition allowed mungbean to utilize available resources more effectively, contributing to enhanced nitrogen absorption. Conversely, in the intercropped plots with maize and the control condition, the shared resources and interspecific competition likely created a less favorable environment for nitrogen uptake by mungbean. The absence of additional fertilizers in the control condition further limited the nutrient supply, compromising the nitrogen uptake efficiency of mungbean. The varying growth patterns and nutrient requirements between mungbean and maize in intercropped settings could have exacerbated the challenges associated with nitrogen uptake. Moreover, the intercropped plots may have experienced greater competition for nitrogen, as maize and mungbean may have had differing nitrogen demands. This competition, coupled with the absence of supplemental fertilizers in the control condition, led to a reduced nitrogen uptake by mungbean in intercropped plots, resulting in the minimum recorded Mean value of N uptake in straw. Chavan (2019), Rawat *et al.* (2020), Mir *et al.* (2015), Dhansil *et al.* (2018), Prihastani *et al.* (2018), Shebl *et al.* (2019), Singh (2015), Suriyaprabha *et al.* (2012), Nibin (2019), and Prasad *et al.* (2012) all documented an increased uptake of nutrients, particularly N, P, and K, attributed to the application of nanofertilizers.

The interaction between the cropping system and various fertilizer levels were recorded to be significant in 2020, 2021 and as in the mean statistics. The maximum mean value of N uptake in straw was recorded in sole mungbean in

conjunction with 50% RDF while the minimum was found in intercrop mungbean in combination with the control in both seasons (2020 and 2021) as well as when data were pooled (Table 4.2.12a).

4.1.2.3.2 Nitrogen uptake in grain (kg/ha)

The cropping system and various fertilizer levels' impact on the mungbean nitrogen uptake in grain during the 2020 and 2021 *kharif* seasons, and in the mean statistics, were shown in Table 4.2.13. In the year 2020, the higher uptake of N in grain was noted in the plot where mungbean was grown as sole mungbean while the lower uptake of N in grain was recorded in the plot where mungbean was cultivated with maize. In the case of 2021 and mean statistics, similar outcomes to those of 2020 were observed. This difference can be attributed to the conditions in the sole crop scenario, where mungbean faced reduced competition for crucial resources such as nitrogen, sunlight, water, and nutrients. The unhindered access to these resources allowed mungbean plants to absorb a more substantial amount of nitrogen from the soil, resulting in an elevated N uptake in the grains. The absence of interspecific competition in the sole crop setting created an environment conducive to efficient nutrient uptake and allocation to reproductive structures, such as grains. In contrast, in the intercropped plots with maize, the shared resources and interspecific competition likely created less favorable conditions for nitrogen uptake by mungbean. The presence of maize may have limited the availability of nitrogen in the soil, diminishing the efficiency of nitrogen uptake by mungbean. The differing growth patterns and nutrient requirements between mungbean and maize could have additionally contributed to suboptimal nitrogen uptake by mungbean in intercropped plots. The asynchronous growth cycles of the two crops might have led to inefficient resource utilization, particularly affecting nitrogen uptake during critical stages of grain development. Mohan *et al.* (2023) observed a substantial increase in nitrogen (N), phosphorus (P), and potassium (K) uptake in both seed and stover, in the exclusive cultivation of soybean. In contrast, the lowest uptake and yields were noted in rice intercropped with soybean. This difference may be attributed to the significantly enhanced nutrient absorption by seed and stover, influenced by their higher yields resulting from increased total dry matter in sole soybean cultivation. Additionally, Gao *et al.* (2020) noted a decline in nitrogen (N) uptake specifically for peanuts within a maize-peanut intercropping system.

The nitrogen uptake of grain was significantly impacted by varied levels of fertilizers in both seasons, 2020 and 2021, as well as when the data were average. The plot treated with 50% RDF + 50% Nano NPK fertilizer had the maximum nitrogen uptake in grain in 2020, followed by 100% RDF and 50% Nano NPK fertilizers, respectively. On the control plot, the year 2020 had reported the lowest N uptake in grain. However, when data were mean and in the year 2021 as well a similar pattern was reported. In the plot treated with 50% RDF + 50% Nano NPK fertilizer, a synergistic effect likely played a crucial role in optimizing nitrogen uptake in grains. The balanced combination of conventional RDF and nano-scale NPK fertilizers provided an ideal blend of nutrients, enhancing nutrient absorption efficiency. This synergistic action resulted in the plot achieving the highest recorded nitrogen uptake in grains in 2020 and 2021. The plot treated with 100% RDF also performed well, indicating the effectiveness of adhering to the recommended dose of conventional fertilizers. This approach ensured an ample and balanced supply of essential nutrients, supporting efficient nitrogen uptake and contributing to the notable nitrogen content in the grains. Similarly, the plot treated with 50% Nano NPK fertilizers showcased a favorable outcome. The nano-scale nature of the fertilizers likely enhanced nutrient absorption efficiency, contributing to a notable nitrogen uptake in grains, although slightly lower than that of the 50% RDF + 50% Nano NPK plot. This study is supported by the outcomes of Abdel-Aziz *et al.* (2016), who stated that usage of nanofertilizers foliarly in conjunction with mineral fertilizers increased nitrogen uptake by crops. Similar findings were reported by Upadhyay *et al.* (2023) in their study. They found that, whether applied individually or in combination, nano-fertilizers consistently exhibited comparable levels of nitrogen uptake in mustard crops throughout the entire research period.

The interaction between the cropping system and different fertilizer levels were noted to be significant in both the years (2020 and 2021) as well as when the data from both years were mean. The sole mungbean was shown to have the highest uptake of N in grain when combined with 50% RDF + 50% Nano NPK fertilizers while the minimum was recorded in intercrop mungbean in combination with the control in both seasons (2020 and 2021) as well as when data were mean (Table 4.2.12b).

Table 4.2.12.: Effect of cropping system and different levels of fertilizers on the nitrogen uptake of straw and grain of sole and intercrop mungbean during the growing years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Nitrogen uptake (kg/ha)		Nitrogen uptake (kg/ha)		Nitrogen uptake (kg/ha)	
	Straw	Grain	Straw	Grain	Straw	Grain
A –Cropping system						
M ₂	25.30 ^a	40.17 ^a	26.69 ^a	42.45 ^a	25.99 ^a	41.31 ^a
M ₃	20.75 ^b	31.00 ^b	21.94 ^b	31.04 ^b	21.35 ^b	30.19 ^b
SEm (±)	0.26	0.39	0.26	0.45	0.26	0.25
CD (P=0.05)	1.58	2.40	1.61	2.75	1.58	1.55
B-Different levels of fertilizer						
S ₁	10.67 ^d	16.45 ^d	11.21 ^d	17.27 ^d	10.94 ^d	16.86 ^d
S ₂	26.56 ^b	42.11 ^b	27.89 ^b	44.21 ^b	27.23 ^b	43.16 ^b
S ₃	18.59 ^c	33.87 ^c	20.07 ^c	36.58 ^c	19.33 ^c	35.22 ^c
S ₄	36.28 ^a	46.59 ^a	38.09 ^a	48.92 ^a	37.18 ^a	47.75 ^a
SEm (±)	0.58	0.86	0.59	0.88	0.58	0.87
CD (P=0.05)	1.79	2.65	1.83	2.72	1.81	2.69
Interaction (Ax B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.12a: Interaction between cropping system and different levels of fertilizers on the nitrogen uptake of straw (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	12.78 ^d	30.67 ^b	20.73 ^b	41.42 ^a	13.42 ^d	32.09 ^b	22.38 ^b	43.49 ^a	13.10 ^d	31.31 ^b	21.55 ^b	42.46 ^a
M₃	8.57 ^e	22.57 ^{cd}	16.44 ^c	31.13 ^b	9.00 ^e	23.70 ^{cd}	17.76 ^c	32.69 ^b	8.79 ^e	23.13 ^{cd}	17.10 ^d	31.91 ^b
SEm (±)	0.82				0.84				0.83			
CD(P=0.05)	2.53				2.59				2.56			

Table 4.2.12b: Effect of cropping system and different levels of fertilizers on the nitrogen uptake of grain (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	20.08 ^e	49.47 ^b	36.36 ^c	54.79 ^a	21.08 ^e	51.95 ^b	39.26 ^c	57.52 ^a	20.58 ^e	50.71 ^b	37.81 ^c	56.15 ^a
M₃	12.82 ^f	34.74 ^{cd}	31.38 ^d	38.39 ^c	13.46 ^f	36.47 ^{cd}	33.90 ^d	40.31 ^c	13.14 ^f	35.61 ^{cd}	32.64 ^d	39.35 ^c
SEm (±)	1.22				1.25				1.24			
CD(P=0.05)	3.75				3.85				3.80			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.3.3 Phosphorous uptake in straw (kg/ha)

The impact of various fertilizer levels and cropping system on the phosphorous uptake of straw in both seasons (2020 and 2021) and mean data was significant (Table 4.2.13). A higher uptake of P in straw was recorded in the plot where mungbean was grown as the sole crop whereas a lower uptake of P in straw was recorded in the plot where mungbean was intercropped with maize in both the seasons 2020 and 2021 and also when both data were mean. This result can be attributed to mungbean which stood as the sole crop, which diminished competition for essential resources, including phosphorus, sunlight, water, and nutrients, facilitated unobstructed access for mungbean plants. This unhindered access allowed for an increased uptake of phosphorus from the soil, resulting in a heightened P uptake in the straw. The absence of interspecific competition in the sole crop setting created a more favorable environment for efficient nutrient uptake and allocation to various plant structures, particularly the straw. Conversely, in plots where mungbean was intercropped with maize, the shared resources and interspecific competition likely generated a less favorable environment for phosphorus uptake by mungbean. The presence of maize may have constrained the availability of phosphorus in the soil, diminishing the efficiency of phosphorus uptake by mungbean. The distinct growth patterns and nutrient requirements between mungbean and maize further contributed to suboptimal phosphorus uptake in intercropped plots. Furthermore, the intercropped plots may have faced heightened competition for phosphorus, given the varying phosphorus demands of maize and mungbean. This competition, coupled with the shared resources, likely restricted the availability of phosphorus in the soil, resulting in a lower phosphorus uptake by mungbean in intercropped plots. Akhtar *et al.* (2022) found that chickpea performed more effectively as a sole crop, demonstrating higher biomass yield and accumulating greater nitrogen (N) and phosphorus (P) contents in the grain compared to the intercropping of chickpea with wheat. In the findings of Tang *et al.* (2021), it was observed that the uptake of phosphorus (P) was comparatively lower in intercrops involving legumes and cereal intercropping, as opposed to sole crops.

In the case of different levels of fertilizer treatment, in 2020, the plot supplied with 50 % RDF +50 % Nano NPK fertilizers had the highest uptake of phosphorous in straw followed by the plot treated with 100 % RDF and 100 % Nano

NPK fertilizers. According to statistics, the control plot's 2020 uptake of phosphorus from straw was the lowest. When both sets of data were average, a similar pattern was seen in the year 2021 as well. This result could be attributed to the improved efficiency of nutrient release and uptake facilitated by the Nano NPK fertilizers, providing a balanced and readily available supply of phosphorus to the plants. The combination of 50% RDF and Nano NPK likely optimized nutrient utilization, resulting in enhanced phosphorus uptake in the straw compared to other fertilizer treatments. The effectiveness of nanofertilizers application through foliar spray not only improves the uptake mechanism but also depends on factors such as leaf surface area (Babu *et al.* 2022), plant nutritional requirements (Tarafdar *et al.* 2012), the quantity of applied nitrogen (Grillo *et al.* 2021), and the efficiency of utilizing native soil nitrogen (Tarafdar *et al.* 2014).

In 2020 and 2021 growing years as well as when the data from both years were mean, it was determined that there was no significant interaction between the cropping system and different fertilizer levels.

4.1.2.3.4 Phosphorous uptake in grain (kg/ha)

The phosphorus uptake of grain was significantly impacted by varied levels of fertilizers and cropping system in 2020 and 2021, as well as when the two sets of data were mean (Table 4.2.13). A higher uptake of P in grain was recorded in the plot where mungbean was grown as the sole crop whereas a lower uptake of P in grain was recorded in the plot where mungbean was intercropped with maize in both the seasons 2020 and 2021 as well as when both the data were mean. The rationale behind this observed difference lies in the reduced competition for essential resources, including P, in the sole crop scenario. When mungbean was grown as the sole crop, it experiences unimpeded access to nutrients, sunlight, water, and other resources, allowing for a more efficient uptake of P from the soil. This favorable environment promotes optimal nutrient absorption and allocation to reproductive structures, such as grains. Conversely, in the intercropped plots with maize, shared resources and interspecific competition likely created a less favorable environment for phosphorus uptake by mungbean. The competing presence of maize may have restricted the availability of phosphorus in the soil, diminishing the efficiency of P uptake by mungbean in intercropped plots. The consistent data emphasizes the importance of resource competition in influencing phosphorus uptake efficiency in mixed-crop systems. Comparable

outcomes in sole groundnut over intercropped groundnut with maize were found by Mandal *et al.* (2014). Lyndoh *et al.* (2020) demonstrated that the exclusive cultivation of sole groundnut resulted in a greater total P uptake, providing evidence that groundnut exhibits enhanced efficiency in utilizing available phosphorus. This efficiency is further supported by the higher P content observed in both the grain and stover of groundnut plants.

In the case of different levels of fertilizer treatment, in the year 2020, the plot treated with 50% RDF +50% Nano NPK fertilizers had the highest uptake of P in grain followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot had the lowest uptake of P in grain in 2020. When data were mean and in 2021, a similar pattern was observed. The reason for this outcome can be attributed to the synergistic effect created by the balanced combination of conventional RDF and nano-scale NPK fertilizers in the 50% RDF + 50% Nano NPK treatment. This optimal blend provided an enhanced nutrient supply, leading to improved P absorption efficiency and resulting in the highest recorded uptake in grains. Similarly, the plot treated with 100% RDF demonstrated effective P uptake, indicating the benefits of adhering to the recommended dose of conventional fertilizers. The plot treated with 100% Nano NPK fertilizers also exhibited favorable phosphorus uptake, likely owing to the advantageous properties of nano-scale fertilizers. The data emphasizes the importance of nutrient management practices, specifically the synergistic combination of conventional and nano-scale fertilizers, in influencing P uptake efficiency in crop cultivation. Similarly, Zahedi *et al.* (2020) reported that the application of nanofertilizers improves growth and yield by enhancing protein content and facilitating the uptake of other essential nutrients. Consistent findings were documented in studies conducted by Prasad *et al.* (2012), Suriyaprabha *et al.* (2012), Anonymous (2016), El Metwally *et al.* (2018), Vinh *et al.* (2019), Al-Gym and Al-Asady (2020), and Melika *et al.* (2015).

It was determined that the interaction between the cropping system and different fertilizer levels was not significant in either of the two years (2020 and 2021) and when the data from two years were mean, a similar trend was recorded.

Table 4.2.13: Effect of cropping system and different levels of fertilizers on the phosphorous uptake of straw and grain (kg/ha) of sole and inter-crop mungbean during the years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Phosphorous uptake (kg/ha)		Phosphorous uptake(kg/ha)		Phosphorous uptake (kg/ha)	
	Straw	Grain	Straw	Grain	Straw	Grain
A –Cropping system						
M₂	4.14 ^a	5.48 ^a	4.55 ^a	5.92 ^a	4.34 ^a	5.63 ^a
M₃	2.89 ^b	3.93 ^b	3.18 ^b	3.93 ^b	3.04 ^b	3.73 ^b
SEm (±)	0.09	0.21	0.10	0.22	0.09	0.21
CD (P=0.05)	0.57	1.27	0.59	1.33	0.58	1.30
B-Different levels of fertilizer						
S₁	1.02 ^d	2.13 ^d	1.12 ^d	1.70 ^d	1.07 ^d	1.61 ^d
S₂	4.13 ^b	5.54 ^b	4.55 ^b	6.08 ^b	4.34 ^b	5.75 ^b
S₃	3.06 ^c	4.00 ^c	3.37 ^c	4.08 ^c	3.21 ^c	3.86 ^c
S₄	5.85 ^a	7.15 ^a	6.44 ^a	7.86 ^a	6.14 ^a	7.50 ^a
SEm (±)	0.17	0.27	0.18	0.30	0.17	0.29
CD (P=0.05)	0.53	0.84	0.56	0.93	0.55	0.89
Interaction (A x B)	NS	NS	NS	NS	NS	NS

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.3.5 Potassium uptake in straw (kg/ha)

In both the 2020 and 2021 growing seasons, as well as when the two sets of data were mean, different fertilizer doses and cropping system had a significant impact on the potassium uptake of straw (Table 4.2.14). Higher uptake of K in straw was recorded in the plot where mungbean was cultivated as the sole crop while the lower uptake of K in straw was recorded in the plot where mungbean was intercropped with maize. The results recorded are true for both the growing seasons (2020 and 2021) as well as when the data were mean. In the case of sole mungbean crop, reduced competition for essential resources, including potassium, sunlight, water, and nutrients, created favorable conditions for mungbean. This unimpeded access allowed mungbean plants to take up a greater amount of potassium from the soil, resulting in a higher potassium uptake in the straw. The absence of interspecific competition in the sole crop setting facilitated efficient nutrient uptake and allocation to various plant structures, particularly the straw. Conversely, in plots where mungbean was intercropped with maize, shared resources and interspecific competition likely created a less favorable environment for potassium uptake by mungbean. The presence of maize may have restricted the availability of K in the soil, diminishing the efficiency of potassium uptake by mungbean. The distinct growth patterns and nutrient requirements between mungbean and maize further contributed to suboptimal K uptake in intercropped plots. Moreover, the intercropped plots may have faced heightened competition for K, as maize and mungbean may have had differing potassium demands. This competition, coupled with shared resources, likely limited the availability of K in the soil, resulting in a lower K uptake by mungbean in intercropped plots. Likewise, according to Lyngdoh *et al.* (2020), soybean grown alone exhibited a greater K uptake in grains, while mungbean planted in a 1:1 ratio displayed the lowest K uptake in grains. Gao *et al.* (2020) presented comparable findings, noting that the exclusive cultivation of groundnut resulted in higher uptake of NPK compared to the intercropping of maize and groundnut, where each crop was grown together.

The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest uptake of potassium in straw in the case of varying levels of fertilizers treatment in the year 2020, next to the plot treated with 100% RDF and 100% Nano NPK fertilizers. According to statistics, the control plot had the lowest K uptake in straw in 2020. However, a comparable pattern was noted in the year 2021 and

in the mean statistics. The data consistently reveals that the plot subjected to a combination of 50% RDF and 50% Nano NPK fertilizers demonstrated the highest K uptake in straw. The rationale behind this lies in the plot treated with 50% RDF + 50% Nano NPK fertilizers, where a synergistic effect is believed to have played a pivotal role in optimizing potassium uptake in straw. The harmonious combination of traditional RDF and nano-scale NPK fertilizers created an optimal nutrient blend, thereby enhancing the efficiency of nutrient absorption. This synergistic interaction culminated in the plot achieving the highest recorded K uptake in straw. AL-Gym and Al-Asady (2020) suggested that the increased nutrient absorption facilitated by the application of nanofertilizers could be attributed to their role in enhancing the solubility and dispersion of insoluble nutrients in the soil. Additionally, nanofertilizers may contribute to reducing nutrient mineralization and stabilizing the soil, thereby increasing the bioavailability of nutrients. This effect is linked to the improved efficiency of soil biology, influenced by the enhanced effectiveness of additives (Veronica *et al.* 2015).

In the growing seasons of 2020 and 2021, as well as when the data sets were mean, it was found that there was considerable interaction between the cropping system and various fertilizer levels. The maximum mean value of K uptake in straw was recorded in sole mungbean in conjunction with 50 % RDF + 50 % Nano NPK fertilizers which was comparable to higher than all other interaction effects. While the minimum uptake of K in straw was found in intercrop mungbean in combination with the control in both years i.e., 2020 and 2021 as well as when data were mean (Table 4.2.14a).

4.1.2.3.6 Potassium uptake in grain (kg/ha)

The potassium uptake of grain in both the 2020 and 2021 growing seasons, as well as when data were mean, had been significantly affected by the effects of varied fertilizer levels and cropping system (Table 4.2.14). In the year 2020, a higher uptake of K in grain was recorded in the plot where mungbean was grown as the sole crop whereas lower uptake of K in grain was recorded in the plot where mungbean was intercropped with maize. A similar pattern was also recorded in 2021 and when data were mean. The plots with sole mungbean cultivation exhibited higher K uptake in grain, attributed to reduced competition for resources. Conversely, intercropped plots with maize showed lower K uptake due to shared resources and interspecific competition, limiting nutrient availability for

mungbean. The distinct growth patterns and varying K demands between mungbean, and maize further contributed to suboptimal K uptake in intercropped plots. Comparable suppositions were confirmed by Singh *et al.* (2018), who also found that the chickpea seed and stover had the maximum levels of N, P, and K uptake, respectively. Related outcomes were made by Lyngdoh *et al.* (2020), who stated that sole soybean absorbed more NPK nutrients than when they were combined with maize.

In the case of different levels of fertilizer treatment, in the year 2020, the plot applied with 50 % RDF +50 % Nano NPK fertilizers had the highest uptake of K in grain, next to the plot treated with 100 % RDF and 100 % Nano NPK fertilizers. Statically, the least uptake of K in grain was recorded in the control plot in 2020. A comparable pattern was noted in 2021 and in the mean data. This outcome can be attributed to the enhanced efficiency of nutrient release and uptake facilitated by the Nano NPK fertilizers, which provided a balanced and readily available supply of K to the plants. The combination of 50% RDF and Nano NPK likely optimized nutrient utilization, resulting in improved K uptake in the grains compared to other fertilizer treatments. As stated by Lopez-Valdez *et al.* (2018), nanofertilizers play a crucial role in making specific nutrients available and promoting plant growth, achieving results that conventional fertilizer systems cannot reach. The application of nanofertilizers significantly influenced the absorption of NPK. Consistent findings supporting these outcomes were also reported by Manikandan and Subramanian (2016), Ha *et al.* (2018), and Raliya *et al.* (2016).

The interaction between the cropping system and various fertilizer levels was shown to be significant in both the years (2020 and 2021) as well as when data were mean. The highest mean value of uptake of potassium in grain was recorded in sole mungbean in conjunction with 50% RDF + 50 % Nano NPK fertilizers which was statically superior to all other interactions effect while intercrop mungbean was found to have the minimum uptake of potassium in grain in 2020, 2021 and mean data (Table 4.2.14b).

Table 4.2.14: Effect of cropping system and different levels of fertilizers on the potassium uptake of straw and grain (kg/ha) of sole and inter-crop mungbean during the years (2020 and 2021) and mean data.

Treatments	2020		2021		Mean data	
	Potassium uptake(kg/ha)		Potassium uptake (kg/ha)		Potassium uptake(kg/ha)	
	Straw	Grain	Straw	Grain	Straw	Grain
A –Cropping system						
M₂	18.47 ^a	11.56 ^a	19.39 ^a	12.02 ^a	18.93 ^a	11.79 ^a
M₃	15.24 ^b	9.60 ^b	16.00 ^b	9.98 ^b	15.62 ^b	9.79 ^b
SEm (±)	0.49	0.19	0.67	0.48	0.58	0.34
CD (P=0.05)	1.52	1.22	2.05	1.49	1.78	1.36
B-Different levels of fertilizer						
S₁	8.13 ^d	4.30 ^d	8.54 ^d	4.47 ^d	8.33 ^d	4.39 ^d
S₂	20.78 ^b	13.34 ^b	21.81 ^b	13.88 ^b	21.29 ^b	13.61 ^b
S₃	15.14 ^c	9.46 ^c	15.89 ^c	9.84 ^c	15.51 ^c	9.65 ^c
S₄	23.37 ^a	15.21 ^a	24.54 ^a	15.82 ^a	23.95 ^a	15.51 ^a
SEm (±)	0.47	0.18	0.49	0.21	0.48	0.20
CD (P=0.05)	1.45	1.19	1.52	1.25	1.49	1.22
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.2.14a: Interaction between cropping system and different levels of fertilizers on the potassium uptake of straw (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

Straw	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	9.38 ^e	21.42 ^{bc}	20.73 ^b	24.07 ^a	9.84 ^e	22.49 ^{bc}	19.96 ^b	25.27 ^a	9.61 ^e	21.95 ^{bc}	19.48 ^b	24.67 ^a
M ₃	6.88 ^f	20.12 ^c	16.44 ^d	22.66 ^{ab}	7.23 ^f	21.13 ^c	11.82 ^d	23.80 ^{ab}	7.05 ^f	20.63 ^c	11.55 ^{ab}	23.23 ^{ab}
SEm (±)	0.68				0.70				0.69			
CD(P=0.05)	2.10				2.16				2.13			

Table 4.2.14b: Interaction between cropping system and different levels of fertilizers on the potassium uptake of grain (kg/ha) of sole and intercrop mungbean during the years (2020 and 2021) and mean data.

Grain	2020				2021				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	5.77 ^f	14.86 ^b	9.92 ^d	15.68 ^a	6.00 ^f	15.46 ^b	10.32 ^d	16.30 ^a	5.88 ^f	15.16 ^b	10.12 ^d	15.98 ^a
M ₃	2.83 ^g	11.82 ^c	9.00 ^e	14.74 ^b	2.94 ^g	12.94 ^c	9.36 ^e	15.33 ^b	2.89 ^g	12.06 ^c	9.18 ^e	15.04 ^b
SEm (±)	0.22				0.23				0.22			
CD(P=0.05)	0.68				0.70				0.69			

Means followed by different letters (a, b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.2.5.4. Correlation Analysis

Simple correlation analysis to study the degree of association between the growth and yield component with the grain yield was carried out for each season (2020, 2021 and mean data). In the 2020 *kharif* season, the relationship between yield, growth, and yield characteristics of mungbean is presented in Table 4.2.15. The relationship between seed yield and yield characteristics including plant height, no. of leaves, LA, LAI, no. of branches per plant, shoot dry weight, CGR, no. of pods per plant, no. of seeds per plant, no. of seeds per pod, pod length, and test weight was positive and highly significant. The relationship between the plant height and the other growth and yield parameters was positive and significant. The correlation between the leaf area index, growth, and yield characteristics is likewise favorable and significant. All the growth and yield characteristics were shown to be significantly correlated with the no. of branches per plant, shoot dry weight, CGR, no. of pods per plant, no. of seeds per plant, no. of seeds per pod, pod length, and test weight.

The *kharif* season of 2021's mungbean seed yield, growth, and yield characteristics are correlated, as shown in Table 4.2.16. Between grain yield, growth (no. of leaves, LA, LAI, no. of branches per plant, shoot dry weight, CGR), and yield attributes (no. of pods per plant, no. of seeds per plant, no. of seeds per pod, pod length, and test weight), a significant and positive correlation was observed in the year 2021. The plant height, growth, and yield characteristics also showed a positive and significant correlation. The no. of leaves, LA, LAI, branches per plant, shoot dry weight, CGR, pods per plant, seeds per plant, seeds per pod, pod length, and test weight were also found to be significantly linked with all growth and yield characteristics.

The relationship between mungbean seed yield, growth, and yield characteristics is shown in Table 4.2.17 (Mean data). The seed yield and growth, as well as yield traits like plant height, no. of leaves, LA, leaf LAI, no. of branches per plant, shoot dry weight, crop growth rate, no. of pods per plant, no. of seeds per plant, no. of seeds per pod, pod length, and test weight, were all positively and highly significantly correlated in the Mean data. The variables of plant height, growth, and yield also showed a favorable and significant correlation. All the growth and yield parameters were found to significantly correlate with the no. of leaves, LA, LAI, no. of branches per plant, shoot dry weight, CGR, no. of pods

per plant, no. of seeds per plant, no. of seeds per pod, pod length, and test weight.

The positive and highly significant correlation between seed yield and various yield characteristics in maize, as revealed by the data, can be ascribed to the positive association with plant height, number of leaves, Leaf Area (LA), Leaf Area Index (LAI), and shoot dry weight indicates that taller and more vigorously growing plants tend to allocate increased resources to seed production. Similarly, the positive relationships observed with the number of branches per plant, number of pods per plant, and pod length underscore the contribution of greater branching and prolific pod development to overall seed yield. Reproductive metrics, such as the number of seeds per plant and number of seeds per pod, exhibit positive correlations, emphasizing that higher reproductive efficiency correlates with enhanced seed yield. Furthermore, the positive correlation with Crop Growth Rate (CGR) indicates that a faster and sustained crop growth contributes positively to overall seed yield. Lastly, the positive relationship with test weight suggests that heavier seeds play a role in achieving a higher seed yield. Collectively, these findings underscore the interplay of genetic, environmental, and management factors promoting optimal growth, development, and reproductive success in maize plants, ultimately leading to increased seed production. This outcome is coherent with the outcomes of [Kumar *et al.* 2014], they found a positive association between seed yield and the yield components in pea. Comparable outcomes were stated by [Panigrahi *et al.* (2014); Sheak (2017)], who found that most mung bean attributes were positively and substantially correlated with seed yield. Thus, any improvement in these characteristics would result in a significant increase in seed production. Zaid *et al.* (2012) also reported comparable findings. Similar significant and favourable correlations between seed yield per hectare and yield components were determined by Degefa *et al.* (2014); Kumar *et al.* (2013); Reni *et al.* (2013); Mathivathana *et al.* (2015); Jyothsna *et al.* (2016) previously explained significant positive connections between plant height and growth and yield components.

Table 4.2.15: Matrix of the correlation coefficient between growth and yield attributes of sole and intercrop mungbean during the year 2020 *kharif* season in Punjab.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.764*)	1.000										
3	(0.899*)	(0.774*)	1.000									
4	(0.937*)	(0.712*)	(0.866*)	1.000								
5	(0.865*)	(0.707*)	(0.834*)	(0.789*)	1.000							
6	(0.913*)	(0.636*)	(0.846*)	(0.943*)	(0.788*)	1.000						
7	(0.891*)	(0.598*)	(0.797*)	(0.939*)	(0.750*)	(0.990*)	1.000					
8	(0.901*)	(0.781*)	(0.916*)	(0.912*)	(0.799*)	(0.820*)	(0.796*)	1.000				
9	(0.944*)	(0.649*)	(0.881*)	(0.958*)	(0.812*)	(0.963*)	(0.952*)	(0.865*)	1.000			
10	(0.811*)	(0.802*)	(0.827*)	(0.809*)	(0.699*)	(0.770*)	(0.748*)	(0.799*)	(0.808*)	1.000		
11	(0.874*)	(0.846*)	(0.910*)	(0.887*)	(0.802*)	(0.844*)	(0.803*)	(0.913*)	(0.848*)	(0.925*)	1.000	
12	(0.896*)	(0.848*)	(0.915*)	(0.919*)	(0.920*)	(0.852*)	(0.845*)	(0.807*)	(0.913*)	(0.862*)	(0.928*)	1.000

1. Seed yield

2. Plant height

3. Number of leaves

4. Leaf area index

5. Number of branches/plant

* = Significant at 5 % level of probability

7. Shoot dry weight.

8. Crop growth rate

9. Number of pods/plant

10. Number of seeds/plant

11. Pod length

12. Test weight

Table 4.2.16: Matrix of the correlation coefficient between growth and yield attributes of sole and intercrop mungbean during the year 2021 *kharif* season in Punjab.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.782*)	1.000										
3	(0.945*)	(0.827*)	1.000									
4	(0.961*)	(0.870*)	(0.947*)	1.000								
5	(0.960*)	(0.869*)	(0.946*)	(0.961*)	1.000							
6	(0.917*)	(0.790*)	(0.907*)	(0.917*)	(0.942*)	1.000						
7	(0.938*)	(0.716*)	(0.912*)	(0.920*)	(0.910*)	(0.859*)	1.000					
8	(0.920*)	(0.668*)	(0.871*)	(0.900*)	(0.896*)	(0.890*)	(0.969*)	1.000				
9	(0.928*)	(0.826*)	(0.933*)	(0.918*)	(0.956*)	(0.920*)	(0.868*)	(0.875*)	1.000			
10	(0.943*)	(0.825*)	(0.938*)	(0.939*)	(0.941*)	(0.900*)	(0.968*)	(0.912*)	(0.878*)	1.000		
11	(0.931*)	(0.919*)	(0.911*)	(0.893*)	(0.949*)	(0.885*)	(0.899*)	(0.861*)	(0.893*)	(0.935*)	1.000	
12	(0.897*)	(0.871*)	(0.914*)	(0.919*)	(0.922*)	(0.869*)	(0.847*)	(0.817*)	(0.927*)	(0.863*)	(0.942*)	1.000

1. Seed yield

2. Plant height

3. Number of leaves

4. Leaf area index

5. Number of branches/plant

* = Significant at 5 % level of probability

7. Shoot dry weight.

8. Crop growth rate

9. Number of pods/plant

10. Number of seeds/plant

11. Pod length

12. Test weight

Table 4.2.17: Matrix of the correlation coefficient between growth and yield attributes of sole and intercrop mungbean (Mean data).

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.773*)	1.000										
3	(0.922*)	(0.801*)	1.000									
4	(0.949*)	(0.791*)	(0.907*)	1.000								
5	(0.913*)	(0.788*)	(0.890*)	(0.875*)	1.000							
6	(0.913*)	(0.713*)	(0.877*)	(0.930*)	(0.865*)	1.000						
7	(0.915*)	(0.654*)	(0.855*)	(0.930*)	(0.830*)	(0.925*)	1.000					
8	(0.911*)	(0.725*)	(0.894*)	(0.906*)	(0.848*)	(0.855*)	(0.966*)	1.000				
9	(0.936*)	(0.738*)	(0.907*)	(0.938*)	(0.884*)	(0.942*)	(0.836*)	(0.870*)	1.000			
10	(0.877*)	(0.814*)	(0.883*)	(0.874*)	(0.820*)	(0.835*)	(0.960*)	(0.856*)	(0.843*)	1.000		
11	(0.903*)	(0.881*)	(0.911*)	(0.890*)	(0.876*)	(0.865*)	(0.862*)	(0.887*)	(0.871*)	(0.930*)	1.000	
12	(0.897*)	(0.860*)	(0.915*)	(0.919*)	(0.921*)	(0.861*)	(0.846*)	(0.812*)	(0.920*)	(0.863*)	(0.935*)	1.000

1. Seed yield

2. Plant height

3. Number of leaves

4. Leaf area index

5. Number of branches/plant

* = Significant at 5 % level of probability

7. Shoot dry weight.

8. Crop growth rate

9. Number of pods/plant

10. Number of seeds/plant

11. Pod length

12. Test weight

4.1.2.6. Economics of mungbean

The impact of different fertilizer levels and cropping systems on the economics of the mungbean are illustrated in Table 4.2.18. (2020, 2021 and mean data). When 2020, 2021, and mean data were considered, the plot with mungbean as the sole crop produced superior economics than the plot with mungbean intercropped with maize, which resulted in lower values for all the economies. Considering the benefit-cost ratio in both situations exceeded 1, this research is anticipated to add value. This indicates that the benefits derived from the agricultural activities outweighed the costs incurred. The anticipation that this research would add value is grounded in the consistent economic viability revealed by the benefit-cost ratio exceeding 1 in cropping scenarios. The decision to cultivate mungbean as a sole crop, as opposed to intercropping with maize, proved to be economically favorable based on the data, providing valuable insights for optimizing agricultural practices and resource allocation in the future. According to Ghosh *et al.* (2020), the elevated productivity in the legume system can be attributed to the higher market prices of pulse crops (such as chickpea, pigeon pea, and mung bean) compared to cereals (including rice, wheat, and maize), as well as the increased productivity of the pulse crop. Kinyua *et al.* (2023) observed that the enhanced productivity of legumes in comparison to maize-legume intercrops is attributed to reduced competition for growth resources. Additionally, they noted that the yield of pigeon pea under traditional farming practices surpassed that of improved maize-legume systems.

The plot treated with 50% RDF + 50% Nano NPK fertilizers produced the highest economics among the various fertilizer treatments followed by plot treated with 100 % RDF and 100 % Nano NPK fertilizers respectively. As opposed to the control plot, which had the lowest gross returns per hectare, cultivation costs per hectare, net benefits per hectare, and benefit-cost ratio. This research is expected to be valuable because, except for the control plot, all fertilizer application levels yielded BCR values higher than 1 (2020, 2021, and mean data). The reason for this outcome can be attributed to the synergistic effect created by the balanced combination of conventional RDF and nano-scale NPK fertilizers in the 50% RDF + 50% Nano NPK treatment. This optimal blend provided an enhanced nutrient supply, leading to improved nutrient absorption efficiency, and ultimately resulted in higher economic returns. The plot treated with 100% RDF

also demonstrated favorable economic outcomes, indicating the effectiveness of adhering to the recommended dose of conventional fertilizers. Similarly, the plot treated with 100% Nano NPK fertilizers showcased positive economic results, likely due to the advantageous properties of nano-scale fertilizers. The data underlines the economic advantages associated with specific fertilizer treatments, providing valuable insights for future agricultural practices and resource management. Nibin (2019) observed that the application of nano NPK formulations led to an enhancement in net returns for okra. Similar positive outcomes were documented by Spruogis *et al.* (2013) in spring barley. El-Saadony *et al.* (2021) noted a reduction in costs and an improvement in nutrient utilization efficiency when utilizing nutrients in nano form. Sadhukhan *et al.* (2021) found that the use of nanofertilizers resulted in a higher benefit-to-cost (B:C) ratio compared to alternative treatments. This can be attributed to the higher-grade classification (A grade) of produce from crops treated with nanofertilizers in the market, while produce from other treatments received B grade or lower due to compromised quality parameters. These findings align with the results reported by Kumar *et al.* (2014).

The interaction between the cropping system and different fertilizer levels demonstrated significance in both the years 2020 and 2021, as well as when the data were mean. The highest mean values for economic parameters (Gross return, net return, and B:C ratio) were observed in sole mungbean combined with 50 % RDF+50 % Nano NPK fertilizers. This combination exhibited statistically superior results compared to all other interactions. In contrast, intercrop mungbean showed the lowest mean values for all economic indicators in both 2020 and 2021, as well as in the mean data (Table 4.2.18a, 4.2.18b, and 4.2.18c).

Table 4.2.18.: Economics of sole and intercrop mungbean as influenced by cropping system and different fertilizer levels during the years (2020 and 2021) and mean data.

Treatments	2020			2021			Mean data		
	Gross re- turn (Rs/ha)	Net return (Rs/ha)	B: C ratio	Gross return (Rs/ha)	Net return (Rs/ha)	B: C ratio	Gross return (Rs/ha)	Net return (Rs/ha)	B: C ratio
A –Cropping system									
M₂	77777.93 ^a	46399.41 ^a	1.44 ^a	90448.13 ^a	58264.40 ^a	1.76 ^a	84113.03 ^a	52331.91 ^a	1.60 ^a
M₃	59469.43 ^b	31018.91 ^b	1.04 ^b	69366.11 ^b	40110.39 ^b	1.31 ^b	64417.77 ^b	35564.65 ^b	1.18 ^b
SEm (±)	1526.55	1254.85	0.04	1884.06	1758.76	0.05	1705.31	1506.80	0.04
(P= 0.05)	9287.44	7634.43	0.26	11462.56	10700.20	0.29	10375.00	9167.31	0.27
B-Different levels of fertilizer									
S₁	39466.42 ^d	16530.42 ^d	0.71 ^c	45280.46 ^d	21539.26 ^d	0.89 ^d	42373.44 ^d	19034.84 ^d	0.80 ^d
S₂	76957.27 ^b	43314.97 ^b	1.28 ^b	89789.06 ^b	55341.57 ^b	1.60 ^b	83373.16 ^b	49328.27 ^b	1.44 ^b
S₃	64127.46 ^c	33291.96 ^c	1.07 ^b	74459.06 ^c	42818.36 ^c	1.35 ^c	69293.26 ^c	38055.16 ^c	1.21 ^c
S₄	93943.58 ^a	61699.29 ^a	1.90 ^a	110099.90 ^a	77050.41 ^a	2.31 ^a	102021.74 ^a	69374.85 ^a	2.11 ^a
SEm (±)	2185.68	2300.96	0.06	2412.26	2447.69	0.07	2298.97	2374.33	0.07
(P= 0.05)	6733.75	7088.91	0.20	7431.78	7540.94	0.22	7082.76	7314.93	0.21
Interaction (AxB)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table.4.2.18a: Interaction between cropping system and different level of fertilizers on the Gross return (Rs/ha) of sole and intercrop mungbean.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₂	46442 ^c	83965 ^a	70715 ^a	109990 ^a	54497 ^c	97927 ^b	81228 ^b	128141 ^a	50470 ^e	90946 ^b	75972 ^c	119065 ^a
M₃	32491 ^d	69949 ^a	57540 ^b	77898 ^a	36064 ^d	81651 ^b	67690 ^b	92059 ^b	34277 ^f	75800 ^c	62615 ^d	84978 ^{bc}
SEm (±)	3087				3411				3249			
CD(P=0.05)	9511				10510				10011			

Table.4.2.18b: Interaction between cropping system and different levels of fertilizers on the Net return (Rs/ha) of sole and intercrop mungbean.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₂	22042 ^e	48859 ^b	38416 ^c	76281 ^a	29292 ^e	62015 ^b	48123 ^c	93627 ^a	25667 ^e	55437 ^b	43269 ^c	84954 ^a
M₃	11019 ^f	37771 ^{cd}	28168 ^{de}	47117 ^{bc}	13787 ^f	48668 ^{cd}	37513 ^{de}	60474 ^b	12403 ^f	43220 ^{cd}	32841 ^{de}	53795 ^{bc}
SEm (±)	3254				3498				3376			
CD(P=0.05)	10025				10778				10402			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table.4.2.18c: Interaction between cropping system and different levels of fertilizer on the B:C ratio of sole and intercrop mungbean.

	2020				2021				Mean Data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₂	0.90 ^f	1.39 ^{cd}	1.19 ^d	2.26 ^a	1.16 ^d	1.73 ^c	1.45 ^{cd}	2.71 ^a	1.03 ^e	1.56 ^{cd}	1.32 ^d	2.49 ^a
M₃	0.51 ^g	1.17 ^{de}	1.00 ^{ef}	1.53 ^{bc}	0.62 ^e	1.48 ^c	1.24 ^d	1.91 ^b	0.57 ^f	1.33 ^d	1.10 ^e	1.73 ^{bc}
SEm (±)	0.08				0.10				0.09			
CD(P=0.05)	0.26				0.31				0.28			

Means followed by different letters (a ,b, c, and d) are statically different at 0.05 %, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₂= Mungbean (sole), M₃= Maize + Mungbean (intercropping), S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3. WHEAT

4.1.3.1 Growth components

4.1.3.1.1 Plant population (m²)

The emphasis of the current study is on the impacts of the crop residues and the different fertilizer levels on the population of wheat plants during the *rabi* seasons of 2020–2021 and 2021–2022 along with mean statistics. In 2020–2021 and 2021–2022 and in the mean statistics, the residual effect of crops influenced the population of wheat plants. The maximum plant population, which was comparable to the plot where mungbean was planted as a sole crop before wheat but much better than the other treatments, was found in the plot where mungbean and maize were intercropped before wheat. The lowest number of plant population was reported in the plot where maize was the only crop grown before wheat. When the statistics were mean, a comparable pattern was seen (Table 4.3.1). The observed phenomenon in the wheat plant population can be attributed to the findings of several studies. Shukla *et al.* (2021) reported that residue incorporation of summer legumes has proven to be beneficial in enhancing various growth parameters and growth indices. This suggests that the residual effects of legumes may have contributed to the increased wheat plant population, as seen in the plot where mungbean, a legume, was cultivated before wheat. Furthermore, Padma *et al.* (2019) highlighted the importance of crop residue management, specifically focusing on legumes, and its impact on the growth and yield of succeeding maize. Their findings support the idea that the residual effects of legumes, such as mungbean, could have positively influenced the wheat plant population, given the intercropping practices mentioned. Ndiso *et al.* (2018) suggested that the enhanced growth of crops, such as maize, might result from increased mineralization, a high concentration of nitrogen accumulated in legume residues returned to the soil, and the addition of organic matter through crop residues. This aligns with the notion that the residual effects of mungbean, and maize intercropping could have enriched the soil with essential nutrients, contributing to the observed higher wheat plant population.

During the two growing seasons and after the data were mean, different fertilizer levels had a significant influence on the plant population of wheat. The plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the maximum plant population among the various fertilizer rates followed by the plot treated with 100

% RDF and 100 % Nano NPK fertilizers in both the seasons 2020-2021 and 2021-2022 as well as when both the data were mean. The control plot, however, had the smallest plant population in both growing seasons. Similar data to those from both years were found when the data were mean. This outcome suggests that the application of Nano NPK fertilizers alongside conventional fertilizers had a positive impact on plant growth. The combination of traditional RDF and Nano NPK fertilizers likely might have provided a more balanced and readily available nutrient supply, promoting optimal plant development and, consequently, a higher plant population. The positive effects observed in both the 2020-2021 and 2021-2022 growing seasons, as well as when the data were Mean, indicate the consistency and reliability of this fertilizer combination across different periods. Similarly, plots treated with 100 % RDF and 100 % Nano NPK fertilizers also showed favorable results, although the combination of 50 % RDF and 50 % Nano NPK outperformed them in terms of plant population. The control plot, which did not receive any additional fertilizers, exhibited the smallest plant population, underscoring the importance of proper nutrient supplementation for optimal crop growth. Pooling the data from both years further confirmed the trends observed in individual seasons, emphasizing the reliability and robustness of the findings. Overall, the results highlight the significance of finding the right balance in fertilizer application, particularly the incorporation of Nano NPK fertilizers, to enhance wheat plant population and, by extension, potentially improve yield. The significant influence of different fertilizer levels on wheat plant population during the two growing seasons, and after pooling the data, can be further elucidated by insights from research studies. Nongbet *et al.* (2022) highlighted that nanofertilizers enhance plant growth through direct application as well as foliar methods. Studies, including Lv *et al.* (2019) and Rossi *et al.* (2019), have suggested that exposure to nanoparticles within certain limits stimulates plant growth and seed germination. Furthermore, Ghosh and Bera (2021) emphasized the positive impact of nanofertilizers on various aspects of crop development, including seed germination, shoot and root growth, chlorophyll content, photosynthesis, and abiotic stress tolerance, ultimately leading to increased crop yield and quality. Saharan *et al.* (2016), Kondal *et al.* (2021), and Saharan *et al.* (2015) found that nanoparticles had favorable effects on morphological and physiological features in germinating seeds and foliar treatments, enhancing the growth of seedlings,

biomass, germination capacity, and seed vigor index in various crops such as chickpea, maize, and tomato seedlings. Moreover, studies by Acharya *et al.* (2020) and Anand *et al.* (2020) associated nanoparticles with developing seed vigor, suggesting that they may penetrate the hard coating of seeds, facilitating water absorption and the germination process. Verma *et al.* (2022) contributed to the understanding by indicating that nano-fertilizers significantly enhance plant growth performance. These nanofertilizers can either directly supply one or more nutrients to plants, leading to enhanced growth and yield, or facilitate the better performance of conventional fertilizers. Al-Juthery *et al.* (2018) also supported the positive influence of nano-fertilizers on plant growth parameters in wheat. Collectively, these findings provide a scientific basis for the observed higher wheat plant population in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers. The nanofertilizers ability to enhance plant growth, nutrient absorption, and overall crop performance aligns with the consistently observed trend in wheat plant population across the two growing seasons and when the data were Mean.

The residual impact of crops and various fertilizer levels interacted significantly during the growing years (2020-2021 and 2021-2022) and in the mean data. The plot where mungbean was planted as the sole crop earlier than wheat along with 50 % RDF + 50 % Nano NPK fertilizers had the highest mean value of plant population in both growing seasons. While the mean value of plant population was lowest in plots where maize was previously the sole crop planted along with no fertilizer (control). Similar results were observed when the data were mean (Table 4.3.1a, 4.3.1b, 4.3.1c, 4.3.1d, and 4.3.1e).

Table 4.3.1.: Effect of the residual effect of crops and different fertilizer levels on the plant population of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	Plant population/m ²		
	2020-2021	2021-2022	Mean data
A. Residual effect of crops			
M₁	175.16 ^b	176.91 ^b	176.04 ^b
M₂	178.49 ^a	180.27 ^a	179.38 ^a
M₃	175.68 ^{ab}	177.44 ^{ab}	176.56 ^{ab}
SEm (±)	1.00	1.08	1.04
(P=0.05)	3.05	3.27	3.16
B. Different levels of fertilizers			
S₁	166.26 ^d	167.92 ^d	167.09 ^d
S₂	180.60 ^b	182.40 ^b	181.50 ^b
S₃	175.61 ^c	177.36 ^c	176.49 ^c
S₄	183.31 ^a	185.15 ^a	184.23 ^a
SEm (±)	0.71	0.95	0.83
(P=0.05)	2.16	2.88	2.52
Interaction (Ax B)	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.1a.:Interaction between residual effect of crops and different levels of fertilizer on the plant population/m² of wheat during years (2020-21,2021-22) and mean data.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	165.32 ^e	180.86 ^{bc}	173.06 ^d	181.40 ^b	166.98 ^e	182.67 ^{bc}	174.79 ^d	183.22 ^b	166.15 ^e	181.76 ^{bc}	173.93 ^d	182.31 ^b
M₂	166.83 ^e	181.40 ^b	179.29 ^c	186.43 ^a	168.50 ^e	183.22 ^b	181.08 ^c	188.29 ^a	167.66 ^e	182.31 ^b	180.19 ^c	187.36 ^a
M₃	166.63 ^e	179.53 ^c	174.47 ^d	182.11 ^b	168.30 ^e	181.33 ^c	176.21 ^d	183.93 ^b	167.46 ^e	180.43 ^c	175.34 ^d	183.02 ^b
SEm (±)	0.86				1.03				0.95			
CD (P=0.05)	2.61				3.12				2.87			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer,M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.2 Plant height (cm)

The current study emphasizes the impact of the crop residues and various levels of fertilizer on wheat plant height during the 2020-2021 and 2021-2022 *rabi* seasons as well as the mean statistics. Results showed that as the plant matured in the seasons 2020–2021 and 2021–2022, and in the mean data. At all sampling intervals, in both the seasons 2020-2021 and 2021-2022, the highest wheat plant height was noted in the plot where mungbean was cultivated as sole crop before wheat, followed by the plot where maize and mungbean were intercropped. Conversely, the lowest plant height was recorded in the plot where maize was cultivated as the sole crop before wheat. A comparable pattern was noted when the data were mean. This pattern could be attributed to the preceding cultivation of mungbean providing favorable conditions for wheat growth, while the sole cultivation of maize before wheat may have had less conducive effects on wheat plant height. The same findings were revealed by Fabunmi and Balogun (2015), who indicated that maize produced taller plants in cowpea residue-treated plots. Comparable scores were observed by Ndiso *et al.* (2018), they suggested that the increase in the growth of crops might be the result of enhanced mineralization, high concentration of nitrogen that had accumulated in the legume residue that was returned to the soil, and the addition of organic matter in the form of crop residues that amplified the accessibility of nitrogen and other essential nutrients that may have contributed to better maize crop growth. Furthermore, Gerami *et al.* (2012); Hoque *et al.* (2016) also stated that the height of wheat was significantly impacted by preceding legumes as equated to non-legume crops, which may be because of the release of several macro and micronutrients, particularly nitrogen, from the residues of these legumes. According to Shuaibu *et al.* (2015), the addition of soybean and cowpea residues increased the plant height for the subsequent maize crop. Additionally, according to Shukla *et al.* (2021), the incorporation of legume residues significantly enhanced the height of maize. Moreover, the production of hydrogen gas (H₂) as a by-product of beneficial nitrogen-fixing when legumes are cultivated as a preceding crop has a noteworthy influence on the makeup of the soil microbial population, encouraging the growth of bacteria that stimulate plant growth (Angus *et al.* 2015).

The plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the maximum plant height among the various fertilizer applications at all sampling periods in both the seasons 2020-2021 and 2021-2022 as well as when both the data were mean while it was statistically comparable to the 100 % recommended dose of NPK application at 30 DAS and 60 DAS followed by the plot applied with 100 % Nano NPK fertilizers but was considerably superior to the other treatments. The longest plant height was seen in plots applied with 50 % RDF + 50 % Nano NPK fertilizers at 90 DAS, 120 DAS, and at harvest, next by the 100% recommended dose of NPK treatment and 100 % Nano NPK fertilizers. In the years 2020-21 and 2021-22, the control had the lowest plant height at all sample periods. When the data were mean, similar data to those obtained in 2020-2021 and 2021 were noted. This superiority can be attributed to the synergistic effects of combining 50 % RDF with 50 % Nano NPK fertilizers, resulting in an optimal balance of macro and micronutrients for plant growth. The comparable performance to the 100% recommended dose of NPK at specific intervals suggests efficient nutrient utilization in the 50% RDF + 50% Nano NPK treatment, contributing to robust plant height. The considerable superiority over other treatments, including 100% Nano NPK, implies that the combined application provided a more balanced and beneficial nutrient profile for sustained plant growth throughout the sampling periods. Similarly, wheat plants grew taller after receiving 50% RDF and 50% Nano NPK fertilizer applications, possibly because these fertilizers encouraged both root and shoot growth, particularly root growth, which resulted in taller growth and taller plants. Similar results were reported by Benzon *et al.* in 2015, who highlighted that the application of conventional and nanofertilizers promoted plant height and stated the potential of nanofertilizers to provide nutrients as well as aid in the transportation or absorption of readily available nutrients as the reason for this. Several research findings propose that the foliar application of nanofertilizers exerts a more pronounced influence on overall plant growth. This phenomenon is attributed to the efficient absorption of nutrients through stomata, resulting in a reduced time lag between application and uptake, particularly during the rapid growth stage. Noteworthy studies supporting this perspective include those conducted by Solanki *et al.* (2015); Abdel-Aziz *et al.* (2016); Eleyan *et al.* (2018); Sohair *et al.* (2018); Adisa *et al.* (2019); Abd El-Azeim *et al.* (2020); Rajput *et al.* (2021); Kalwani *et al.* (2022), and Verma *et al.* (2022). Abd Alqader

et al. (2020) documented that the application of both conventional and nanofertilizers led to an enhancement in plant height. They proposed that the notable impact of high concentrations of nanofertilizers on promoting increased plant height could be attributed to the substantial permeability and rapid delivery associated with nanofertilizers. This specific characteristic facilitates the easier penetration of plant leaves, playing a pivotal role in stimulating plant growth. The study emphasized nitrogen, a constituent of nanofertilizers, for its positive influence on boosting the activity of meristematic tissues and cell division. Furthermore, the significance of nitrogen in synthesizing amino acids, such as Tryptophan, was highlighted as a foundation for the production of Auxins, which in turn contribute to both cell division and expansion.

The crop residues and various fertilizer levels interacted significantly in the year (2020-2021 and 2021-2022) and in the mean data at all sampling periods. The plot where mungbean was previously grown as a sole crop along with 50% RDF + 50% Nano NPK fertilizers had the maximum plant height during all sampling periods (30DAS, 60DAS, 90DAS, 120DAS, and at harvest) during the growing years, i.e., 2020-2021 and 2021-2022. Whereas the plant height was minimum on plots where maize had previously grown the sole crop coupled with no fertilizer (control). Similarly, when the data were mean, a similar trend was acquired in all the growing periods (Table 4.3.1a, 4.3.1b, 4.3.1c, 4.3.1d and 4.3.1e).

Table 4.3.2.: Effect of the residual effect of crops and different fertilizer levels on the plant height (cm) of wheat at all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	(2020-2021)					(202-2022)					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest
A. Residual effect of crops															
M₁	18.66 ^b	45.51 ^b	71.46 ^b	81.40 ^b	83.29 ^c	20.39 ^a	46.70 ^b	72.10 ^c	82.79 ^b	83.33 ^b	19.53 ^b	46.10 ^b	71.78 ^c	82.09 ^b	83.31 ^b
M₂	21.16 ^a	49.91 ^a	78.71 ^a	90.70 ^a	90.87 ^a	22.95 ^a	51.18 ^a	80.79 ^a	93.45 ^a	95.10 ^a	22.06 ^a	50.55 ^a	79.75 ^a	92.07 ^a	92.98 ^a
M₃	18.87 ^b	47.22 ^{ab}	74.09 ^{ab}	86.91 ^a	88.10 ^b	20.74 ^a	49.67 ^a	75.25 ^b	86.85 ^a	88.37 ^a	19.80 ^b	48.45 ^a	74.67 ^b	86.88 ^a	88.24 ^{ab}
SEm (±)	0.37	0.80	1.22	1.74	1.42	0.39	0.74	1.66	1.84	2.13	0.38	0.77	1.44	1.79	1.77
CD (P= 0.05)	1.47	3.15	4.78	6.84	5.57	1.53	2.89	6.53	7.21	8.34	1.50	3.02	5.66	7.03	6.96
B-Different levels of fertilizers															
S₁	17.07 ^b	43.67 ^c	59.51 ^c	68.49 ^d	69.27 ^d	17.02 ^c	43.13 ^c	60.26 ^d	68.60 ^d	69.54 ^d	17.05 ^c	43.40 ^c	59.89 ^d	68.54 ^d	69.40 ^d
S₂	21.05 ^a	48.67 ^a	81.93 ^a	94.75 ^b	95.25 ^b	23.62 ^a	52.31 ^a	82.14 ^b	94.67 ^b	95.58 ^b	23.34 ^a	50.49 ^a	82.03 ^b	94.71 ^b	95.42 ^b
S₃	17.60 ^b	47.20 ^b	72.88 ^b	83.75 ^c	85.04 ^c	20.36 ^b	47.68 ^b	73.86 ^c	87.78 ^c	88.01 ^c	18.98 ^b	47.44 ^b	73.37 ^c	85.76 ^c	86.52 ^c
S₄	22.53 ^a	50.65 ^a	84.70 ^a	98.37 ^a	100.12 ^a	24.44 ^a	53.62 ^a	87.93 ^a	99.74 ^a	102.61 ^a	23.49 ^a	52.13 ^a	86.31 ^a	99.06 ^a	101.36 ^a
SEm (±)	0.41	0.81	1.16	1.55	1.64	0.40	0.85	1.44	1.75	1.79	0.41	0.83	1.31	1.65	1.71
CD (P= 0.05)	1.22	2.40	3.44	4.62	4.87	1.20	2.51	4.29	5.19	5.31	1.21	2.46	3.87	4.90	5.09
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.2a: Interaction between the residual effect of crops and different levels of fertilizer on the plant height of wheat.

30DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	16.67 ^d	19.50 ^c	17.31 ^d	21.16 ^c	16.34 ^d	22.05 ^c	20.26 ^d	22.92 ^c	16.51 ^d	22.77 ^c	18.79 ^d	22.04 ^c
M ₂	17.55 ^d	23.44 ^{ab}	17.98 ^d	25.66 ^a	17.81 ^d	26.14 ^{ab}	20.64 ^d	27.35 ^a	17.62 ^d	24.79 ^{ab}	19.31 ^d	26.51 ^a
M ₃	16.99 ^d	20.21 ^c	17.49 ^d	20.77 ^{bc}	17.08 ^d	22.68 ^c	20.17 ^d	23.07 ^{bc}	17.01 ^d	21.45 ^c	18.83 ^d	21.92 ^{bc}
SEm (±)	0.82				0.70				0.76			
CD (P=0.05)	2.22				2.08				2.25			

Table 4.3.2b: Interaction between the residual effect of crops and different levels of fertilizer on the plant height of wheat.

60DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	39.92 ^c	48.33 ^a	43.21 ^{bc}	50.56 ^a	41.14 ^c	51.02 ^a	41.05 ^{bc}	53.61 ^a	40.53 ^c	49.68 ^a	42.13 ^{bc}	52.08 ^a
M ₂	50.19 ^a	47.88 ^a	50.78 ^a	50.79 ^a	44.85 ^a	53.88 ^a	51.74 ^a	54.26 ^a	47.52 ^a	50.88 ^a	51.26 ^a	52.53 ^a
M ₃	40.91 ^c	49.80 ^a	47.60 ^a	50.59 ^a	43.41 ^c	52.03 ^a	50.26 ^a	52.98 ^a	42.16 ^c	50.91 ^a	48.93 ^a	51.78 ^a
SEm (±)	1.40				1.46				1.43			
CD (P=0.05)	4.16				4.35				4.26			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.2c: Interaction between the residual effect of crops and different levels of fertilizer on the plant height of wheat.

90DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	58.68 ^e	77.86 ^c	70.60 ^d	78.71 ^c	60.51 ^e	78.35 ^c	69.58 ^d	79.95 ^c	59.60 ^e	78.11 ^c	70.09 ^d	79.33 ^c
M ₂	59.79 ^e	85.14 ^b	76.19 ^{cd}	93.72 ^a	60.49 ^e	84.88 ^b	78.53 ^{cd}	99.27 ^a	60.14 ^e	85.01 ^b	77.36 ^{cd}	96.50 ^a
M ₃	60.05 ^e	82.79 ^b	71.84 ^d	81.66 ^{bc}	59.79 ^e	83.18 ^b	73.49 ^d	84.55 ^{bc}	59.92 ^e	82.99 ^b	72.66 ^d	83.11 ^{bc}
SEm (±)	2.01				2.50				2.25			
CD (P=0.05)	5.96				7.43				6.70			

Table 4.3.2d: Interaction between the residual effect of crops and different levels of fertilizer on the plant height of wheat.

120DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	68.16 ^f	88.66 ^{cd}	79.34 ^e	89.44 ^c	69.24 ^f	90.41 ^{cd}	80.12 ^e	91.38 ^c	68.70 ^f	89.53 ^{cd}	79.73 ^e	90.41 ^c
M ₂	69.64 ^f	96.68 ^b	87.39 ^d	109.08 ^a	68.01 ^f	97.58 ^b	98.05 ^d	110.18 ^a	68.82 ^f	97.13 ^b	92.72 ^d	109.63 ^a
M ₃	67.65 ^f	98.91 ^b	84.50 ^{de}	96.59 ^{bc}	68.55 ^f	96.01 ^b	85.17 ^{de}	97.68 ^{bc}	68.10 ^f	97.46 ^b	84.84 ^{de}	97.13 ^{bc}
SEm (±)	2.69				3.02				2.86			
CD (P=0.05)	8.00				8.99				8.49			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.2e: Interaction between residual effect of crops and different levels of fertilizer on the plant height of wheat.

At harvest	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	70.49 ^{ef}	89.06 ^c	79.44 ^d	94.17 ^{bc}	69.57 ^f	90.43 ^c	81.00 ^d	92.31 ^{bc}	70.03 ^{ef}	89.75 ^c	80.22 ^d	93.24 ^{bc}
M ₂	69.88 ^f	96.39 ^b	87.13 ^{cd}	110.10 ^a	69.14 ^f	98.30 ^b	98.49 ^{cd}	114.45 ^a	69.51 ^f	97.34 ^b	92.81 ^{cd}	112.28 ^a
M ₃	67.45 ^f	100.32 ^b	88.54 ^c	96.08 ^b	69.90 ^f	97.99 ^b	84.54 ^c	101.07 ^b	68.68 ^f	99.16 ^b	86.54 ^c	98.57 ^b
SEm (±)	2.84				3.10				2.97			
CD (P=0.05)	8.43				9.20				8.82			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.3 Number of leaves

The impact of crop residues and different fertilizer levels on the number of wheat leaves throughout the 2020–2021 and 2021–2022 *rabi* seasons is shown in Table 4.3.3 along with mean data. The plot where mungbean was grown as a sole crop before wheat produced the most leaves per plant during all sample periods (30DAS, 60DAS, 90DAS, 120DAS, and at harvest), followed by the plot where maize and mungbean intercrop was grown before wheat. While the plot where maize was cultivated as the sole crop before wheat produced the fewest leaves per plant in both the seasons (2020-2021 and 2021-2022). A similar trend was observed when the data were mean. This observed pattern can be attributed to the preceding crop's influence on the soil nutrient availability and microbial activity. The cultivation of mungbean as a sole crop likely contributed to improved soil fertility and microbial diversity, creating a more favorable environment for wheat growth. The intercropping of maize and mungbean may have provided some beneficial interactions, enhancing nutrient availability. In contrast, the sole cultivation of maize before wheat might have led to a depletion of certain nutrients or the release of allelopathic substances, negatively impacting the subsequent wheat crop and resulting in fewer leaves per plant. Related conclusions were stated by Ali and colleagues in the year 2015, who found that plots previously planted with legumes have a significant influence on growth components probably as an outcome of the legumes' improved fertility. According to Adeke and Haruma (2012), the presence of previous legumes had a significant impact on the subsequent maize crop growth components. This might be owing to the higher nitrogen levels that legumes were able to symbiotically fix into the soil as associated to other earlier crop plots. Comparable results were stated by Rahim *et al.* (2019) in wheat growth parameters following the legume crop. Jinnur *et al.* (2023) reported that applying nano nutrients foliarly at 15 DAS led to significantly increased values for various parameters including plant height, number of leaves, leaf area, and other relevant factors.

The application of a fertilizer mixture consisting of 50% RDF combined with 50% Nano NPK to wheat resulted in the highest no. of leaves during all sampling periods in both the 2020-2021 and 2021-2022 seasons. This was followed by plots treated with 100 % RDF and 100 % Nano NPK fertilizers. In contrast, the control plot exhibited the fewest leaves at all sampling periods in both

years as well as when the data was mean. This phenomenon suggests that there exists a beneficial synergy between the components of the 50% RDF + 50 % Nano NPK fertilizer blend that effectively supports and might have enhances the leaf development of wheat plants. The intricate balance achieved by combining these fertilizers appears to optimize nutrient availability and uptake, fostering an environment conducive to increased leaf production. In contrast, the control plot, which did not receive any specialized fertilization, consistently exhibited the fewest number of leaves during all sampling periods in both the years under consideration. This discrepancy in leaf development between the control group and the fertilized plots underscores the importance of nutrient supplementation in achieving optimal crop growth and highlights the positive impact of the 50% RDF + 50% Nano NPK fertilizer blend on wheat leaf proliferation. The observed trends persisted even when the data from both years were combined, further reinforcing the efficacy of this specific fertilizer combination in promoting robust wheat plant growth. Abdel-Aziz *et al.* (2018) observed that the application of nano NPK positively influenced leaf growth in wheat. This effect was attributed to the improved nutrient availability facilitated by the easy penetration of the nano formulations of NPK through stomata on the leaves, utilizing gas uptake mechanisms. Noaema and Alhasany (2020) reported that the application of nano boron to plant leaves plays a pivotal role in transporting processed materials to the growth regions of the plant. This contributes to an augmentation in the number of leaves per plant. This observation is consistent with the findings presented by Alhasany *et al.* (2019) concerning faba bean and by Abo El-Hamd and Abd Elwahed (2018) in the context of okra.

At all sampling intervals, in both the years (2020-2021 and 2021-2022), and when data was mean, the interaction between the crop residues and various levels of fertilizers was significant. In both the growing years, the plot where mungbean was grown as a sole crop earlier combined with 50% RDF + 50% Nano NPK fertilizers had the highest mean no. of leaves during all the sampling periods. Whereas plots where maize was grown as the only crop earlier before wheat combined with no fertilizer were found to have the fewest leaves (control). Similarly, when the data were mean, a comparable trend was acquired in all the growing periods (Table 4.3.3a, 4.3.3b, 4.3.3c, 4.3.3d and 4.3.3e).

Table 4.3.3.: Effect of the residual effect of crops and different fertilizer levels on the number of leaves of wheat at all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	(2020-2021)					(2021-2022)					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har- vest	30DAS	60DAS	90DAS	120DAS	At har- vest	30DAS	60DAS	90DAS	120DAS	At har- vest
A. Residual effect of crops															
M₁	3.97 ^b	8.26 ^b	11.07 ^b	10.10 ^b	9.19 ^b	4.09 ^b	8.60 ^b	11.45 ^b	10.30 ^c	9.31 ^b	4.03 ^b	8.43 ^b	11.26 ^b	10.20 ^b	9.25 ^b
M₂	4.73 ^a	9.18 ^a	14.54 ^a	13.38 ^a	12.29 ^a	4.82 ^a	9.39 ^a	15.20 ^a	13.55 ^a	12.66 ^a	4.77 ^a	9.29 ^a	14.87 ^a	13.46 ^a	12.48 ^a
M₃	4.29 ^b	8.84 ^a	11.84 ^b	10.70 ^b	9.81 ^b	4.47 ^a	9.07 ^{ab}	12.01 ^b	11.13 ^b	10.11 ^b	4.38 ^b	8.95 ^a	11.93 ^b	10.92 ^b	9.96 ^b
SEm (±)	0.10	0.16	0.29	0.26	0.28	0.08	0.14	0.32	0.29	0.25	0.09	0.13	0.30	0.27	0.26
CD (P= 0.05)	0.40	0.48	1.12	1.01	1.08	0.33	0.54	1.26	1.12	0.97	0.37	0.52	1.19	1.07	1.03
B-Different levels of fertilizer															
S₁	3.63 ^d	6.39 ^d	8.93 ^d	8.37 ^d	7.19 ^c	3.71 ^c	6.60 ^d	9.63 ^d	8.34 ^d	7.50 ^c	3.67 ^d	6.49 ^d	9.28 ^d	8.35 ^c	7.35 ^d
S₂	4.60 ^b	9.43 ^b	13.62 ^b	12.56 ^a	11.95 ^a	4.84 ^b	9.66 ^b	13.93 ^b	12.95 ^b	12.26 ^a	4.72 ^b	9.55 ^b	13.78 ^b	12.75 ^a	12.10 ^a
S₃	3.94 ^c	8.62 ^c	12.70 ^c	11.46 ^c	10.77 ^b	4.01 ^b	8.84 ^c	12.98 ^c	11.79 ^c	10.97 ^b	3.98 ^c	8.73 ^c	12.84 ^c	11.63 ^b	10.87 ^c
S₄	5.15 ^a	10.61 ^a	14.68 ^a	13.18 ^a	11.82 ^a	5.28 ^a	10.99 ^a	15.00 ^a	13.56 ^a	12.04 ^a	5.21 ^a	10.80 ^a	14.84 ^a	13.37 ^a	11.93 ^a
SEm (±)	0.10	0.15	0.28	0.27	0.31	0.08	0.19	0.30	0.33	0.31	0.09	0.17	0.29	0.30	0.31
CD (P=0.05)	0.31	0.45	0.84	0.82	0.93	0.23	0.55	0.89	0.97	0.91	0.27	0.50	0.86	0.89	0.92
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.4 Leaf area (cm²)

Table 4.3.4 illustrates the impact of the residual effects of crops and various fertilizer levels on the wheat leaf area throughout the *rabi* seasons of 2020–2021 and 2021–2022 as well as mean statistics. The residual effect of crops on wheat leaf area was shown to be significant in both seasons, i.e., 2020–2021 and 2021–2022, as well as when the data were mean at all sample intervals (30DAS, 60DAS, 90DAS, 120DAS, and harvest). In both the agricultural seasons of 2020–2021 and 2021–2022, the plot in which mungbean was cultivated as a sole crop preceding the wheat planting exhibited the highest leaf area, consistently outperforming other cultivation practices. Following closely, the plot where maize and mungbean were intercropped before wheat also demonstrated a substantial leaf area. Conversely, the plot where maize was grown as a sole crop before wheat consistently recorded the minimum leaf area. This trend persisted across all the designated sampling periods. The notable difference in leaf area among the cultivation practices suggests that the preceding crop type plays a crucial role in influencing the subsequent wheat crop's leaf development. The cultivation of mungbean as a sole crop before wheat appears to have provided favorable conditions for enhanced leaf area. This could be attributed to the specific interactions between mungbean and the subsequent wheat crop, such as nutrient cycling, soil structure improvement, or other beneficial effects associated with mungbean cultivation. The intercropping of maize and mungbean also showed positive effects on leaf area, possibly indicating complementary interactions between the two crops that benefited the subsequent wheat growth. On the other hand, the minimal leaf area observed in the plot where maize was grown as a sole crop before wheat might be indicative of less favorable conditions or potential competition for resources between maize and wheat. The consistency of these trends when the data were Mean across both years further emphasizes the robustness of the observed patterns. It underscores the lasting impact of the preceding crop choice on wheat leaf area, indicating that the cultivation significantly influences the subsequent crop's foliar development. Ali *et al.* (2015) also suggested that the leaf area of maize plants was notably influenced by the presence of preceding legume (L) crops. The findings align with studies by Adeleke and Haruna (2012) and Rekha (2014) which also reported similar effects of various preceding legume crops on the growth parameters of succeeding maize.

Regarding, different levels of fertilizer treatments, at all sampling periods (30DAS, 60DAS, 90DAS, 120DAS, and at harvest), the application of 50% RDF + 50% Nano NPK fertilizers produced the highest leaf area, next to plot treated with 100% RDF and the plot treated with 100% Nano NPK fertilizers while the control plot consistently recorded the lowest leaf area. The data recorded were true for the seasons (2020-2021 and 2021-2022) and when the data were mean. This consistent pattern can be attributed to the synergistic effects of the 50% RDF + 50% Nano NPK fertilizer combination. The balanced combination of nutrients in this specific fertilizer formulation likely optimized the availability and uptake of essential elements, promoting robust leaf development throughout the crop growth stages. The 100% RDF and 100% Nano NPK treatments, while also providing sufficient nutrients, might not have achieved the same optimal balance as the 50% RDF + 50% Nano NPK blend. Conversely, the control plot, devoid of any specialized fertilization, consistently exhibited the lowest leaf area. This emphasizes the importance of nutrient supplementation in achieving optimal leaf development in crops. The cumulative impact of the balanced nutrient supply from the 50% RDF + 50% Nano NPK fertilizers across all sampling periods contributed to the sustained superiority in leaf area compared to the other treatment groups, as observed in the data analysis. Sirisena *et al.* (2013) reported comparable outcomes in rice when utilizing nano-fertilizer. They attributed the observed results to the incorporation of nano-phosphorus with DAP, enhancing the immediate accessibility of nitrogen (N) and phosphorus (P) from both chemical fertilizers and nano-phosphorus. Consequently, this contributes to an increase in leaf area. Jassim *et al.* (2023) also reported the heightened effectiveness of foliar application of nanofertilizers in influencing leaf area. This superiority was evident in both soil and foliar applications when compared to the control treatment. Additionally, Jinnur *et al.* (2023) documented that the foliar application of nanofertilizers led to significantly higher values for various parameters, including plant height, number of leaves, and leaf area of maize. Similarly, Alimam and Al-Qasim (2022) observed that the foliar application of nano-NPK, sprayed three times at different concentrations, significantly enhanced various vegetative growth traits, encompassing height, diameter, number of leaves, and leaf area.

In both the years (2020-2021 and 2021-2022) and when data were mean, the interaction between the crop residues and various fertilizer levels was significant at all sampling intervals. The plot where mungbean was previously grown as a sole crop along with 50% RDF + 50% Nano NPK fertilizers had the highest leaf area during all sampling periods. Whereas plots where maize was previously the sole crop cultivated along with no fertilizer had the least mean value of leaf area noted (control). A similar trend to the data obtained in all the growing years (2020-2021 and 2021-2022) was acquired in all the sampling periods (30DAS, 60DAS, 90DAS, 120DAS, and at harvest) when the data were mean (Table 4.3.4a, 4.3.4b, 4.3.4c, 4.3.4d and 4.3.4e).

Table 4.3.4.: Effect of the residual effect of crops and different fertilizer levels on leaf area (cm²) of wheat at all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	(2020-2021)					(2021-2022)					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest
A. Residual effect of crops															
M ₁	90.14 ^c	580.76 ^c	852.00 ^c	539.30 ^c	431.44 ^c	92.67 ^c	591.21 ^c	869.98 ^c	552.94 ^c	442.35 ^c	91.41 ^c	585.98 ^c	860.99 ^c	546.12 ^c	436.90 ^c
M ₂	141.50 ^a	824.67 ^a	1305.84 ^a	841.22 ^a	672.98 ^a	145.47 ^a	839.51 ^a	1333.39 ^a	862.50 ^a	690.00 ^a	143.49 ^a	832.09 ^a	1319.62 ^a	851.86 ^a	681.49 ^a
M ₃	108.41 ^b	655.54 ^b	1038.23 ^b	640.23 ^b	512.18 ^b	111.44 ^b	667.34 ^b	1060.14 ^b	656.43 ^b	525.14 ^b	109.93 ^b	661.44 ^b	1049.18 ^b	648.33 ^b	518.66 ^b
SEm (±)	2.62	13.40	22.32	17.70	15.58	2.59	13.46	22.24	22.16	14.52	2.60	13.43	22.28	19.93	15.05
CD (P=0.05)	10.29	52.60	87.64	69.49	61.15	10.15	52.85	87.31	87.00	57.00	10.22	52.72	87.48	78.25	59.07
B-Different levels of fertilizer															
S ₁	82.02 ^d	453.44 ^d	681.14 ^d	357.63 ^d	286.11 ^d	84.32 ^d	461.60 ^d	695.51 ^d	366.68 ^d	293.34 ^d	83.17 ^d	457.52 ^d	688.32 ^d	362.16 ^d	289.72 ^d
S ₂	121.68 ^b	743.23 ^b	1198.48 ^b	789.80 ^b	631.84 ^b	125.09 ^b	756.60 ^b	1223.77 ^b	809.78 ^b	647.8 ^b	123.38 ^b	749.91 ^b	1211.13 ^b	799.79 ^b	639.83 ^b
S ₃	105.68 ^c	678.04 ^c	1078.00 ^c	651.09 ^c	520.87 ^c	108.64 ^c	690.24 ^c	1100.74 ^c	667.56 ^c	534.05 ^c	107.16 ^c	684.14 ^c	1089.37 ^c	659.32 ^c	527.46 ^c
S ₄	144.03 ^a	873.24 ^a	1303.81 ^a	895.81 ^a	716.65 ^a	148.06 ^a	888.96 ^a	1331.32 ^a	918.47 ^a	734.78 ^a	146.04 ^a	881.10 ^a	1317.57 ^a	907.14 ^a	725.71 ^a
SEm (±)	2.95	14.36	19.90	19.59	16.54	2.99	15.10	21.21	20.08	16.07	2.97	14.73	20.38	20.40	16.30
CD (P=0.05)	8.75	42.66	59.13	58.19	49.14	8.88	44.85	63.00	59.66	47.73	8.82	43.76	60.54	60.59	48.43
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.4a: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area (cm²) of wheat.

30DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	67.38 ^g	90.98 ^e	84.44 ^f	117.57 ^d	69.27 ^g	93.53 ^e	86.80 ^f	121.08 ^d	68.32 ^g	92.25 ^e	85.62 ^f	119.43 ^d
M ₂	100.37 ^e	152.06 ^b	130.37 ^c	183.22 ^a	103.18 ^e	156.32 ^b	134.02 ^c	188.35 ^a	101.78 ^e	154.19 ^b	132.19 ^c	185.78 ^a
M ₃	78.31 ^{fg}	122.00 ^d	102.24 ^e	131.09 ^d	80.50 ^{fg}	125.41 ^d	105.10 ^e	134.76 ^d	79.40 ^{fg}	123.71 ^d	103.67 ^e	132.92 ^d
SEm (±)	5.10				5.18				5.14			
CD (P=0.05)	15.16				15.37				15.27			

Table 4.3.4b: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area (cm²) of wheat.

60DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	420.25 ⁱ	614.94 ^{ef}	558.55 ^{fg}	729.28 ^d	427.82 ⁱ	626.01 ^{ef}	568.60 ^{fg}	742.40 ^d	424.04 ⁱ	620.48 ^{ef}	563.58 ^{fg}	735.84 ^d
M ₂	500.89 ^{gh}	899.18 ^b	823.91 ^c	1074.70 ^a	509.90 ^{gh}	915.37 ^b	838.74 ^c	1094.05 ^a	505.39 ^h	907.28 ^b	831.32 ^c	1084.37 ^a
M ₃	439.19 ^{hi}	715.55 ^d	651.66 ^e	815.74 ^c	447.09 ^{hi}	728.43 ^d	663.39 ^e	830.43 ^c	443.14 ^{hi}	721.99 ^d	657.53 ^e	823.08 ^c
SEm (±)	24.87				26.15				25.51			
CD (P=0.05)	73.89				77.68				75.79			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.4c: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area (cm²) of wheat.

90DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	569.37 ⁱ	934.83 ^{fg}	870.62 ^{gh}	1033.20 ^{ef}	581.39 ⁱ	954.55 ^{fg}	888.99 ^{gh}	1055.00 ^{ef}	575.38 ⁱ	944.69 ^{fg}	879.80 ^{gh}	1044.10 ^{ef}
M ₂	803.69 ^h	1496.18 ^b	1310.47 ^c	1613.02 ^a	820.64 ^h	1527.75 ^b	1338.12 ^c	1647.06 ^a	812.17 ^h	1511.97 ^b	1324.29 ^c	1630.04 ^a
M ₃	670.36 ⁱ	1164.45 ^d	1052.90 ^e	1265.22 ^{cd}	684.50 ⁱ	1189.02 ^d	1075.12 ^e	1291.92 ^{cd}	677.43 ⁱ	1176.73 ^d	1064.01 ^e	1278.57 ^{cd}
SEm (±)	34.47				36.12				35.30			
CD (P=0.05)	102.41				107.31				104.86			

Table 4.3.4d: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area (cm²) of wheat.

120DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	291.06 ^f	608.04 ^d	539.75 ^{de}	718.34 ^c	298.42 ^f	623.42 ^d	553.40 ^{de}	736.52 ^c	294.74 ^f	615.73 ^d	546.58 ^{de}	727.43 ^c
M ₂	444.96 ^e	1016.84 ^a	806.30 ^{bc}	1096.78 ^a	456.22 ^e	1042.57 ^a	826.70 ^{bc}	1124.53 ^a	450.59 ^e	1029.70 ^a	816.50 ^{bc}	1110.65 ^a
M ₃	336.87 ^f	744.52 ^c	607.21 ^d	872.31 ^b	345.39 ^f	763.36 ^c	622.57 ^d	1124.53 ^b	396.55 ^f	893.55 ^c	716.96 ^d	998.42 ^b
SEm (±)	33.93				36.73				35.33			
CD (P=0.05)	100.79				81.41				104.95			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.4e: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area (cm²) of wheat.

At harvest	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	232.85 ^g	486.43 ^d	431.80 ^{ef}	574.67 ^c	238.74 ^g	498.74 ^d	442.72 ^{ef}	589.21 ^c	235.79 ^g	492.58 ^d	437.26 ^{ef}	581.94 ^c
M₂	355.97 ^f	813.47 ^a	645.04 ^{bc}	877.42 ^a	364.98 ^f	834.05 ^a	661.36 ^{bc}	899.62 ^a	360.47 ^f	823.76 ^a	653.20 ^{bc}	888.52 ^a
M₃	269.50 ^g	595.62 ^c	485.77 ^{de}	697.85 ^b	276.32 ^g	610.69 ^c	498.06 ^{de}	715.50 ^b	272.91 ^g	603.15 ^c	491.91 ^{de}	706.68 ^b
SEm (±)	28.65				27.83				28.24			
CD (P=0.05)	85.11				82.67				83.89			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizer

3.1.5 Leaf Area Index (LAI)

Table 4.3.5 illustrates the impact of various fertilizer levels and crop residues on wheat's leaf area index throughout the *rabi* seasons of 2020–2021 and 2021–2022, as well as the mean data. The maximum leaf area index was consistently observed in the plot where mungbean was cultivated as the sole crop before wheat at all sampling intervals. Following closely, the plot where maize and mungbean were grown as an intercrop before wheat exhibited the next highest leaf area. In contrast, the minimum leaf area was consistently recorded when maize was cultivated as the sole crop before wheat in both the seasons, 2020 and 2021, and when the data were mean. This observed variation in leaf area index can be attributed to the preceding crops' influence on the soil environment and nutrient availability. The cultivation of mungbean as the sole crop before wheat likely contributed to improved soil fertility, providing favorable conditions for wheat growth and resulting in the highest leaf area. The intercropping of maize and mungbean, while not as conducive as the sole cultivation of mungbean, still showed a positive effect on leaf area, possibly due to complementary interactions between the two crops. On the contrary, the plot where maize was grown as the sole crop before wheat consistently recorded the minimum leaf area. This may be indicative of potential nutrient competition or less favorable soil conditions for wheat growth following maize cultivation. In comparison to the other crop that was grown before wheat, the mungbean may have fixed extra nitrogen into the soil by symbiotic nitrogen fixation, which may have contributed to the preceding crop (wheat) superior growth traits and because of nitrogen fixation, it might have sped up vegetative growth and had a direct effect on cell division, growth, enzyme synthesis, chlorophyll, and other factors. Support for this assertion is provided by Adeleke and Haruna (2012), who also noted a rise in the no. of plants, LAI and TDM in the maize crop following the harvest of the legume crop. Shukla *et al.* (2021) reported analogous findings concerning the influence of cluster bean crop residues on the growth parameters of maize. They suggested that the differences in maize growth among various preceding legumes could be associated with their distinct capabilities to retain nitrogen, thereby supporting the subsequent maize crop.

Throughout all sampling periods, including 30DAS, 60DAS, 90DAS, 120DAS, and at harvest, the application of 50% RDF combined with 50% Nano NPK consistently resulted in the highest leaf area index for the wheat crop. Following closely, the plots treated with 100% RDF and 100% Nano NPK fertilizers exhibited the next highest leaf area index. Conversely, in both the seasons, 2020-2021 and 2021-2022, the control plot consistently showed the lowest leaf area index. This trend was also evident in the mean data. The substantial growth in wheat plant leaf area and LAI due to the use of 50% RDF and 50% Nano NPK fertilizers may be attributed to the fact that sprayed nanofertilizers could have been absorbed through the stomata of wheat leaves, translocating into the plants and resulting in higher LA and LAI (Abdel-Aziz *et al.* 2016). Additionally, the increased leaf area and LAI might have been induced by the high reactivity of nano fertilizers, characterized by their increased specific surface area and enhanced density of reactive regions, thereby facilitating greater plant absorption (Dhoke *et al.* 2013). This suggests that the specific characteristics of the 50% RDF+50% Nano NPK fertilizer blend, including its nano-components, contributed to the observed superior performance in terms of wheat leaf development. The trends observed in both seasons and the Mean data underscore the enduring impact of fertilizer application on wheat leaf area, emphasizing the crucial role of historical cultivation practices in influencing current crop performance.

During all sampling intervals (30DAS, 60DAS, 90DAS, 120DAS, and at harvest), in both the years (2020-2021 and 2021-2022), and when data was mean, it was noted that the interaction between the crop residues and various doses of fertilizers was significant. In all the sampling periods, the plot where mungbean was grown as a sole crop earlier before wheat combined with 50% RDF + 50% Nano NPK fertilizers noted the maximum leaf area index, while where maize was cultivated as a sole crop earlier before wheat combined with no fertilizer noted the least leaf area index. The data recorded were true for the years (2020-2021 and 2021-2022) and when the data were mean (Table 4.3.5a, 4.3.5b, 4.3.5c, 4.3.5d, and 4.3.5e).

Table 4.3.5.: Effect of the residual effect of crops and different levels of fertilizers on leaf area index of wheat at all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	(2020-2021)					(2021-2022)					Mean data				
	30DAS	60DAS	90DAS	120DAS	At harvest	30DAS	60DAS	90DAS	120DAS	At harvest	30DAS	60DAS	90DAS	120DAS	At harvest
A. Residual effect of crops															
M ₁	0.40 ^c	2.58 ^c	3.79 ^c	2.40 ^c	1.92 ^c	0.41 ^c	2.63 ^c	3.87 ^c	2.46 ^c	1.97 ^c	0.41 ^c	2.60 ^c	3.83 ^c	2.43 ^c	1.94 ^c
M ₂	0.63 ^a	3.67 ^a	5.80 ^a	3.74 ^a	2.99 ^a	0.65 ^a	3.73 ^a	5.93 ^a	3.83 ^a	3.07 ^a	0.64 ^a	3.70 ^a	5.86 ^a	3.79 ^a	3.03 ^a
M ₃	0.48 ^b	2.91 ^b	4.61 ^b	2.85 ^b	2.28 ^b	0.50 ^b	2.97 ^b	4.71 ^b	2.92 ^b	2.33 ^b	0.49 ^b	2.94 ^b	4.66 ^b	2.88 ^b	2.31 ^b
SEm (±)	0.012	0.087	0.093	0.106	0.064	0.012	0.047	0.073	0.084	0.079	0.012	0.067	0.083	0.095	0.071
CD (P=0.05)	0.045	0.343	0.366	0.415	0.251	0.046	0.183	0.288	0.329	0.309	0.045	0.263	0.327	0.372	0.280
B-Different levels of fertilizer															
S ₁	0.36 ^d	2.02 ^d	3.03 ^d	1.59 ^d	1.27 ^d	0.37 ^c	2.05 ^d	3.09 ^d	1.63 ^d	1.30 ^d	0.37 ^d	2.03 ^d	3.06 ^d	1.61 ^d	1.29 ^d
S ₂	0.54 ^b	3.30 ^b	5.33 ^b	3.51 ^b	2.81 ^b	0.56 ^b	3.36 ^b	5.44 ^b	3.60 ^b	2.88 ^b	0.55 ^b	3.33 ^b	5.38 ^b	3.55 ^b	2.84 ^b
S ₃	0.47 ^c	3.01 ^c	4.79 ^c	2.89 ^c	2.31 ^c	0.48 ^d	3.07 ^c	4.89 ^c	2.97 ^c	2.37 ^c	0.48 ^c	3.04 ^c	4.84 ^c	2.93 ^c	2.34 ^c
S ₄	0.64 ^a	3.88 ^a	5.79 ^a	3.98 ^a	3.19 ^a	0.66 ^a	3.95 ^a	5.92 ^a	4.08 ^a	3.27 ^a	0.65 ^a	3.92 ^a	5.86 ^a	4.03 ^a	3.23 ^a
SEm (±)	0.010	0.099	0.098	0.0095	0.072	0.011	0.084	0.082	0.091	0.075	0.010	0.091	0.090	0.093	0.074
CD (P=0.05)	0.030	0.293	0.292	0.283	0.213	0.032	0.249	0.244	0.271	0.224	0.031	0.271	0.268	0.277	0.219
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.5a: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area index of wheat.

30DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	0.30 ⁱ	0.40 ^g	0.38 ^h	0.52 ^e	0.31 ^h	0.42 ^f	0.39 ^{fg}	0.54 ^a	0.30 ^h	0.41 ^g	0.38 ^g	0.53 ^a
M ₂	0.45 ^f	0.68 ^b	0.58 ^{cd}	0.81 ^a	0.46 ^e	0.69 ^c	0.60 ^d	0.84 ^b	0.45 ^f	0.69 ^d	0.59 ^e	0.83 ^b
M ₃	0.35 ^h	0.54 ^d	0.45 ^f	0.58 ^c	0.36 ^g	0.56 ^d	0.47 ^e	0.60 ^b	0.35 ^g	0.55 ^e	0.46 ^f	0.59 ^c
SEm (±)	0.017				0.019				0.018			
CD (P=0.05)	0.052				0.056				0.054			

Table 4.3.5b: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area index of wheat.

60DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	1.87 ^h	2.73 ^e	2.48 ^f	3.24 ^d	1.90 ⁱ	2.78 ^{fg}	2.53 ^g	3.05 ^{bc}	1.88 ⁱ	2.76 ^g	2.50 ^g	3.27 ^b
M ₂	2.23 ^g	4.00 ^b	3.66 ^c	4.78 ^a	2.27 ^h	4.07 ^c	3.73 ^d	4.86 ^a	2.25 ^h	4.03 ^c	3.69 ^d	4.82 ^a
M ₃	1.95 ^h	3.18 ^d	2.90 ^e	3.63 ^c	1.99 ⁱ	3.24 ^e	2.95 ^f	3.69 ^b	1.97 ⁱ	3.21 ^e	2.92 ^f	3.66 ^b
SEm (±)	0.171				0.145				0.158			
CD (P=0.05)	0.508				0.431				0.470			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.5c: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area index of wheat.

90DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	2.53 ⁱ	4.15 ^{fg}	3.87 ^{gh}	4.59 ^f	2.58 ⁱ	4.24 ^{fg}	3.95 ^h	4.69 ^f	2.56 ⁱ	4.20 ^{fg}	3.91 ^h	4.64 ^f
M ₂	3.57 ^h	6.65 ^b	5.82 ^c	6.86 ^a	3.65 ^h	6.79 ^b	5.95 ^c	6.97 ^a	3.61 ^h	6.72 ^b	5.89 ^c	6.91 ^a
M ₃	2.98 ⁱ	5.18 ^d	4.68 ^e	5.62 ^{cd}	3.04 ⁱ	5.28 ^d	4.78 ^e	5.74 ^{cd}	3.01 ⁱ	5.23 ^d	4.73 ^e	6.02 ^{cd}
SEm (±)	0.170				0.143				0.156			
CD (P=0.05)	0.506				0.423				0.465			

Table 4.3.5d: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area index of wheat.

120DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	1.29 ^h	2.70 ^{de}	2.40 ^e	3.19 ^c	1.33 ^f	2.77 ^d	2.46 ^d	3.27 ^{bc}	1.31 ^f	2.74 ^d	2.43 ^d	3.23 ^{bc}
M ₂	1.98 ^f	4.52 ^a	3.58 ^b	4.87 ^a	2.03 ^e	4.63 ^a	3.67 ^b	5.00 ^a	2.00 ^e	4.58 ^a	3.63 ^b	4.94 ^a
M ₃	1.50 ^h	3.31 ^c	2.70 ^{de}	3.88 ^b	1.54 ^f	3.39 ^c	2.77 ^d	3.98 ^b	1.52 ^f	3.35 ^c	2.73 ^d	3.93 ^b
SEm (±)	0.165				0.158				0.161			
CD (P=0.05)	0.490				0.469				0.480			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.5e: Interaction between the residual effect of crops and different levels of fertilizer on the leaf area index of wheat.

At harvest	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	1.03 ^h	2.16 ^e	1.92 ^f	2.55 ^c	1.06 ^g	2.22 ^e	1.97 ^e	2.62 ^{bc}	1.05 ^h	2.19 ^e	1.94 ^f	2.59 ^d
M ₂	1.58 ^g	3.62 ^a	2.87 ^c	3.90 ^a	1.62 ^f	3.71 ^a	2.94 ^{cd}	4.00 ^a	1.60 ^g	3.66 ^b	2.90 ^d	3.95 ^a
M ₃	1.20 ^h	2.65 ^d	2.16 ^e	3.10 ^b	1.23 ^g	2.71 ^d	2.21 ^e	3.18 ^b	1.21 ^h	2.68 ^d	2.19 ^e	3.14 ^c
SEm (±)	0.124				0.131				0.127			
CD (P=0.05)	0.369				0.388				0.379			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer,M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.6 Shoot dry weight (g/m²)

Table 4.3.6 shows the influence of residual crop effects and different levels of fertilizer on wheat shoot dry weight. Wheat's shoot dry weight was significantly impacted by the crop residues of previous crops. The plot where mungbean was cultivated as the sole crop before wheat consistently showed the highest shoot dry weight, closely followed by the plot where maize was intercropped with mungbean before wheat, across all sampling intervals. In contrast, the plot where maize was grown as the sole crop prior to wheat consistently exhibited the lowest shoot dry weight in both seasons, 2020-2021 and 2021-2022. The same patterns persisted when the data were mean. This observed variation in shoot dry weight can be attributed to the influence of preceding crops on soil nutrient availability and interactions between plant species. The cultivation of mungbean as the sole crop likely contributed to improved soil fertility and nutrient availability, providing favorable conditions for robust shoot development in the subsequent wheat crop. The intercropping of maize with mungbean also showed positive effects on shoot dry weight, possibly due to beneficial interactions between the two crops, such as nitrogen-fixing capabilities of legumes. Additionally, Ammaji and Rao (2021) noted a significant impact on the dry matter production of *rabi* maize due to residue management of *kharif* legume crops. Their findings reported that cowpea, when used as a preceding legume for maize, exhibited the highest accumulation of dry matter in both the first and second years. This heightened dry matter accumulation was attributed to the improvement in soil nitrogen status facilitated by the biological nitrogen fixation of legumes. Furthermore, they emphasized the role of nitrogen supply in enhancing chlorophyll content, leading to increased photosynthetic activity and, consequently, an elevated rate of dry matter accumulation, as supported by Adeleke and Haruna (2012).

In the case of different levels of fertilizer treatments, the plot treated with 50% recommended dose of fertilizer combined with 50 % Nano NPK fertilizers consistently exhibited the maximum shoot dry weight at all sampling periods, including 30DAS, 60DAS, 90DAS, 120DAS, and at harvest. Following closely, the plot treated with 100% RDF and the one treated with 100% Nano NPK fertilizers consistently showed the next highest shoot dry weights in both seasons, 2020-2021 and 2021-2022. Conversely, the control plot consistently displayed the least shoot dry weight at all sampling periods in both growing years. This

consistent pattern was also observed when the statistics were mean. The observed variations in shoot dry weight can be attributed to the different fertilizer treatments and their impact on nutrient availability for the wheat crop. The application of 50% RDF + 50% Nano NPK fertilizer likely optimized the balance and availability of essential nutrients, resulting in enhanced shoot development across all growth stages. According to Hasan and Saad (2020), the application of NPK nutrients via nano and mineral fertilization boosted the growth and yield of wheat by ensuring sufficient amounts of available nutrients throughout the crop's growth stages. Moreover, this increase could be associated with the rapid absorption of nano fertilizers by plants, potentially leading to heightened rates of photosynthesis and an accumulation of dry matter, as noted by Navya *et al.* (2022). Comparable outcomes were also witnessed in studies conducted by Samui *et al.* (2022), Sannathimmappa *et al.* (2023); Gupta *et al.* (2022); Kashyap and Bainade (2022).

The interaction between the crop residues and various fertilizer levels in both the years (2020-2021 and 2021-2022) as well as when the data were mean, was significant in all the sampling intervals (30DAS, 60DAS, 90DAS, 120 DAS, and at harvest). In all the sampling periods (30DAS, 60DAS, 90DAS, 120 DAS, and at harvest) the highest mean value of shoot dry weight was noted in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF+50% Nano NPK fertilizers whereas the lowest mean value was acquired in the plot where maize was grown as sole crop prior to wheat combined with no fertilizers (control) in 2020-2021 and 2021-2022 and when data were mean (Table 4.3.6a, 4.3.6b, 4.3.6c, 4.3.6d and 4.3.6e).

Table 4.3.6.: Effect of the residual effect of crops and different fertilizer levels on the shoot dry weight (g/m²) of wheat in all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	(2020-2021)					(2021-2022)					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest
A. Residual effect of crops															
M₁	201.38 ^c	421.40 ^c	1036.84 ^c	1359.53 ^c	1481.74 ^c	207.46 ^c	442.64 ^c	1099.57 ^c	1455.51 ^c	1601.31 ^c	204.41 ^c	431.98 ^c	1068.08 ^c	1407.32 ^c	1541.27 ^c
M₂	236.56 ^a	517.54 ^a	1308.60 ^a	1750.55 ^a	1943.77 ^a	243.70 ^a	543.63 ^a	1387.77 ^a	1874.14 ^a	2100.63 ^a	240.12 ^a	530.53 ^a	1348.02 ^a	1812.08 ^a	2021.86 ^a
M₃	217.63 ^b	466.15 ^b	1152.84 ^b	1520.74 ^b	1672.80 ^b	224.20 ^b	489.65 ^b	1222.59 ^b	1628.11 ^b	1807.80 ^b	220.90 ^b	477.85 ^b	1187.57 ^b	1574.20 ^b	1740.01 ^b
SEm (±)	3.04	11.99	38.60	43.04	50.16	3.97	12.59	42.03	47.93	59.92	3.51	12.29	40.32	45.49	55.04
CD (P=0.05)	11.92	47.07	151.54	168.99	218.40	15.59	49.44	165.01	188.17	244.93	13.76	48.26	158.28	178.58	231.67
B-Different levels of fertilizer															
S₁	161.67 ^d	317.90 ^d	755.85 ^d	960.73 ^d	992.21 ^d	166.55 ^d	333.92 ^d	801.58 ^d	1028.56 ^d	1072.29 ^d	164.10 ^d	325.87 ^d	778.62 ^d	994.50 ^d	1032.08 ^d
S₂	235.38 ^b	506.46 ^b	1266.47 ^b	1701.97 ^b	1890.06 ^b	242.49 ^b	531.99 ^b	1343.09 ^b	1822.13 ^b	2042.59 ^b	238.92 ^b	519.18 ^b	1304.63 ^b	1761.79 ^b	1965.99 ^b
S₃	210.52 ^c	446.29 ^c	1092.58 ^c	1415.84 ^c	1562.65 ^c	216.88 ^c	468.79 ^c	1158.68 ^c	1515.80 ^c	1688.75 ^c	213.69 ^c	457.50 ^c	1125.49 ^c	1465.61 ^c	1625.43 ^c
S₄	266.52 ^a	602.81 ^a	1549.48 ^a	2095.89 ^a	2352.82 ^a	274.56 ^a	633.19 ^a	1643.22 ^a	2243.86 ^a	2542.70 ^a	270.53 ^a	617.94 ^a	1596.16 ^a	2169.56 ^a	2447.35 ^a
SEm (±)	2.92	10.19	33.68	40.37	54.45	3.13	10.45	35.72	44.22	56.23	3.03	10.32	34.70	42.30	55.34
CD (P=0.05)	11.47	35.42	132.24	158.49	202.34	12.28	36.20	140.24	173.62	214.77	11.88	35.81	140.24	166.06	208.56
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.6a: Interaction between the residual effect of crops and different levels of fertilizer on the shoot dry weight (g/m²) of wheat.

30DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	153.97 ^f	232.45 ^c	180.66 ^e	218.41 ^d	158.62 ^g	239.42 ^c	186.11 ^e	225.01 ^d	156.28 ^h	235.93 ^{cd}	183.37 ^f	221.70 ^e
M₂	169.03 ^e	255.04 ^b	234.87 ^c	258.05 ^a	174.13 ^{ef}	262.70 ^{ab}	241.96 ^c	265.85 ^a	171.57 ^{fg}	258.86 ^{ab}	238.40 ^c	261.94 ^a
M₃	162.00 ^{ef}	244.51 ^{bc}	216.05 ^d	229.67 ^c	166.90 ^{fg}	251.85 ^{bc}	222.57 ^d	236.61 ^d	164.44 ^{gh}	248.16 ^{bc}	219.30 ^e	233.13 ^{de}
SEm (±)	2.97				3.86				3.42			
CD (P=0.05)	11.65				15.16				13.41			

Table 4.3.6b: Interaction between the residual effect of crops and different levels of fertilizer on the shoot dry weight (g/m²) of wheat.

60DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	295.32 ^g	444.48 ^d	374.39 ^e	463.44 ^d	310.21 ^h	466.81 ^e	393.26 ^f	486.79 ^d	302.73 ^h	455.60 ^e	383.79 ^f	475.07 ^e
M₂	339.89 ^f	511.33 ^b	504.61 ^b	561.98 ^a	357.02 ^g	537.02 ^b	530.04 ^{bc}	590.31 ^a	348.42 ^g	524.13 ^b	517.27 ^b	576.09 ^a
M₃	318.48 ^{fg}	479.22 ^c	459.88 ^d	493.97 ^{bc}	334.53 ^{gh}	503.29 ^{cd}	483.06 ^{de}	518.87 ^b	326.47 ^{gh}	491.21 ^{cd}	471.43 ^{de}	506.37 ^{bc}
SEm (±)	8.99				9.45				9.22			
CD (P=0.05)	26.71				28.06				27.39			

Means followed by different letters (a, b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat, M₃= Residual effect of Maize+ Mungbean on wheat, S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.6c: Interaction between the residual effect of crops and different levels of fertilizer on the shoot dry weight (g/m²) of wheat.

90DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	699.55 ^e	1050.82 ^c	915.36 ^{cd}	1151.76 ^b	741.87 ^f	1114.30 ^{cd}	970.74 ^{de}	1221.44 ^b	720.62 ^f	1082.43 ^{cd}	942.94 ^{de}	1186.46 ^b
M₂	811.81 ^{de}	1219.22 ^b	1234.71 ^b	1418.88 ^a	860.93 ^{ef}	1292.89 ^b	1309.41 ^b	1504.72 ^a	836.27 ^{ef}	1255.90 ^b	1271.91 ^b	1461.63 ^a
M₃	756.19 ^e	1135.79 ^b	1127.67 ^b	1228.78 ^b	801.94 ^f	1204.41 ^b	1195.89 ^{bc}	1303.12 ^b	778.97 ^f	1169.96 ^b	1161.64 ^{bc}	1265.79 ^b
SEm (±)	34.80				36.90				35.85			
CD (P=0.05)	136.61				144.87				140.74			

Table 4.3.6d: Interaction between the residual effect of crops and different levels of fertilizer on the shoot dry weight (g/m²) of wheat.

120DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	874.19 ^h	1312.77 ^e	1166.51 ^f	1554.47 ^{cd}	935.9 ^e	1405.35 ^c	1248.86 ^f	1653.51 ^{bc}	904.91 ^e	1358.86 ^c	1207.51 ^f	1598.76 ^{bc}
M₂	1061.40 ^{fg}	1593.59 ^{bc}	1623.62 ^b	1910.49 ^a	1136.33 ^d	1706.00 ^b	1738.25 ^b	2045.37 ^a	1098.70 ^d	1649.56 ^b	1680.69 ^b	1977.64 ^a
M₃	946.61 ^{gh}	1421.41 ^{de}	1457.39 ^c	1650.95 ^b	1013.44 ^{de}	1521.65 ^c	1560.28 ^b	1767.51 ^b	979.88 ^{de}	1471.32 ^c	1508.62 ^b	1708.98 ^b
SEm (±)	41.61				46.08				43.85			
CD (P=0.05)	163.37				180.92				172.15			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.6e: Interaction between the residual effect of crops and different levels of fertilizer on the shoot dry weight (g/m²) of wheat.

At harvest	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	896.25 ^f	1345.88 ^d	1270.19 ^{de}	1698.85 ^b	968.58 ^f	1454.37 ^d	1372.70 ^{de}	1835.95 ^b	932.26 ^f	1399.89 ^{de}	1321.22 ^{de}	1767.10 ^b
M₂	1107.37 ^{ef}	1662.56 ^{bc}	1812.32 ^b	2138.10 ^a	1196.74 ^{ef}	1796.61 ^{bc}	1958.57 ^b	2310.64 ^a	1151.86 ^{ef}	1729.29 ^b	1885.13 ^b	2224.00 ^a
M₃	973.01 ^f	1461.02 ^{cd}	1605.44 ^c	1833.23 ^b	1051.54 ^f	1578.81 ^c	1735.00 ^c	1981.18 ^b	1012.11 ^f	1519.66 ^c	1669.94 ^c	1906.88 ^a
SEm (±)	58.98				63.79				61.39			
CD (P=0.05)	213.77				232.66				223.22			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.7 Crop growth rate (g/m²/day)

Crop residues have a significant impact on crop growth rate. In the years 2020-2021, the plot where mungbean was cultivated as the sole crop before wheat consistently exhibited the highest Crop Growth Rate (CGR) across all sampling intervals, including 30-60 DAS, 60-90 DAS, 90-120 DAS, and 120 DAS to harvest. Following closely, the plot where maize and mungbean were intercropped before wheat showed the next highest CGR. Conversely, the plot where maize was grown as the sole crop before wheat consistently displayed the lowest CGR at all sampling intervals. A similar result was also observed in the year 2021-2022 and when the data were mean (Table 4.3.7). This observed pattern in CGR can be attributed to the influence of preceding crops on soil fertility and nutrient availability for the subsequent wheat crop. The cultivation of mungbean as the sole crop likely contributed to improved soil nitrogen status and nutrient availability, creating favorable conditions for robust wheat growth and resulting in the highest CGR. The intercropping of maize with mungbean also exhibited positive effects on CGR, possibly due to complementary interactions between the two crops, such as nitrogen-fixing capabilities of legumes. Shukla *et al.* (2021) also highlighted the substantial impact of incorporating legume (cluster bean) residues on the crop growth rate of maize. They proposed that this effect might be attributed to the enhanced availability of nitrogen and other nutrients in the soil, benefiting the growth of the maize crop due to the presence of preceding legume crops. The variation in maize growth observed among different preceding legumes could be attributed to their distinct nitrogen carryover capacities for the subsequent maize crop. These findings align with similar outcomes reported in studies by Rekha (2014), and Ali *et al.* (2015), which also demonstrated a comparable influence of various preceding legume crops on the growth parameters of subsequent maize crops.

In the case of different levels of fertilizer treatments, the plot treated with 50% RDF combined with 50% Nano NPK consistently exhibited the maximum mean value of crop growth rate at all sampling periods, including 30-60 DAS, 60-90 DAS, 90 DAS-120 DAS, and 120 DAS to harvest. Following closely, the plots treated with 100% RDF and 100% Nano NPK fertilizers consistently showed the next highest mean CGR. Conversely, the control plot consistently displayed the lowest mean CGR at all sampling periods in both the years 2020-2021 and 2021-

2022, and when the data were mean. The observed variations in CGR can be attributed to the different fertilizer treatments and their impact on nutrient availability for the wheat crop. The application of 50% RDF+50 % Nano NPK fertilizer likely optimized the balance and availability of essential nutrients, resulting in enhanced CGR across all growth stages. The higher CGR at regular intervals may have been caused by increased dry matter build-up after the application of 50% RDF and 50% Nano NPK fertilizers. Other possible explanations for the increase in growth parameters include plant absorption, which uses nitrogen in particular for the manufacture of chlorophyll, proteins, enzymes, hormones, and amino acids, and the enhanced accessibility of nutrients in the soil as an outcome of fertilizer administration (both 50 % RDF + 50 % Nano NPK fertilizers). Sarkar *et al.* (2023) reported comparable results, emphasizing an increased crop growth rate following the foliar application of both nanofertilizers and conventional fertilizer. The authors attributed this enhancement to heightened levels of growth-promoting chemicals and naturally occurring phytohormones associated with increased nitrogen supplies. The benefits were linked to the early and ample availability of nitrogen, evident from the improved nutritional status of plants at various growth stages, establishing a more favorable nutritional environment for root zone growth and development. These findings resonate with the results reported by Satyanarayana *et al.* (2017), Rahman *et al.* (2021), and Yadav *et al.* (2023). The persistence of these trends across both years and when the data were Mean underscores the enduring impact of fertilizer application on wheat Mean CGR, highlighting the significance of historical cultivation practices in influencing current crop performance.

The interaction between the crop residues and various fertilizer levels throughout the growing seasons (2020-2021 and 2021-2022) and in the mean statistics was significant throughout the sampling periods (30-60 DAS, 60-90 DAS, 90 DAS-120 DAS, 120 DAS-harvest). In the sampling periods, the highest mean value of CGR was acquired in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF + 50% Nano NPK fertilizers. In contrast, the minimal crop growth rate was measured in the plot where maize was cultivated as the sole crop before wheat was added along with no fertilizers (control) throughout both the seasons as well as when the data were mean (Table 4.3.7a, 4.3.7b, 4.3.7c, and 4.3.7d).

Table 4.3.7.: Effect of the residual effect of crops and different fertilizer levels on the crop growth rate (g/m²/day) of wheat at all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021				2021-2022				Mean data			
	30-60 DAS	60-90 DAS	90-120DAS	120 DAS- at harvest	30-60 DAS	60-90 DAS	90-120DAS	120 DAS- at harvest	30-60 DAS	60-90 DAS	90-120DAS	120 DAS- at harvest
A. Residual effect of crops												
M₁	0.185 ^c	0.516 ^b	0.270 ^b	0.101 ^b	0.195 ^b	0.546 ^b	0.295 ^b	0.120 ^b	0.190 ^b	0.531 ^b	0.282 ^b	0.111 ^b
M₂	0.231 ^a	0.650 ^a	0.363 ^a	0.157 ^a	0.244 ^a	0.687 ^a	0.395 ^a	0.183 ^a	0.238 ^a	0.668 ^a	0.379 ^a	0.170 ^a
M₃	0.208 ^b	0.575 ^{ab}	0.307 ^{ab}	0.126 ^{ab}	0.220 ^{ab}	0.608 ^a	0.335 ^a	0.148 ^a	0.214 ^a	0.591 ^a	0.321 ^a	0.137 ^a
SEm (±)	0.006	0.020	0.014	0.002	0.008	0.022	0.017	0.003	0.007	0.021	0.016	0.002
CD (P=0.05)	0.018	0.080	0.061	0.040	0.033	0.088	0.066	0.044	0.026	0.084	0.063	0.042
B-Different levels of fertilizer												
S₁	0.139 ^d	0.390 ^d	0.182 ^d	0.028 ^d	0.148 ^d	0.412 ^d	0.200 ^d	0.039 ^d	0.143 ^d	0.401 ^d	0.191 ^d	0.033 ^d
S₂	0.222 ^b	0.623 ^b	0.357 ^b	0.154 ^b	0.235 ^b	0.659 ^b	0.389 ^b	0.179 ^b	0.229 ^b	0.641 ^b	0.373 ^b	0.167 ^b
S₃	0.199 ^c	0.544 ^c	0.272 ^c	0.124 ^c	0.210 ^c	0.575 ^c	0.298 ^c	0.144 ^c	0.204 ^c	0.560 ^c	0.285 ^c	0.134 ^c
S₄	0.271 ^a	0.764 ^a	0.441 ^a	0.207 ^a	0.287 ^a	0.807 ^a	0.480 ^a	0.239 ^a	0.279 ^a	0.785 ^a	0.481 ^a	0.223 ^a
SEm (±)	0.005	0.012	0.009	0.001	0.006	0.016	0.011	0.008	0.006	0.014	0.009	0.008
CD (P=0.05)	0.014	0.042	0.026	0.023	0.016	0.046	0.033	0.025	0.015	0.090	0.030	0.024
Interaction (A x B)	S	S	S	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.7a: Interaction between the residual effect of crops and different levels of fertilizer on the crop growth rate (g/m²/day) of wheat.

30-60DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	0.127 ^h	0.201 ^d	0.166 ^{fg}	0.245 ^{ef}	0.134 ^h	0.212 ^d	0.176 ^{fg}	0.259 ^{ef}	0.131 ^h	0.206 ^d	0.171 ^{fg}	0.252 ^{ef}
M₂	2.078 ^d	3.159 ^b	2.870 ^c	0.301 ^a	0.161 ^d	0.262 ^b	0.236 ^c	0.318 ^a	0.156 ^d	0.255 ^b	0.229 ^c	0.310 ^a
M₃	0.139 ^{gh}	0.218 ^d	0.207 ^d	0.268 ^e	0.148 ^{gh}	0.231 ^d	0.219 ^d	0.283 ^e	0.143 ^{gh}	0.224 ^d	0.213 ^d	0.275 ^e
SEm (±)	0.010				0.020				0.015			
CD (P=0.05)	0.031				0.060				0.046			

Table 4.3.7b: Interaction between the residual effect of crops and different levels of fertilizer on the crop growth rate (g/m²/day) of wheat.

60--90DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	0.362 ^d	0.564 ^{bc}	0.463 ^c	0.676 ^a	0.383 ^d	0.596 ^{bc}	0.489 ^c	0.715 ^a	0.373 ^d	0.580 ^c	0.476 ^c	0.695 ^a
M₂	0.419 ^{cd}	0.700 ^b	0.603 ^b	0.878 ^a	0.443 ^{cd}	0.739 ^b	0.637 ^b	0.607 ^a	0.431 ^{cd}	0.719 ^b	0.620 ^b	0.903 ^a
M₃	0.389 ^d	0.606 ^b	0.567 ^b	0.737 ^a	0.411 ^d	0.641 ^b	0.599 ^b	0.779 ^a	0.400 ^d	0.623 ^b	0.583 ^b	0.758 ^a
SEm (±)	0.051				0.053				0.052			
CD (P=0.05)	0.150				0.157				0.154			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.7c: Interaction between the residual effect of crops and different levels of fertilizer on the crop growth rate (g/m²/day) of wheat.

90-120DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	0.156 ^f	0.322 ^d	0.215 ^{ef}	0.386 ^b	0.172 ^f	0.350 ^d	0.236 ^{ef}	0.420 ^b	0.164 ^f	0.336 ^d	0.225 ^{ef}	0.403 ^b
M ₂	0.222 ^e	0.401 ^c	0.321 ^d	0.507 ^a	0.242 ^e	0.437 ^c	0.351 ^d	0.551 ^a	0.232 ^e	0.419 ^c	0.336 ^d	0.529 ^a
M ₃	0.169 ^f	0.348 ^{cd}	0.280 ^{de}	0.431 ^b	0.186 ^f	0.379 ^{cd}	0.306 ^{de}	0.469 ^b	0.178 ^f	0.364 ^{cd}	0.293 ^e	0.450 ^b
SEm (±)	0.025				0.027				0.026			
CD (P=0.05)	0.074				0.080				0.077			

Table 4.3.7d: Interaction between the residual effect of crops and different levels of fertilizer on the crop growth rate (g/m²/day) of wheat.

120DAS-At harvest	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	0.020 ^h	0.127 ^e	0.089 ^f	0.171 ^b	0.029 ^h	0.148 ^e	0.105 ^f	0.198 ^b	0.024 ^h	0.137 ^e	0.097 ^f	0.184 ^b
M ₂	0.041 ^g	0.186 ^c	0.156 ^d	0.247 ^a	0.053 ^g	0.215 ^c	0.180 ^d	0.283 ^a	0.047 ^g	0.200 ^c	0.168 ^d	0.265 ^a
M ₃	0.024 ^h	0.151 ^d	0.126 ^e	0.205 ^b	0.034 ^h	0.175 ^d	0.147 ^e	0.236 ^b	0.029 ^h	0.163 ^d	0.136 ^e	0.220 ^b
SEm (±)	0.004				0.007				0.006			
CD (P=0.05)	0.012				0.020				0.016			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.8. Relative growth rate (g/g/day)

Table 4.3.8 illustrates the impact of various fertilizer levels and crop residues on wheat's relative growth rate. The RGR was significantly impacted by the crop residues. The plot where mungbean was cultivated as the sole crop before wheat in 2020–2021 had the highest RGR at all sampling intervals (30–60 DAS, 60–90 DAS, 90–120 DAS, and 120–DAS–harvest), which was comparable to the plots where maize and mungbean were intercropped before wheat and the plot where maize was grown as the sole crop before wheat but was comparatively highest than all other levels. Whereas the lowest RGR was observed in the plot where maize was grown as the sole crop before wheat at all sampling intervals. Similar results were acquired in the year 2021–2022 as well as when the data were mean. The variations observed in relative growth rate can be ascribed to the diverse residue management practices associated with different preceding crops. The residues derived from mungbean cultivation are likely contributors to enhanced soil fertility and increased nutrient availability. This creates a conducive environment for robust wheat growth, resulting in the highest RGR. Additionally, the intercropping of maize with mungbean demonstrates positive effects on RGR, possibly due to the complementary interactions between the two crops and the incorporation of diverse residues. Conversely, the plot where maize was cultivated as the sole crop before wheat exhibited the least RGR. This could be attributed to specific residue characteristics or nutrient dynamics that did not favor optimal wheat growth. In a study conducted by Ali *et al.* in 2015, legumes used as a preceding crop were found to have a significant impact on both growth and yield parameters. In contrast, fallow as a preceding practice led to the lowest growth and yield parameters compared to legumes as preceding crops. This disparity may be linked to the residual soil nitrogen content resulting from the incorporation and decomposition of legumes. Similarly, Kumar *et al.* (2018) documented that the preceding *kharif* green gram exhibited elevated growth parameters in maize for both years.

The various fertilizers levels have a significant impact on the RGR of wheat. The plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest relative growth rate at all sampling intervals, followed by the plot treated with 100% RDF and 100% Nano NPK fertilizers. While throughout the sampling period, the control plot consistently had the lowest crop growth rate. The data were

accurate for both seasons (2020-2021 and 2021-2022) and when the data were mean. The observed variations in RGR can be attributed to the different fertilizer treatments and their impact on nutrient availability for the wheat crop. The application of 50% RDF + 50% Nano NPK fertilizer likely optimized the balance and availability of essential nutrients, resulting in enhanced crop growth rates across all growth stages. The higher RGR at regular intervals may have been caused by increased dry matter build-up after the application of 50 % RDF and 50 % Nano NPK fertilizers. Other possible explanations for the increase in growth parameters include plant absorption, which uses nitrogen in particular for the manufacture of chlorophyll, proteins, enzymes, hormones, and amino acids, and the enhanced accessibility of nutrients in the soil as an outcome of fertilizer administration (both 50% RDF + 50% Nano NPK fertilizers), both of which contribute to plant development [Al-Samawi (2012); Mandal *et al.* (2014)]. Similarly, Choudhary *et al.* (2023) noted a significant improvement in the relative growth rate of wheat by employing a combination of nanofertilizers and chemical fertilizers via foliar spray.

When data were mean and sampled over the years 2020–2021 and 2021–2022, the interaction between the crop's residual effect and different fertilizer levels was significant, but it was non-significant in the sampling periods of 30-60 DAS and 120 DAS to harvest. In the sampling period of 60-90 DAS and 90-120 DAS, the highest mean value of RGR was acquired in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF +50 % Nano NPK fertilizers. However, the plot with maize cultivated as the sole crop prior to wheat combined with no fertilizers (control) in both the seasons (2020-2021 and 2021-2022) as well as when the data were mean, had the least mean value of RGR (Table 4.3.8a and 4.3.8b).

Table 4.3.8.: Effect of the residual effect of crops and different fertilizer levels on the relative growth rate (g/g/day) of wheat at all observation stages during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021				2021-2022				Mean data			
	30-60 DAS	60-90 DAS	90-120DAS	120 DAS- at harvest	30-60 DAS	60-90 DAS	90-120DAS	120 DAS- at harvest	30-60 DAS	60-90 DAS	90-120DAS	120 DAS- at harvest
A. Residual effect of crops												
M₁	0.0243 ^a	0.0299 ^a	0.0088 ^b	0.0026 ^a	0.0249 ^b	0.0302 ^a	0.0091 ^a	0.0029 ^a	0.0246 ^c	0.0300 ^a	0.0089 ^a	0.0028 ^a
M₂	0.0257 ^a	0.0306 ^a	0.0096 ^a	0.0032 ^a	0.0264 ^a	0.0309 ^a	0.0099 ^a	0.0036 ^a	0.0260 ^a	0.0308 ^a	0.0097 ^a	0.0034 ^a
M₃	0.0251 ^a	0.0300 ^a	0.0090 ^{ab}	0.0029 ^a	0.0257 ^b	0.0303 ^a	0.0093 ^a	0.0032 ^a	0.0254 ^b	0.0302 ^a	0.0092 ^a	0.0031 ^a
SEm (±)	0.0005	0.0008	0.0004	0.0002	0.0008	0.0009	0.0005	0.0003	0.0007	0.0009	0.0005	0.0003
CD (P=0.05)	0.0019	0.0042	0.0015	0.0012	0.0039	0.0090	0.0026	0.0017	0.0020	0.0066	0.0021	0.0014
B-Different levels of fertilizer												
S₁	0.0225 ^c	0.0289 ^b	0.0080 ^b	0.0011 ^c	0.0231 ^b	0.0292 ^d	0.0083 ^c	0.0014 ^b	0.0228 ^d	0.0290 ^b	0.0081 ^c	0.0012 ^b
S₂	0.0255 ^{ab}	0.0305 ^b	0.0099 ^a	0.0035 ^b	0.0261 ^{ab}	0.0308 ^b	0.0102 ^{ab}	0.0038 ^a	0.0258 ^{bc}	0.0307 ^b	0.0100 ^{ab}	0.0037 ^a
S₃	0.0250 ^b	0.0298 ^b	0.0086 ^b	0.0033 ^b	0.0256 ^b	0.0302 ^c	0.0089 ^{bc}	0.0036 ^a	0.0253 ^{cd}	0.0300 ^b	0.0087 ^{bc}	0.0034 ^a
S₄	0.0271 ^a	0.0314 ^a	0.0101 ^a	0.0039 ^a	0.0278 ^a	0.0317 ^a	0.0104 ^a	0.0042 ^a	0.0275 ^a	0.0315 ^a	0.0102 ^a	0.0040 ^a
SEm (±)	0.0004	0.0006	0.0002	0.0001	0.0005	0.0010	0.0004	0.0002	0.0005	0.0008	0.0003	0.0002
CD (P=0.05)	0.0017	0.0033	0.0010	0.0008	0.0021	0.0040	0.0018	0.0010	0.0019	0.0037	0.0014	0.0009
Interaction (Ax B)	NS	S	S	NS	NS	S	S	NS	NS	S	S	NS

Means followed by different letters (a, b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat, M₃= Residual effect of Maize+ Mungbean on wheat, S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.8a: Interaction between the residual effect of crops and different levels of fertilizer on the relative growth rate (g/g/day) of wheat.

60-90DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	0.0287 ^b	0.0303 ^b	0.0298 ^b	0.0305 ^a	0.0291 ^d	0.0307 ^b	0.0301 ^{cd}	0.0308 ^a	0.0289 ^d	0.0305 ^b	0.0300 ^{cd}	0.0307 ^a
M ₂	0.0290 ^b	0.0309 ^b	0.0298 ^b	0.0327 ^a	0.0293 ^d	0.0312 ^b	0.0301 ^{cd}	0.0330 ^a	0.0292 ^d	0.0310 ^b	0.0300 ^{cd}	0.0328 ^a
M ₃	0.0288 ^b	0.0304 ^b	0.0299 ^b	0.0309 ^a	0.0291 ^d	0.0308 ^{bc}	0.0302 ^c	0.0313 ^a	0.0290 ^d	0.0305 ^{bc}	0.0301 ^c	0.0311 ^a
SEm (±)	0.0010				0.0013				0.0012			
CD (P=0.05)	0.0032				0.0060				0.0046			

Table 4.3.8b: Interaction between the residual effect of crops and different levels of fertilizer on the relative growth rate (g/g/day) of wheat.

90-120DAS	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	0.0074 ^d	0.0098 ^b	0.0081 ^{cd}	0.0098 ^a	0.0077 ^c	0.0101 ^b	0.0084 ^c	0.0101 ^a	0.0076 ^d	0.0099 ^b	0.0082 ^{cd}	0.0100 ^a
M ₂	0.0089 ^{bc}	0.0099 ^b	0.0091 ^b	0.0103 ^a	0.0093 ^b	0.0102 ^b	0.0094 ^b	0.0106 ^a	0.0091 ^{bc}	0.0101 ^b	0.0093 ^b	0.0104 ^a
M ₃	0.0075 ^d	0.0098 ^b	0.0086 ^b	0.0101 ^a	0.0078 ^c	0.0102 ^b	0.0089 ^{bc}	0.0104 ^a	0.0076 ^d	0.0100 ^b	0.0087 ^c	0.0102 ^a
SEm (±)	0.0004				0.0005				0.0005			
CD (P=0.05)	0.0011				0.0015				0.0013			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.1.9 Days to 50 % flowering

The impact of the crop residues and different levels of fertilizers on the number of days it takes for wheat to reach 50 % flowering during the 2020-2021 and 2021-2022 *rabi* seasons as well as the mean statistics are illustrated in Table 4.3.9. The longer days to 50 % flowering were recorded in the plot where mungbean was cultivated as the sole crop before wheat followed by the plot where maize and mungbean were grown as an intercrop before wheat. While shorter days were recorded in plots where maize was grown as the sole crop before wheat in both seasons i.e., 2020-2021 and 2021-2022. A similar trend was recorded when the data were mean. The longer days to 50 % flowering recorded in the plot where mungbean was cultivated as the sole crop before wheat, followed by the plot where maize and mungbean were grown as an intercrop before wheat, can be further understood by considering the effects of preceding legumes and their impact on phenological development. Nawab *et al.* (2017) reported that days to first flowering were significantly affected by legumes, providing insights into the potential influence of leguminous crops on subsequent crops like wheat. The observed delayed flowering in the mungbean-cultivated plot could be attributed to the allelopathic effects and nutrient competition, as previously explained. Additionally, they suggest that leguminous crops, like mung bean, may significantly impact phenological development. Khan *et al.* (2014) found that early flowering, pod formation, and physiological maturity in mungbean were associated with the application of a higher phosphorus (P) rate. Khalil *et al.* (2019) further support these findings by describing that an increase in P level results in earlier phenological development, while a decrease in P levels causes delays. These insights align with the concept that the prolonged days to 50 % flowering in the mungbean-cultivated plot may be influenced not only by allelopathy but also by the potential residual effects of increased P levels from the preceding leguminous crop. The competitive nutrient uptake and allelopathic substances might have collectively contributed to the observed delay in the reproductive phase of the subsequent wheat crop. Conversely, when maize was grown as the sole crop before wheat, a shorter duration to 50 % flowering was observed. This aligns with the notion that maize, being less allelopathic, and having different nutrient requirements compared to wheat, may have left a more favorable soil condition for the

timely initiation of the reproductive phase.

The application of various levels of fertilizer to wheat significantly affected the days to 50 % flowering in both seasons (2020-2021 and 2021-2022) as well as when the data were mean. Plots treated with 50% RDF + 50% Nano NPK fertilizers took longer days to attain 50 % flowering followed by 100% NPK fertilizers and 100% Nano NPK fertilizers in both seasons (2020-2021 and 2021-2022) and when data was mean. In both seasons and when data were mean, the control plot took fewer days to reach 50% flowering. The delayed flowering observed in plots treated with 50% RDF + 50% Nano NPK fertilizers can be further substantiated by findings in the literature. Upadhyay *et al.* (2023) observed that the application of a combination of the recommended dose of chemical fertilizers along with nanofertilizers resulted in the highest values at flowering in pearl millet. This aligns with the notion that a balanced combination of fertilizers, including nanofertilizers, can significantly impact flowering stages positively. Similarly, Al-Ghazali *et al.* (2023) reported that the addition of 50% chemical fertilizer with 50% bio-fertilizer and 50% nano-fertilizer improved vegetative growth traits. However, the optimal results were achieved when using the specified fertilizer compound with nano fertilizer, indicating the importance of an appropriate nutrient balance for efficient plant development. Midde *et al.* (2021) demonstrated that the application of 50% recommended dose of nitrogen (RDN) through Urea + 50% nitrogen through Nano urea led to superior performance and shortened the period needed for 50% blooming in rice. This supports the idea that the balance and form of nutrients, especially nano-forms, play a crucial role in promoting early flowering. Moreover, findings in *Gladiolus* (Sarhan *et al.* 2022) and *Euphorbia pulcherrima* (Kaviani *et al.* 2016) emphasized the positive impact of Nano NPK and nanofertilizers on flower quality and flowering. Foliar spraying of nanoparticles was also noted to be beneficial in improving flowering in various plants, including peach (El-Gioushy *et al.* 2021; Mahmoud *et al.* 2022; Mosa *et al.* 2021). The delayed 50 % flowering in plots treated with 50 % RDF + 50 % Nano NPK fertilizers aligns with literature indicating that an optimal combination of chemical and nanofertilizers, providing a balanced and efficient nutrient supply, is crucial for promoting early and healthy flowering in plants.

The interaction between the residual effect of crops and various levels of fertilizer in all the growing years (2020-2021 and 2021-2022) and mean statistics

was recorded as significant. In the years (2020-2021 and 2021-2022) and when data were mean, the least mean value of 50 % flowering was recorded in the plot where maize was grown as the sole crop before wheat combined with no fertilizers (control). Whereas the highest mean value of 50 % flowering was recorded in the plot where mungbean was grown as a sole crop before wheat combined with 50 % RDF + 50 % Nano NPK fertilizers (Table 4.3.9a).

4.1.3.1.10 Days to 90 % maturity

. In Table 4.3.9, the impact of residual effects of crops and various fertilizer levels on the duration for wheat to achieve 90 % maturity during the *rabi* seasons of 2020–2021 and 2021–2022 is presented. The residual effects of crops and varying fertilizer application rates in both years, as well as when the data were mean, were found to significantly influence the days required for wheat to reach 90 % maturity. Notably, plots where mungbean was grown as the sole crop preceding wheat exhibited an extended duration for 90 % maturity, a trend that was statistically comparable with both the plots where maize and mungbean were intercropped before wheat and where maize was grown as a sole crop before wheat. This consistent pattern was evident across both seasons (2020-2021 and 2021-2022) and when the data were mean. This observation suggests that the residue characteristics or nutrient dynamics associated with maize cultivation as a preceding crop created conditions conducive to the accelerated maturity of the subsequent wheat crop. This trend remained consistent across various growing seasons and when the data were mean. In support of these findings, Takele *et al.* (2017) reported similar results, indicating that maximum days to reach maturity were recorded in plots where legumes were grown, while the minimum days were noted in the control treatment. This aligns with a study conducted by Kidist in 2013, where an increase in nitrogen fertilizer due to legumes was found to significantly affect the days to physiological maturity. In Kidist's study, plants in the control treatment matured early, while plants at the highest nitrogen rates matured later. Nawab *et al.* (2017) also emphasized the significant impact of legumes on days to physiological maturity, further supporting the idea that the choice of preceding crops influences the maturity timeline of subsequent crops. Additionally, Mota *et al.* (2021) found that an increased fertilizer rate led to delayed maturity. According to Kaysha *et al.* (2020), nitrogen (N) improved luxuriant vegetative growth, thereby delaying maturity in mung beans. Furthermore, Nuru (2020)

highlighted that days to maturity were prolonged in response to increased levels of nitrogen, phosphorus, and sulfur. The delay in days to maturity at the highest NPS rate could be attributed to the fact that nitrogen fertilization increases the vegetative growth of plants.

The application of 50% RDF + 50% Nano NPK fertilizers consistently required more days to reach 90% maturity, followed by plots treated with 100% RDF and 100% Nano NPK fertilizers, and so forth. This trend persisted across both years (2020-2021 and 2021-2022) and when the data were mean. Notably, the control plot exhibited the lowest number of days taken for 90% maturity in both seasons (2020-2021 and 2021-2022) and when the data were mean (Table 4.3.9). The prolonged time to achieve 90% maturity in plots treated with 50% RDF + 50% Nano NPK fertilizers, as well as those with 100% RDF and 100% Nano NPK fertilizers, could be attributed to the specific nutrient compositions and interactions within these fertilizers. These formulations might have influenced the physiological processes of the wheat crop, potentially slowing down the maturation process. Conversely, the control plot, which did not receive additional fertilizer applications, demonstrated the shortest duration to reach 90% maturity. This suggests that the natural nutrient levels in the soil or other environmental factors in the control plot were conducive to an expedited maturation of the wheat crop. The current observation, where the application of various fertilizer levels significantly influenced the days to 90% maturity in wheat, aligns with the research conducted by Ashenafi *et al.* (2023). In their study, Ashenafi *et al.* reported delayed physiological maturity in maize attributed to the application of nanofertilizers. They proposed that the increased rate of nitrogen from the nanofertilizers, combined with other fertilizers, might have contributed to the delay in physiological maturity by promoting vegetative growth and development in the plants. This finding resonates with the extended duration required for 90% maturity in the specific treatment of 50% RDF + 50% Nano NPK fertilizer observed in the present study. Similarly, the results reported here are consistent with the findings of Redda and Abay (2015), who observed that the use of a larger dose of fertilizer led to longer days to physiological maturity. The prolonged flowering period and delayed maturation observed in the treatment with 50 % RDF + 50 % Nano NPK fertilizer in the present study could be associated with the increased nutrient levels, mirroring the trends identified in Redda and Abay's study.

Contrary to these findings, Hailu *et al.* (2016) and Tekulu *et al.* (2019) reported results that contradict the observed trend. They suggested that maturity is significantly affected by the application of Nanofertilizers blended fertilizer rates, with shorter maturity days observed with the administration of Nanofertilizers blended fertilizer compared to the control, which took the longest days to reach maturity. The disparities in results between these studies and the present investigation may stem from variations in nutrient formulations, combinations, and specific crop responses to nanofertilizers.

In the years (2020-2021 and 2021-2022) and when the data were mean, there was a significant interaction between the crop residues and various fertilizer levels. The plot where mungbean was grown as the sole crop prior to wheat combined with 50 % RDF and 50 % Nano NPK fertilizers took the longest to reach 90 % maturity. However, the plot where mungbean was intercropped with maize prior to wheat in combination with the control took the shortest days for 90 % maturity in both seasons (2020-2021 and 2021-2022) as well as when the data were mean (Table 4.3.9b).

Table 4.3.9.: Effect of the residual effect of crops and different fertilizer levels on the days of different developmental stages of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021		2021-2022		Mean data	
	Days to 50% flowering	Days to 90% maturity	Days to 50 % flowering	Days to 90% maturity	Days to 50 % flowering	Days to 90% maturity
A. Residual effect of crops						
M ₁	85.41 ^b	138.53 ^b	85.95 ^b	138.50 ^b	85.68 ^b	138.51 ^b
M ₂	88.79 ^a	141.96 ^a	88.57 ^a	141.97 ^a	88.68 ^a	141.96 ^a
M ₃	87.60 ^{ab}	138.23 ^b	87.47 ^b	137.94 ^b	87.54 ^{ab}	138.09 ^b
SEm (±)	0.63	0.78	0.43	0.83	0.53	0.81
CD (P=0.05)	2.47	3.08	1.69	3.25	2.08	3.16
B-Different levels of fertilizer						
S ₁	81.54 ^d	132.51 ^d	81.50 ^d	132.26 ^d	81.52 ^d	132.38 ^d
S ₂	90.25 ^b	142.48 ^b	90.35 ^b	142.15 ^b	90.30 ^b	142.31 ^b
S ₃	84.74 ^c	137.65 ^c	84.82 ^c	138.02 ^c	84.78 ^c	137.84 ^c
S ₄	92.54 ^a	145.65 ^a	92.64 ^a	145.45 ^a	92.59 ^a	145.55 ^a
SEm (±)	0.59	0.54	0.51	0.67	0.55	0.60
CD (P=0.05)	1.77	1.62	1.52	1.98	1.64	1.30
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.9a: Interaction between the residual effect of crops and different levels of fertilizer on days to 50% flowering of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	80.51 ^e	87.30 ^{bc}	84.43 ^d	89.39 ^b	80.74 ^e	87.83 ^{bc}	84.96 ^d	90.27 ^b	80.62 ^e	87.57 ^{bc}	84.70 ^d	89.83 ^a
M₂	82.76 ^e	93.80 ^a	83.56 ^{de}	95.04 ^a	82.25 ^e	93.35 ^a	84.09 ^{de}	94.59 ^a	82.51 ^e	93.58 ^a	83.82 ^{de}	94.81 ^a
M₃	81.33 ^e	89.66 ^c	86.22 ^{cd}	93.18 ^a	81.53 ^e	89.87 ^c	85.42 ^{cd}	93.07 ^a	81.43 ^e	89.76 ^c	85.82 ^a	93.13 ^a
SEm (±)	1.03				0.88				0.96			
CD (P=0.05)	3.06				2.63				2.84			

Table 4.3.9b: Interaction between the residual effect of crops and different levels of fertilizer on days of 90% maturity of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	133.58 ^d	141.18 ^b	135.50 ^d	143.86 ^b	133.88 ^d	140.51 ^b	135.46 ^d	144.15 ^b	133.73 ^d	140.84 ^b	135.48 ^d	144.00 ^b
M₂	132.81 ^{de}	145.81 ^a	142.02 ^{bc}	147.20 ^a	131.78 ^{de}	145.17 ^a	142.88 ^{bc}	148.05 ^a	132.29 ^{de}	145.49 ^a	142.45 ^{bc}	147.63 ^a
M₃	131.15 ^e	140.46 ^c	135.43 ^d	145.89 ^a	131.11 ^e	140.76 ^c	135.73 ^d	144.15 ^a	131.13 ^e	140.61 ^c	135.58 ^d	145.02 ^a
SEm (±)	0.94				1.15				1.05			
CD (P=0.05)	2.80				3.43				3.11			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.2. Yield components and Yield.

4.1.3.2.1. Number of effective tillers/m²

Table 4.3.10, which also includes the mean data, depicts the impact of residual crop effects and various fertilizer levels on the number of effective tillers /m² during the *rabi* seasons of 2020–2021 and 2021–2022. The no. of effective tillers/m² of wheat in the years 2020–2021 and 2021–2022, as well as when data were mean, was significantly influenced by the residual effects of the crops. In the year 2020–2021, the plot where mungbean was cultivated as the sole crop before wheat showed the highest no. of effective tillers/m², comparable to the plots where maize and mungbean were intercropped before wheat and the plot where maize was cultivated as the sole crop before wheat, but it surpassed all other treatments. Notably, the plot where maize was cultivated as the sole crop before wheat exhibited the fewest effective tillers/square meter. The trends observed in the year 2021–2022 and when the data were mean yielded comparable results (Fig.4.3.10a). This variation in the no. of effective tillers can be attributed to the residual effects of the preceding crops. The cultivation of mungbean as a sole crop before wheat appears to have positively impacted the tillering process, resulting in a higher number of effective tillers. The intercropping of maize and mungbean before wheat also showed positive effects on tiller development, although to a slightly lesser extent. In contrast, the plot where maize was cultivated as the sole crop before wheat exhibited a lower number of effective tillers, indicating a potential negative residual effect on tillering. Adding to this, studies by Kiran Kumar *et al.* (2019) emphasize that higher values of effective tillers/m² were recorded with the groundnut–wheat and soybean–wheat cropping systems, particularly with residue incorporation. The incorporation of groundnuts along with their leaf fall, introduced variable amounts of nitrogen (N) into the soil, significantly influencing the yield attributes of subsequent wheat crops. Mesfin *et al.* (2023) also support these findings, reporting that the number of tillers per plant of wheat in the faba bean–wheat rotation was significantly higher. Legumes contribute to soil nitrogen, providing available nitrogen for subsequent wheat crops. Such legume–wheat rotations have a positive impact on subsequent wheat yield components, as highlighted by Rahman *et al.* (2019), due to increased soil nitrogen through BNF or sparing effect, given that legumes have lower nitrogen demand compared to cereals, as indicated by Uzoh *et al.* (2019). These studies

collectively reinforce the understanding that residue characteristics and nutrient dynamics, influenced by preceding crops, play a pivotal role in shaping wheat tillering dynamics and subsequent crop productivity.

In the case of different levels of fertilizer treatments, the plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the maximum number of effective tillers per meter square followed by the plot treated with 100 % RDF and 100 % Nano NPK fertilizers. While the control plot consistently had the lowest no. of effective tillers per meter square in both the years 2020-2021 and 2021-2022. Similar results were recorded in mean data (Table 4.3.10 and Fig.4.3.10a). The plot treated with 50 % RDF + 50 % Nano NPK fertilizers demonstrated superior performance, indicating the effectiveness of this specific fertilizer combination in promoting the development of effective tillers. This outcome could be attributed to the balanced nutrient supply provided by the combined application, enhancing the overall growth and productivity of the wheat plants. On the other hand, the consistently lower number of effective tillers in the control plot throughout both years indicates that the absence or limited application of external fertilizers, such as Nano NPK and RDF, had a notable impact on tiller development. Moreover, Kumar *et al.* (2023) reported that the count of effective tillers per square meter was significantly higher in the treatment where a combination of chemical nitrogen was applied along with one nano urea spray. Mehta and Bharat (2019) noted that effective tillers per meter row length were influenced by the integrated use of nano and non-nano fertilizers. The increase in yield attributes such as the number of effective tillers per meter row length may be attributed to the promotion of water and nutrient absorption by nano-NPK, leading to improved photosynthesis (Wu, 2013). Gangwar *et al.* (2022) also found that foliar application of nano urea and soil application of NPK significantly increased tillers per plant. This argument is substantiated by the findings of Fatima *et al.* (2021), which align with comparable outcomes reported by previous studies. For instance, Benzon *et al.* (2015) observed similar results, indicating a significant influence on the effective tillers of wheat when using conventional fertilizer in conjunction with nano fertilizer. Moreover, Rathnayaka *et al.* (2018) contributes to this body of evidence by demonstrating that the addition of chemical and nano fertilizers, either individually or in combination, led to a significant increase in the number of tillers on rice plants. Collectively, these studies emphasize the positive impact of both

conventional and nano fertilizers on tiller development in various crops. The Mean data further validates and strengthens the reliability of the findings, emphasizing that the observed differences in effective tillers were not isolated to individual years but were consistent across the entire dataset. This analysis highlights the enduring impact of the chosen fertilizer levels on the tillering dynamics of the wheat crop during the specified period.

The interaction between the crop residues and various fertilizer levels was significant for both the years (2020-2021 and 2021-2022) and the mean data. The highest mean value of the no. of effective tillers per meter square was obtained in the plot where mungbean was grown as the sole crop prior to wheat combined with 50 % RDF + 50 % Nano NPK fertilizers, while the minimum mean value was obtained in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (Table 4.3.10a). Similar outcomes were attained in 2021-2022 and when the data were mean (Table 4.3.10a).

4.1.3.2.2. Number of grains/spike

Table 4.3.9, along with mean data, shows the effect of residual crop effects and varied fertilizer levels on the number of grains per spike in the *rabi* seasons of 2020-2021 and 2021-2022. The plot where mungbean was cultivated as the sole crop before wheat, followed by the plot where maize and mungbean were intercropped before wheat, and the plot where maize was produced as the sole crop before wheat, had the maximum no. of grains per spike in the instance of the years 2020–2021. The plot where maize was cultivated as the sole crop prior to wheat had the least no. of grains per spike, on the other hand. When the data were analyzed in 2021–2022. Similar outcomes were attained in 2021-2022 and when the data were mean (Fig. 4.3.9 b). The observed variations in no. of grain per spike across different crop cultivation practices, including sole mungbean cultivation before wheat, intercropping of maize and mungbean before wheat, and sole maize cultivation prior to wheat, may be attributed to the diverse impacts of crop rotation and intercropping on soil health and nutrient availability. The plot where mungbean was grown as the sole crop before wheat likely facilitated nitrogen fixation, positively influencing the subsequent wheat crop. Intercropping maize and mungbean may have fostered synergies, such as reduced nutrient competition or enhanced pest control, thereby benefiting wheat yield. Additionally, insights from Jat *et al.* (2013) suggest that incorporating residues from

legumes like cowpea and mungbean significantly improves grains per spike, possibly due to enhanced residual nutrient availability for the succeeding wheat crop. Moreover, findings from Mesfin *et al.* (2023) emphasize that wheat in faba bean-wheat rotations exhibit significantly higher seed numbers per spike, attributed to increased soil nitrogen concentration resulting from biological nitrogen fixation by legumes. Zaheer *et al.* (2015) reported analogous findings, revealing an increase in the number of grains per spike in plots where the preceding crop was a legume. Similarly, research by Bangash *et al.* (2023) indicates that incorporating legumes in the rotation leads to a higher no. of spikes, further highlighting the positive impact of legume incorporation on wheat yield attributes.

In both seasons (2020-2021 and 2021-2022), as well as in the case of mean statistics, the number of grains per wheat spike is significantly impacted by the usage of various fertilizer rates. The plot treated with 50 % RDF + 50 % Nano NPK fertilizers produced the highest no. of grains per spike in 2020-21 and 2021-22, whereas the control plot produced the least no. of grains per spike. When the data were mean, a similar pattern was shown (Table 4.3.9 and Fig.4.3.9b). The notable increase in the no. of grains per spike in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers can be attributed to the use of a nano fertilizer containing macronutrients applied during critical phases of tillering, spike emergence, and development. This approach ensured constant nutrient availability, promoting growth by increasing chlorophyll content in the leaves. The heightened chlorophyll content enhanced the efficiency of photosynthesis, leading to an increased number of grains per spike. Similar findings were reported by Kandil *et al.* (2017), who observed the highest Mean values for spike number/m² when nano fertilizers were applied as a foliar spray in both seasons. The synergistic effect of nano fertilizers on the efficacy of conventional fertilizer, as reported by Benzon *et al.* (2015), may explain the increase in yield components observed in the plots treated with 50 % RDF and 50 % Nano NPK fertilizers. Nano fertilizers were found to enhance plant uptake of soil water and nutrients, optimizing the growth of plant parts and metabolic processes such as photosynthesis. This resulted in higher photosynthate accumulation and translocation to economically valuable parts of the plant, contributing to a higher yield. This phenomenon is explained by the increased source (leaves) and sink (economic part) strength. Corroborating these findings, Al-Shamary and Al-Ansari (2022) reported that the

application of nanofertilizers resulted in the highest number of spikes and grains per spike. Sheoran *et al.* (2021) also demonstrated that foliar treatment with various levels of nanofertilizers significantly increased the number of spikes and seeds per spike compared to both bulk fertilizers and control plants. Additionally, Syaifudin *et al.* (2023) found that nanofertilizers improved the no. of spikes per plant in wheat. Moreover, AL-Abody *et al.* (2020) reported that nanofertilizers yielded the highest Mean no. of grains per spike. These collective findings support the conclusion that the strategic use of nano fertilizers can positively influence wheat yield and its associated attributes.

The interaction between the crop residues and various fertilizer levels was significant in both the years (2020-2021 and 2021-2022) as well as when the data were mean. The plot where mungbean was grown as the only crop prior to wheat combined with 50 % RDF + 50 % Nano NPK fertilizers had the highest overall value of the no. of grains per spike in 2020–2021, while the plot where maize was grown as the only crop prior to wheat combined with no fertilizers had the least overall value of the no. of grains/ spike .A comparable pattern was noted in the year 2021-2022 and when the data were mean (Table 4.3.10b).

4.1.3.2.3. Spike length (cm)

Table 4.3.10 shows the influence of residual crop effects and various fertilizer application levels on the length of wheat spikes during the *rabi* seasons of 2020–2021 and 2021–2022 and mean data. The plot where mungbean was grown as the sole crop prior to wheat was statistically similar to the plot where maize and mungbean were intercropped before wheat as well as with the plot where maize was cultivated as the sole crop prior to wheat in the years 2020–2021. A comparable pattern was observed in the year 2021-2022 and when the data were mean (Fig. 4.3.10c). The observed statistical similarity is supported by previous studies. Kiran Kumar *et al.* (2019) concluded that the inclusion of legumes in wheat-based rotations, such as mungbean, and their residue incorporation not only saved nitrogen fertilizer but also improved wheat productivity and soil fertility over a 2-year cropping cycle. Likewise, Kumar *et al.* (2018) reported that preceding *kharif* green gram resulted in higher yield attributes, and overall yield in consecutive years. Hoque *et al.* (2016) also documented enhanced wheat yield parameters in plots treated with various legumes, indicating significant responses in growth and yield parameters to legume residual effects. Das *et al.*, (2016);

Almaz *et al.* (2017), observed a similar outcome, i.e., an increase in maize cob length after the addition of soybean residues. These findings align with the notion that the usage of legumes in diverse cropping systems can lead to a substantial and progressive increase in yield for subsequent non-legume crops, as compared to rotations with non-legume crops, as highlighted by Kebede (2020a). The cumulative evidence from these studies emphasizes the positive impact of legumes on soil fertility and subsequent crop performance, explaining the observed similarities in grain production in the previously mentioned plots during the past seasons and when data were mean.

In both seasons (2020-2021 and 2021-2022), as well as when data were mean, the application of various fertilizer levels had a significant impact on the length of wheat spikes. In the year 2020-2021, the longest spike length was observed in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers which were statistically comparable with 100 % RDF but considerably superior to the other levels. Both in the mean data and for the years 2021–2022, a similar trend was seen. The shortest spike length was recorded in the control plot in both seasons i.e., 2020-2021 and 2021-2022 and in the mean data. The observed variation in spike length can be attributed to the specific fertilization strategy applied. The 50 % RDF + 50 % Nano NPK fertilizer treatment, along with the 100 % RDF, contributed to optimal spike elongation. The inclusion of nano fertilizers in the treatment may have played a crucial role in promoting nutrient uptake, ensuring sustained nutrient availability during critical growth phases. This consistent nutrient supply likely facilitated enhanced cell division and elongation, resulting in longer spikes. Furthermore, findings from Rawate *et al.* (2022) support the influence of nanofertilizers dosage on spike length of wheat. The application of combined application of recommended dose of nitrogen with two sprays of nano urea resulted in maximum spike length. The integrated use of nano and non-nano fertilizers, as highlighted by Mehta and Bharat (2019) and Gomaa *et al.* (2018) has also been shown to significantly influence spike length of wheat. Al-Juthery *et al.* (2019) reported that spraying nanofertilizers increased the length of spikes compared to control treatment. Nano fertilizers, due to their high surface area to volume ratio, were found to be more effective than many conventional fertilizers, as noted by Prajapati *et al.* (2018). Their nature allows slow release and promotes efficient nutrient uptake by crops. In addition, the application of zinc nano-

fertilizer, as reported by Ram *et al.* (2023), significantly increased the spike length of wheat. The increased number of spike length was also recorded with the application of nanofertilizers on wheat, as found by Ghafari and Razmjoo (2013). These findings collectively underscore the positive impact of nano fertilizers on spike length, further supporting the observed results in the 2020-2021 and 2021-2022 growing seasons.

The interaction between the residual effects of crops and various fertilizer levels was significant in 2020-2021 and 2021-2022 and in the mean statistics. In the year 2020-2021, the longest spike length was recorded in the plot where mungbean was grown as the sole crop prior to wheat combined with 50 % RDF + 50 % Nano NPK fertilizers while the shortest spike length was attained in the plot where maize was grown as sole crop prior to wheat combined with no fertilizers. A similar trend was observed in 2021-2022 and when data were mean (Table 4.1.10c).

Table 4.3.10.: Effect of the residual effect of crops and different levels of fertilizer on the yield components of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021			2021-2022			Mean data		
	Number of effective tillers/m ²	Number of grains/spike	Spike length(cm)	Number of effective tillers/m ²	Number of grains/spike	Spike length(cm)	Number of effective tillers/m ²	Number of grains/spike	Spike length(cm)
A. Residual effect of crops									
M₁	322.92 ^b	43.52 ^b	10.31 ^b	324.25 ^b	44.16 ^b	10.87 ^b	323.59 ^b	43.84 ^b	10.59 ^b
M₂	386.13 ^a	50.02 ^a	12.12 ^a	385.10 ^a	51.54 ^a	12.42 ^a	385.61 ^a	50.78 ^a	12.27 ^a
M₃	328.35 ^b	46.83 ^{ab}	11.29 ^{ab}	331.72 ^b	46.95 ^b	11.30 ^b	330.03 ^b	46.89 ^{ab}	11.29 ^{ab}
SEm (±)	8.33	1.08	0.29	8.31	1.02	0.24	8.32	1.05	0.28
CD (P=0.05)	32.69	4.24	1.12	32.61	4.02	1.02	32.65	4.13	1.10
B-Different levels of fertilizer									
S₁	302.46 ^c	40.19 ^c	8.81 ^c	301.84 ^c	39.16 ^c	8.84 ^c	302.15 ^c	39.67 ^c	8.82 ^c
S₂	368.47 ^a	48.09 ^b	12.16 ^b	370.29 ^a	49.47 ^b	12.44 ^b	369.38 ^a	48.78 ^b	12.30 ^b
S₃	323.41 ^b	46.16 ^b	11.39 ^b	324.33 ^b	46.24 ^b	12.07 ^b	323.87 ^b	46.20 ^b	11.73 ^b
S₄	388.86 ^a	52.70 ^a	12.60 ^a	391.64 ^a	55.33 ^a	12.77 ^a	390.25 ^a	54.02 ^a	12.68 ^a
SEm (±)	8.08	1.03	0.29	8.23	1.15	0.28	8.16	1.09	0.28
CD (P=0.05)	24.01	3.07	0.87	24.45	3.41	0.82	24.23	3.24	0.84
Interaction (A x B)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

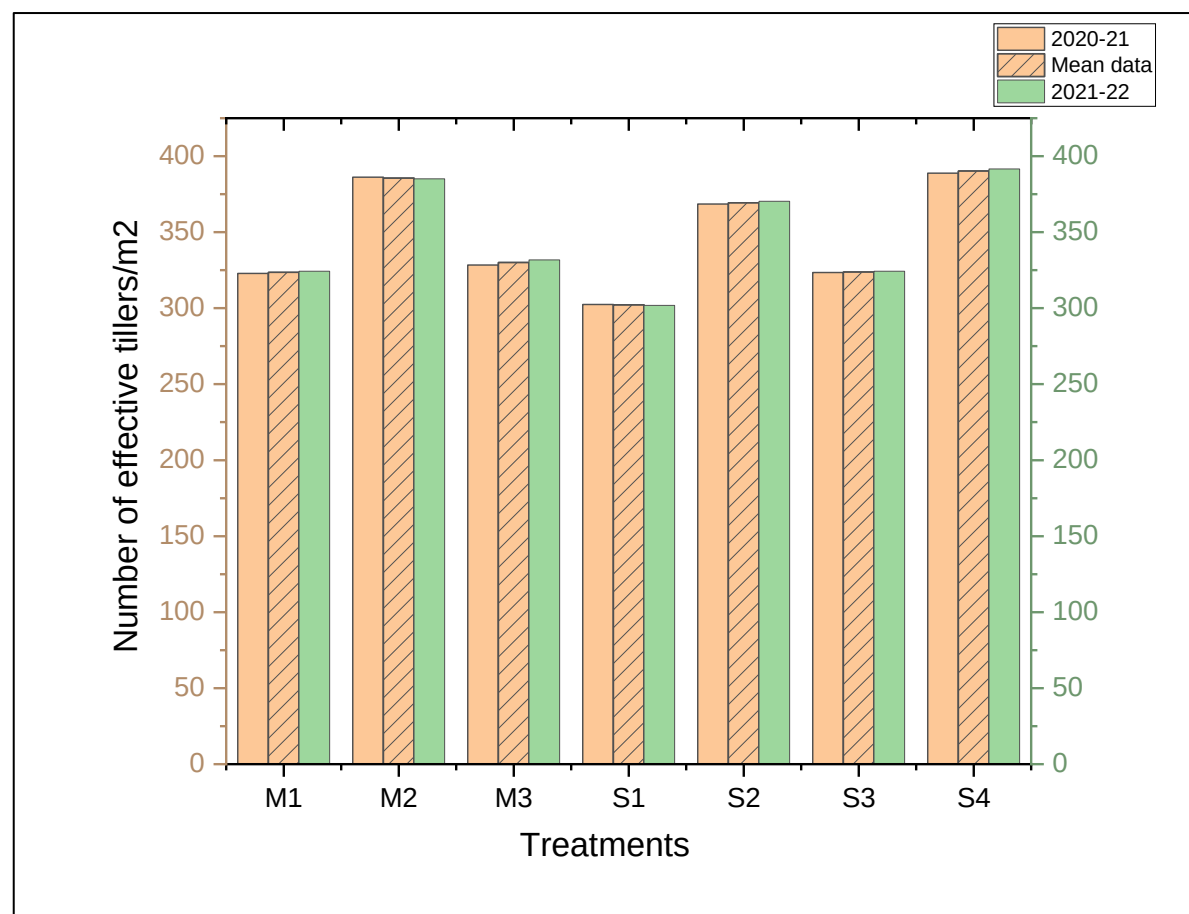


Fig.4.3.10a: Effect of the residual effect and different levels of fertilizers on number of effective tillers/m² of wheat during the years (2020-2021, and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers, RDF=Recommended dose of fertilizers.

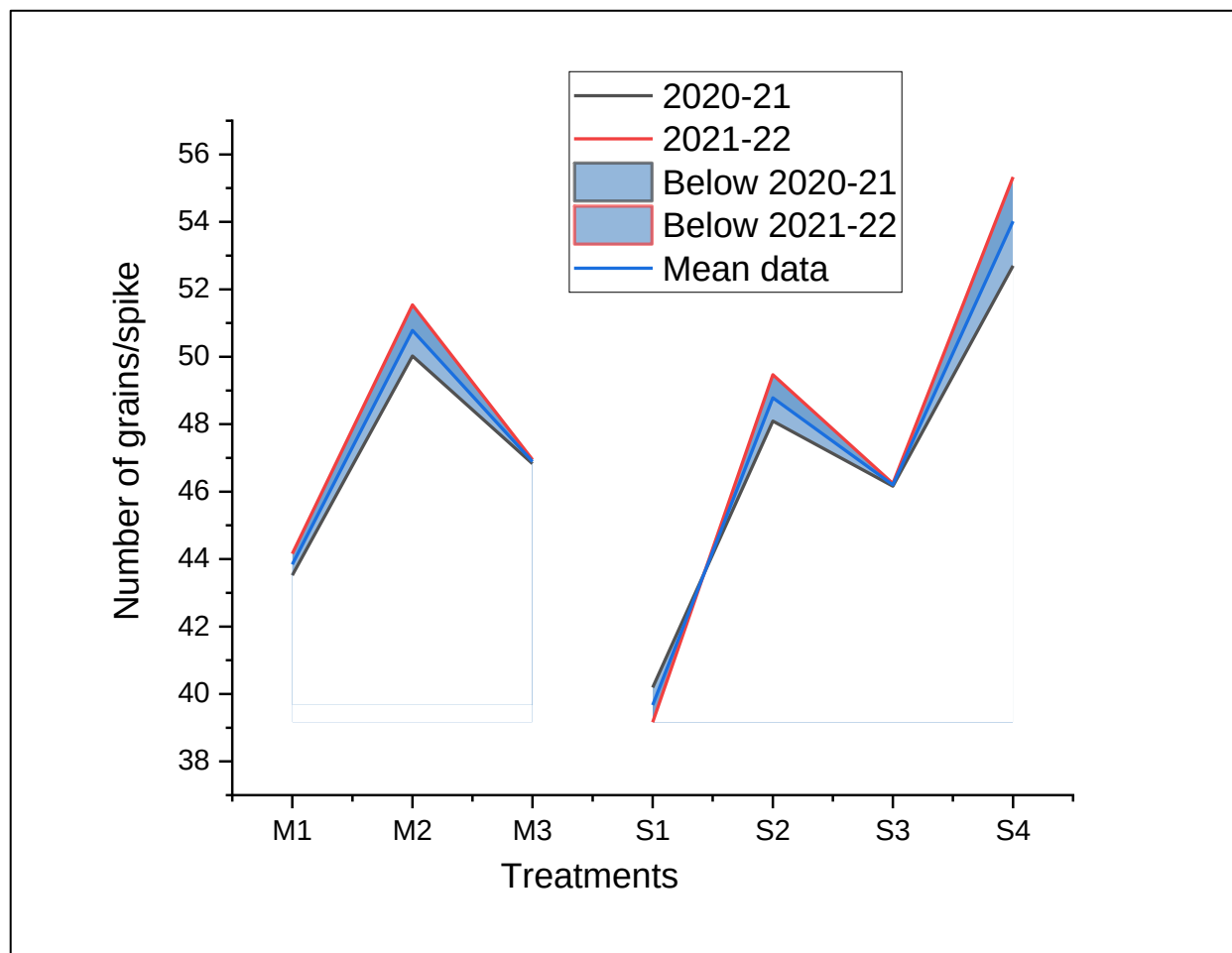


Fig.4.3.10b: Effect of the residual effect and different levels of fertilizers on number of grains/spike of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers, RDF=Recommended dose of fertilizers.

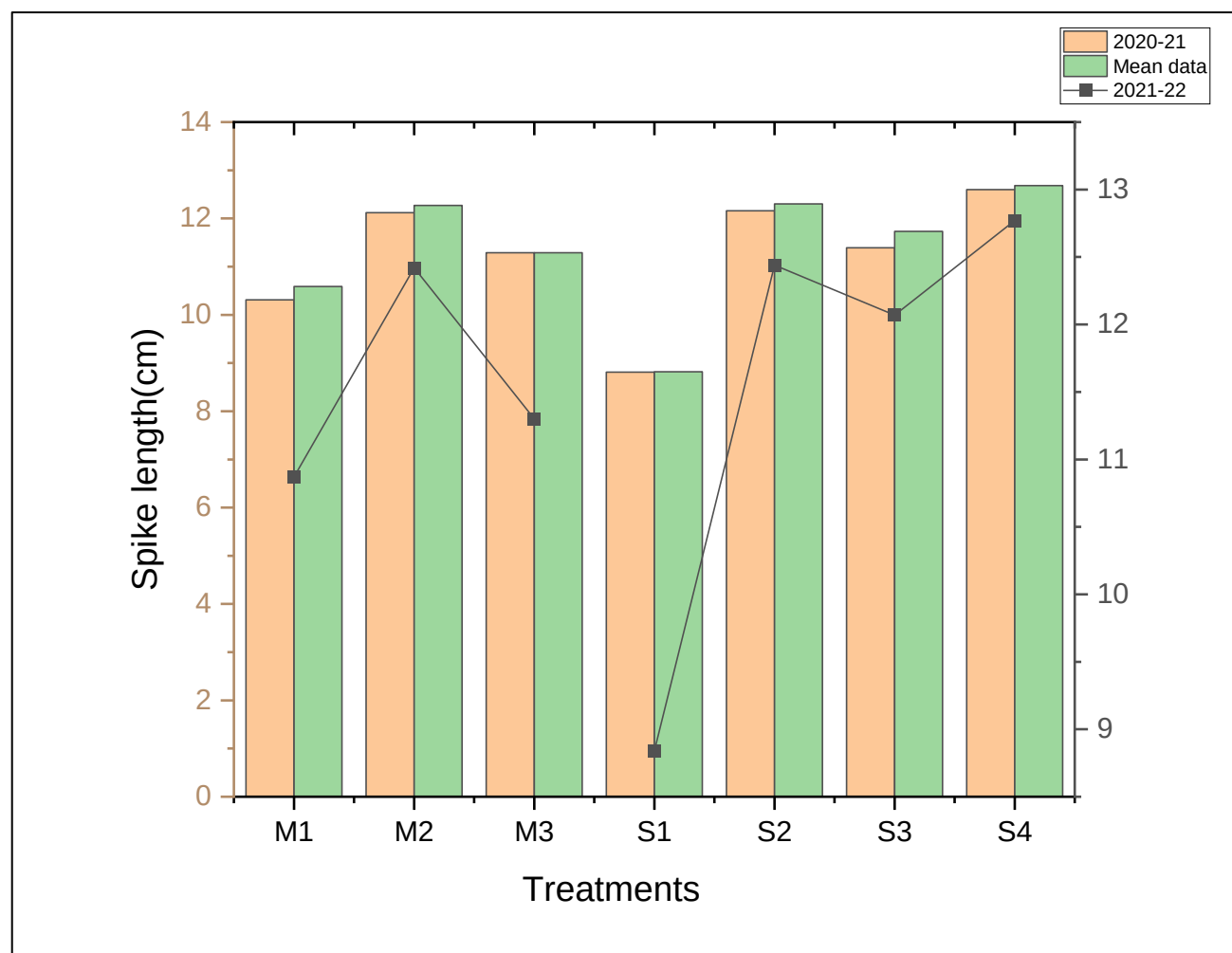


Fig.4.3.10c: Effect of the residual effect and different levels of fertilizers on the spike length (cm) of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers, RDF=Recommended dose of fertilizers.

Table 4.3.10a: Interaction between the residual effect of crops and different levels of fertilizer on the number of effective tillers/m² of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	264.93 ^g	363.53 ^{cd}	287.84 ^f	375.39 ^d	266.13 ^f	365.18 ^c	288.62 ^e	377.07 ^c	265.53 ^h	364.36 ^d	288.23 ^g	376.23 ^e
M₂	369.87 ^e	377.39 ^c	379.05 ^d	418.20 ^a	366.77 ^d	378.85 ^c	380.19 ^c	414.60 ^a	368.32 ^f	378.12 ^{cd}	379.62 ^{de}	416.40 ^a
M₃	272.57 ^f	364.48 ^c	303.34 ^{ef}	373.01 ^b	272.61 ^e	366.83 ^c	304.19 ^d	383.24 ^b	272.59 ^g	365.65 ^d	303.77 ^f	378.12 ^b
SEm (±)	14.00				14.25				14.13			
CD (P=0.05)	41.58				42.34				41.96			

Table 4.3.10b: Interaction between the residual effect of crops and different levels of fertilizer on the number of grains/spike of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	37.22 ⁱ	45.92 ^{ef}	45.32 ^{fg}	45.63 ^b	35.40 ^j	49.53 ^{fg}	44.77 ^{gh}	46.95 ^{cd}	36.31 ^j	47.72 ^f	45.05 ^{gh}	46.29 ^c
M₂	45.63 ^g	50.69 ^c	47.82 ^d	55.92 ^a	44.01 ^h	51.81 ^d	48.25 ^e	62.09 ^a	44.82 ^h	51.25 ^d	48.03 ^e	59.01 ^a
M₃	37.73 ^h	47.67 ^{de}	45.35 ^e	56.56 ^a	38.06 ⁱ	47.08 ^{ef}	45.72 ^f	56.94 ^b	37.90 ⁱ	47.38 ^{ef}	45.53 ^{fg}	56.75 ^b
SEm (±)	1.79				1.99				1.89			
CD (P=0.05)	5.32				5.90				5.61			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.10c: Interaction between the residual effect of crops and different levels of fertilizer on the spike length (cm) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	8.68 ^c	11.18 ^b	10.46 ^b	11.93 ^b	8.02 ^e	11.72 ^d	11.60 ^d	12.15 ^b	8.35 ^e	11.45 ^d	11.03 ^d	11.54 ^b
M₂	8.96 ^c	12.63 ^a	12.12 ^{ab}	14.77 ^a	9.52 ^e	12.89 ^{bc}	12.36 ^c	14.89 ^a	9.25 ^e	12.76 ^{bc}	12.24 ^c	14.83 ^a
M₃	8.78 ^c	12.67 ^b	11.60 ^b	12.09 ^a	8.97 ^e	12.71 ^c	12.25 ^{cd}	11.28 ^a	8.87 ^e	12.69 ^c	11.92 ^{cd}	11.68 ^a
SEm (±)	0.51				0.48				0.49			
CD (P=0.05)	1.50				1.42				1.46			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.2.4. Test weight(g)

The effect of residual effect of crops and the different fertilizer rates had a significant impact on the test weight in both seasons i.e., 2020-2021 and 2021-2022 as was in the mean statistics (Table 4.3.11). The plot where mungbean was cultivated as the sole crop before wheat showed a higher test weight, which was statistically comparable to the plot where maize and mungbean were intercropped before wheat. However, when maize was cultivated as the sole crop before wheat in both the seasons 2020-2021 and 2021-2022 and when data were mean a lower test weight was observed (Fig 4.3.11a). This observed pattern can be explained by the residual effects of mungbean on soil fertility. The cultivation of mungbean as a preceding crop might have contributed to improved nutrient availability, fostering better conditions for wheat growth and development, thereby enhancing the test weight. On the contrary, the lower test weight observed in the plots where maize was grown as the sole crop before wheat could be attributed to potential nutrient imbalances or soil conditions less conducive to optimal wheat performance. This observed pattern is consistent with findings from a field experiment conducted by Fataah and Sarkodie-Addo (2016). They reported that the incorporation of cowpea residues, similar to the beneficial residual impact of sole mungbean cultivation on the wheat crop, resulted in the highest hundred seed weight. The positive impact of legumes on wheat yield parameters, such as test weight, can be attributed to the slow release of nutrients, particularly nitrogen, from legume residues. This was supported by Gerami *et al.* (2013), who found that legumes significantly affected wheat yield parameters compared to non-legume crops. The slow release of nutrients from legumes provides a continuous and sporadic supply throughout the crop growth cycle, positively impacting stem elongation and contributing to higher growth and yield attributes. Rahim *et al.* (2019) similarly highlighted that plots previously sown with legumes significantly affected yield and yield components in wheat, potentially due to enhanced residual soil fertility. Moreover, Angus *et al.* (2015) and Zander *et al.* (2016) found that wheat yield after legumes surpassed wheat yield after wheat, further emphasizing the positive influence of legumes on subsequent crops.

In the case of different levels of fertilizer treatment in the years 2020–2021, the plot treated with 50 % RDF + 50 % Nano NPK fertilizers recorded the highest test weight followed by the plot treated with 100 % RDF, 100 % Nano

NPK nanofertilizers and control. A comparable pattern was noted in the year 2021-2022 and when data were mean (Table 4.3.11 and Fig.4.3.11a). The superior test weight in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers can be attributed to the specific fertilizer combination employed. The inclusion of nano fertilizers, with their distinct properties, likely played a pivotal role in enhancing nutrient absorption and fostering overall plant health. Consequently, this positive impact is believed to have influenced the grain filling process, resulting in higher test weights. This observation aligns with the findings of Jassim *et al.* (2023), who documented the enhanced effectiveness of foliar application of nanofertilizers influencing the weight of 1000 seeds (grams) of wheat. The superiority of this approach was evident in both soil and foliar applications when compared to the control treatment. Additionally, Sahu *et al.* (2022) reported that the highest test weight (grams) of rice was observed under the treatment of 50% Recommended Dose of Nutrients (RDN) as a basal application, along with foliar spray of nano urea at the tillering stage and panicle initiation stage. Similarly, Rawate *et al.* (2022) reported the highest thousand weight of wheat with the combination of RDN with two sprays of nanofertilizers. These findings are in line with Rahman *et al.* (2014), who observed a significant increase in thousand-grain weight with the application of nanofertilizers. Moreover, Ram *et al.* (2023) noted that the maximum increase in hundred seed weight was recorded with the application of nanofertilizers on wheat. Together, these studies support the conclusion that the strategic use of nano fertilizers contributes to improved test weights, substantiating the observed results in the 2020-2021 and 2021-2022 growing seasons.

The interaction between the crop residues and various fertilizer levels was significant in both years (2020-2022 and 2021-2022), as well as in the mean data. The uppermost mean value of the test weight was noted in the plot where mung-bean was grown as the sole crop prior to wheat combined with 50 % RDF+ 50 % Nano NPK fertilizers while the plot with maize as the only crop cultivated before wheat paired with no fertilizers had the least weight. In 2021–2022, as well as when the data were mean, a similar pattern was recorded (Table 4.3.11a).

4.1.3.2.5. Grain yield (kg/ha)

Table 4.3.11, which includes mean data, shows how various fertilizer applications and crops' residual effects affected wheat grain yield throughout the *rabi* seasons of 2020–2021 and 2021–2022. The crop residues had a significant

impact on grain yield. The plot where mungbean was grown as the sole crop before wheat had the highest grain yield, followed by the plot where maize and mungbean were grown together before wheat. Whereas the plot with maize as the sole crop cultivated before wheat had the lowest grain yield in both the seasons of 2020-2021 and 2021-2022 as well in the mean data (Fig.4.3.11b). The observed differences in grain yield can be attributed to the residual effects of crop residues on soil fertility and nutrient availability. Mungbean, when grown as a preceding crop, likely contributed to improved soil conditions and nutrient levels, thereby promoting better wheat growth and higher grain yield. The intercropping of maize and mungbean may have facilitated complementary resource use and nutrient cycling, resulting in a favorable environment for wheat production. On the contrary, the lower grain yield in plots where maize was grown as the sole crop before wheat could be associated with potential nutrient imbalances or conditions less conducive to optimal wheat development. These findings underscore the importance of strategic crop selection and rotations to harness positive residual effects on subsequent crops, enhancing overall agricultural productivity. These observed variations in grain yield align with findings from Deribe and Debele (2016) and Tehulie and Tola (2020), who emphasized the substantial advantages of including legumes in rotations due to their capability to biologically fix nitrogen in symbiosis with rhizobium. The fixed nitrogen becomes available to non-legume crops in succeeding seasons after the decomposition of legume residues. Similarly, Singh and Dhillon (2021) reported that mungbean residues significantly increased yields of the succeeding crop, suggesting that cultivating a sole mungbean crop before wheat could substantially enhance wheat production by contributing significant biomass and nitrogen to the system. Praharaj *et al.* (2020) further supported this notion, highlighting that incorporating leguminous crops into rotations, particularly after rice, could significantly boost upland rice production by adding substantial biomass and nitrogen to the soil. The findings of Almaz *et al.* (2017) in Malaysia, Kalasa *et al.* (2018), and Adesoji *et al.* (2013) in Nigeria further underscore the positive impact of legume residues on subsequent crops, showing higher yields in corn and maize following the incorporation of legume residues. Shuaibu *et al.* (2015) found that application of cowpea or soybean residue increased grain yields of sorghum in Nigeria. Zeng *et al.* (2016) similarly reported a yield increase in legume-preceding plots due to the ability of legumes

to fix atmospheric nitrogen and release it to cereal crops through decomposition, reducing the need for nitrogen fertilizer. Franke *et al.* (2018) supported this, stating that cereal crops following legumes have a reduced requirement for external nitrogen inputs. Moreover, Pagnani *et al.* (2019) highlighted the positive impact of the wheat-faba bean sequence on grain yields, emphasizing the increased grain yield. In contrast, the lowest grain yield was recorded under wheat-wheat sequences. These collective findings provide comprehensive support for the observed variations in grain yield in the current study, emphasizing the crucial role of crop residues, particularly legumes, in influencing subsequent crop productivity.

The plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the highest grain production when different levels of fertilizer were used, followed by 100 % RDF, which was statistically at par to the plot applied with 100 % Nano NPK fertilizers. According to statistics, the control plot's grain yield in 2020–2021 was the lowest. A comparable pattern was noted in 2021-2022 and in mean statistics (Table 4.3.11 and Fig.4.3.11b). The superior grain production in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers can be attributed to the specific fertilizer combination used. The inclusion of nano fertilizers likely played a crucial role in optimizing nutrient absorption, promoting overall plant health, and enhancing the efficiency of nutrient utilization. This, in turn, positively influenced the development and yield of grains. The plot treated with 100 % RDF also demonstrated a high grain yield, suggesting that providing the full recommended dose of conventional fertilizer contributed significantly to grain production. The statistical parity between the 100 % RDF and 100 % Nano NPK fertilizer treatments further underscores the effectiveness of nano fertilizers as a viable alternative or complement to traditional fertilization methods. Conversely, the control plot, which did not receive additional fertilization beyond conventional practices, exhibited the lowest grain yield. The limited availability of nutrients in the control conditions likely restricted optimal plant growth and grain development, leading to reduced overall grain production. This observation aligns with the findings of Yang *et al.* (2023), who observed that the application of a nano fertilizer synergist can stimulate the expression of genes related to N transport and metabolism, promoting N accumulation in wheat plants, and enhancing wheat yield. The enhanced yield can be attributed to improved nutrient availability, leading to an

improved nutritional status, increased leaf chlorophyll content, and a higher assimilation rate. Similar increases in yield due to the application of nano-fertilizers were reported by Zulfiqar *et al.* (2019) and El-Saadony *et al.* (2021). Burhan and AL-Hassan (2019) also noted that the application of nanofertilizers increases the productivity of wheat grain yield. Morsy *et al.* (2018) found that the application of nanofertilizer led to a significantly higher durum wheat yield, particularly under deficit irrigation conditions, as compared to the control. Meena *et al.* (2021) documented that the application of three sprays of nanofertilizers with Recommended Dose of Fertilizers (RDF) resulted in the highest average grain yield. Likewise, Abdelsalam *et al.* (2019) similarly observed a noteworthy rise in yield-related characteristics and grain yield. This increase was particularly notable when a combination of Nano NPK and mineral NPK was applied, outperforming the yields achieved with 100% application of each alone. Saad *et al.* (2022) also documented that the application of nano nitrogen alongside mineral nitrogen resulted in a significantly higher grain yield and improved yield-related characteristics compared to the scenario when the mineral nitrogen dose was doubled. As-taneh *et al.* (2018) determined that the utilization of nano nitrogen in wheat resulted in a higher grain yield even with a reduced nitrogen dose. Jayara *et al.* (2023) observed that nanofertilizers are efficient in enhancing yield while concurrently reducing the need for fertilizer in wheat cultivation. Poudel *et al.* (2023) suggested that the use of nano-phosphorus may enhance nutrient absorption, leading to the optimal growth of various plant parts and improved metabolic processes like photosynthesis. This, in turn, results in higher accumulation of photosynthates and their effective translocation to the economically significant parts of the plant, thereby enhancing overall crop growth, development, and yield.

The interaction between the crop residues and various levels of fertilizer in both seasons (2020-2021 and 2021-2022) and in the mean statistics was found to be significant. The plot where mungbean was grown as the sole crop before wheat and combined with 50 % RDF + 50 % Nano NPK fertilizers had the largest average of grain yield, while the plot where maize was grown as the only crop before wheat and combined with no fertilizers (control) had the smallest average amount of grain yield in both seasons (2020-2021 and 2021-2022), as well as in the case of mean statistics.

4.1.3.2.6. Straw yield (kg/ha)

The 2020–2021 and 2021–2022 *rabi* seasons' straw production per hectare as influenced by various fertilizer levels, residual crop effects, and mean statistics are shown in Table 4.3.10. Straw yield responded considerably to crop residual effects as well as varying levels of fertilizer applications. In both the 2020-2021 and 2021-2022 and in the mean statistics, plots where mungbean was grown as the sole crop prior to wheat produced the highest straw yield followed by the plot where maize and mungbean were intercropped before wheat. Whereas the plot with maize as the sole crop cultivated before wheat had the lowest straw yield in both the seasons of 2020-2021 and 2021-2022 and in the mean statistics. This observed pattern can be attributed to the residual effects of crop residues on soil fertility and organic matter content. The cultivation of mungbean as a preceding crop likely contributed to improved soil conditions, nutrient availability, and increased organic matter, promoting robust straw development in the succeeding wheat crop. The intercropping of maize and mungbean may have also played a role in enhancing nutrient cycling and organic matter content, resulting in a notable straw yield. On the contrary, the lower straw yield in plots where maize was grown as the sole crop before wheat could be associated with potential nutrient imbalances or conditions less conducive to optimal straw development. The differences in straw yield emphasize the importance of strategic crop selection and rotations in not only influencing grain yield but also in determining the quantity of crop residues, such as straw, which contributes to overall soil health and agricultural sustainability. The findings align with previous research, as exemplified by Ndiso *et al.* (2018) in Kenya, who highlighted that incorporation of crop residues demonstrated superior effects on yield parameters. Similarly, Daramy *et al.* (2016) conducted studies in Ghana and reported comparable maize growth and yield in plots with residual N and P from the previous season, as well as in plots that did not receive N and P fertilizers but had incorporated cowpea residues for fertilization. This emphasizes the potential of recycling grain legume residues, potentially yielding net nitrogen as high as 140 kg N ha^{-1} , depending on the legumes. Furthermore, the insights from Padma *et al.* (2019) underscore the conclusion that incorporation or mulching of crop residues tends to enhance the performance of succeeding crops, reflected in terms of significant improvements in yield attributes. Abera *et al.* (2015) also corroborates this, reporting a substantial

yield increment in a legume-cereal rotation compared to continuous cereal cropping. Moreover, the positive impact of incorporating legume crop residues on wheat grain and straw yield, as highlighted by Kiran Kumar *et al.* (2019), aligns with the notion that such practices contribute to improved fertility status of the soil and enhanced nutrient uptake by the succeeding crop. Awad *et al.* (2023) further support this idea, emphasizing that planting wheat after a legume crop tends to improve yield components compared to planting after maize. Similarly, Amgain *et al.* (2019) documented that cultivating green gram before wheat resulted in straw yield.

The plot treated with 50 % RDF+ 50 % Nano NPK fertilizers recorded the maximum straw production among the various levels of fertilizer treatment in both the seasons (2020-2021 and 2021-2022), and in the mean statistics. It was followed by the plot treated with 100 % RDF and 100 % Nano NPK fertilizers. The control plot has consistently had the lowest straw yield in the year 2020-2021. Nonetheless, a comparable pattern was seen in 2021-2022 and mean data (Table 4.3.10 and Fig.4.3.10c). The notable increase in straw production in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers can be attributed to the specific fertilizer combination employed. The inclusion of nano fertilizers likely played a significant role in optimizing nutrient absorption, promoting overall plant health, and enhancing the efficiency of nutrient utilization. This, in turn, positively influenced vegetative growth, leading to higher straw yields. These observations align with the findings of Jinnur *et al.* (2023), who reported that the foliar application of nanofertilizers at 15 days after sowing (DAS) resulted in significantly higher values for various parameters at harvest, including stover yield and grain yield. Sharifi and Namvar (2016) also noted that the foliar application of nanofertilizers could potentially increase the size and efficiency of the source, consequently contributing to higher grain and stover yield. Consistent results were reported by Kole *et al.* (2013) and Rawat *et al.* (2020). Furthermore, Sruthi *et al.* (2022) suggested that the heightened nutrient uptake facilitated by nanofertilizers application could have improved photosynthesis, subsequently leading to an increased straw yield. This observation aligns with the results reported by Kandil and Marie (2017), who found that nano fertilizer application improved the straw yield in wheat. Apoorva *et al.* (2017) documented that the foliar application of nano urea fertilizer enhances both rice grain yield and straw yield, attributing

this effect to an increased rate of photosynthesis, greater production of dry matter, and the accumulation and translocation of photosynthates to economically significant parts of the plant. Similar findings were observed by Mehta and Bharat (2019) in wheat. Additionally, Sahu *et al.* (2022) reported that the highest grain yield and straw yield were observed under the treatment of 50% Recommended Dose of Nutrients (RDN) as a basal application, along with foliar spray of nano urea at the tillering stage and panicle initiation stage. These studies collectively support the conclusion that the strategic use of nano fertilizers, especially in combination with conventional fertilizers, plays a pivotal role in maximizing straw production, reinforcing the observed results in the 2020-2021 and 2021-2022 growing seasons.

Both the data from the growing seasons (2020-2021 and 2021-2022) and mean data revealed a significant interaction between the crop residues and various levels of fertilizer. The plot where mungbean was grown as the sole crop before wheat combined with 50 % RDF + 50 % Nano NPK fertilizers had the highest average of straw yield in 2020-2021 and 2021-2022, as well as when statistics were average. In contrast, the plot where maize was grown as the sole crop before wheat combined with no fertilizers (control) had the lowest average value of straw yield in both seasons (2020-2021 and 2021-2022).

Table 4.3.11.: Effect of the residual effect of crops and different levels of fertilizer on the yield of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021			2021-2022			Mean data		
	Test weight(g)	Grain yield(kg/ha)	Straw yield(kg/ha)	Test weight (g)	Grain yield(kg/ha)	Straw yield(kg/ha)	Test weight (g)	Grain yield(kg/ha)	Straw yield(kg/ha)
A. Residual effect of crops									
M₁	36.21 ^b	3358.81 ^b	4006.38 ^c	36.47 ^b	3504.31 ^b	4152.40 ^c	36.34 ^b	3431.56 ^b	4079.39 ^c
M₂	41.63 ^a	3766.44 ^a	5111.71 ^a	41.82 ^a	3952.91 ^a	5605.09 ^a	41.72 ^a	3859.68 ^a	5358.40 ^a
M₃	38.21 ^b	3646.32 ^{ab}	4619.77 ^b	38.39 ^b	3780.14 ^{ab}	4873.12 ^b	38.30 ^b	3713.23 ^{ab}	4746.44 ^b
SEm (±)	0.36	74.62	95.53	0.39	73.36	101.27	0.37	73.99	98.40
CD (P=0.05)	1.42	292.96	375.05	1.54	287.99	397.56	1.47	290.47	386.31
B. Different levels of fertilizer									
S₁	32.27 ^c	1698.37 ^c	2843.29 ^d	32.35 ^c	1729.16 ^c	3261.12 ^c	32.31 ^b	1713.77 ^c	3052.20 ^d
S₂	40.57 ^b	4338.34 ^a	5325.07 ^b	40.89 ^b	4523.20 ^a	5620.55 ^b	40.73 ^b	4430.77 ^a	5472.81 ^b
S₃	38.98 ^b	3787.42 ^b	4702.78 ^c	39.08 ^b	3994.95 ^b	4875.18 ^c	39.03 ^b	3891.18 ^b	4788.98 ^c
S₄	42.91 ^a	4537.97 ^a	5445.99 ^a	42.24 ^a	4735.85 ^a	5750.64 ^a	43.07 ^a	4636.91 ^a	5598.31 ^a
SEm (±)	0.42	80.12	108.17	0.57	90.79	128.61	0.49	85.46	69.92
CD (P=0.05)	1.25	238.01	321.35	1.71	269.72	382.07	1.48	253.87	207.70
Interaction (A x B)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

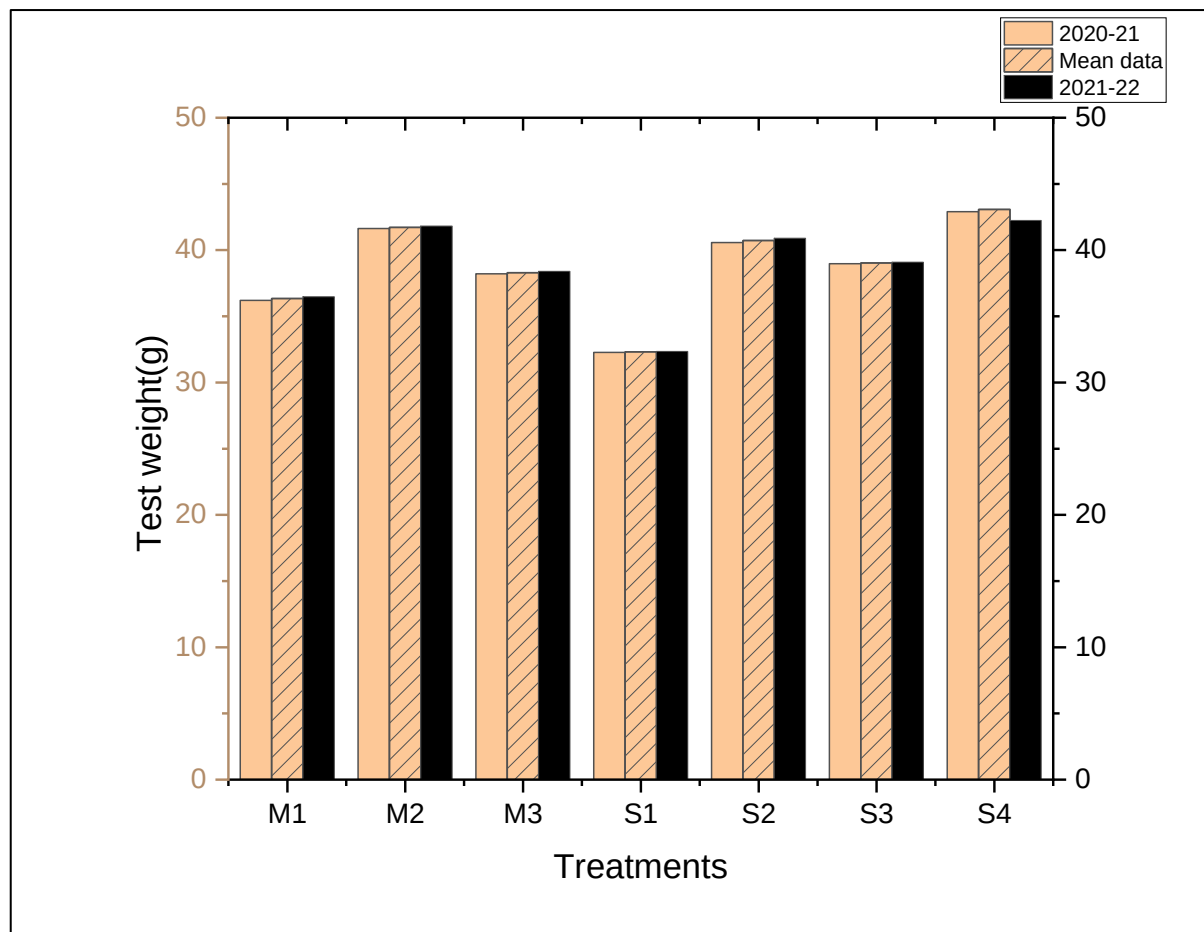


Fig.4.3.11a: Effect of the residual effect and different levels of fertilizers on the test weight (g) of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂-Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers, RDF=Recommended dose of fertilizers.

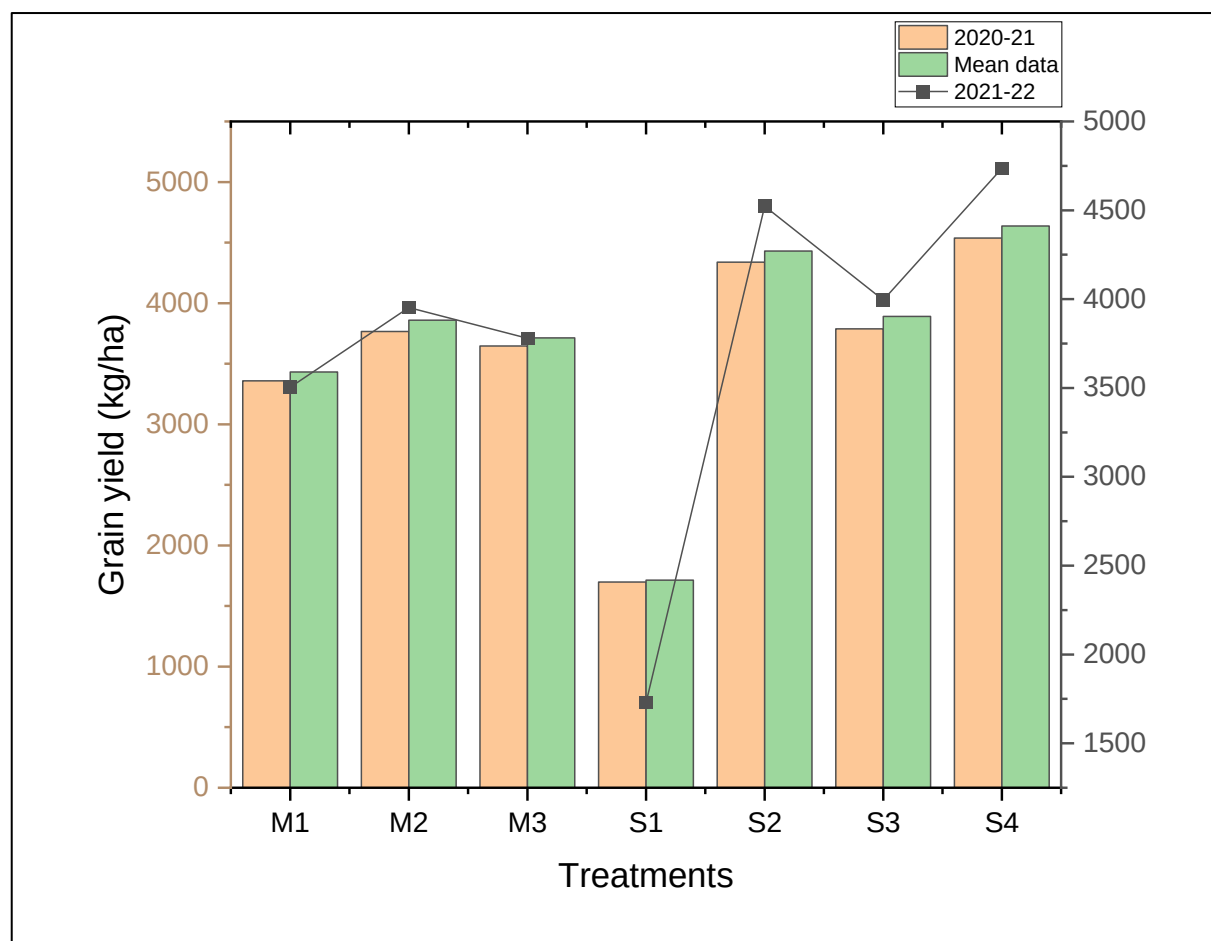


Fig.4.3.11b: Effect of the residual effect and different levels of fertilizers on the grain yield (kg/ha) of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers RDF=Recommended dose of fertilizers.

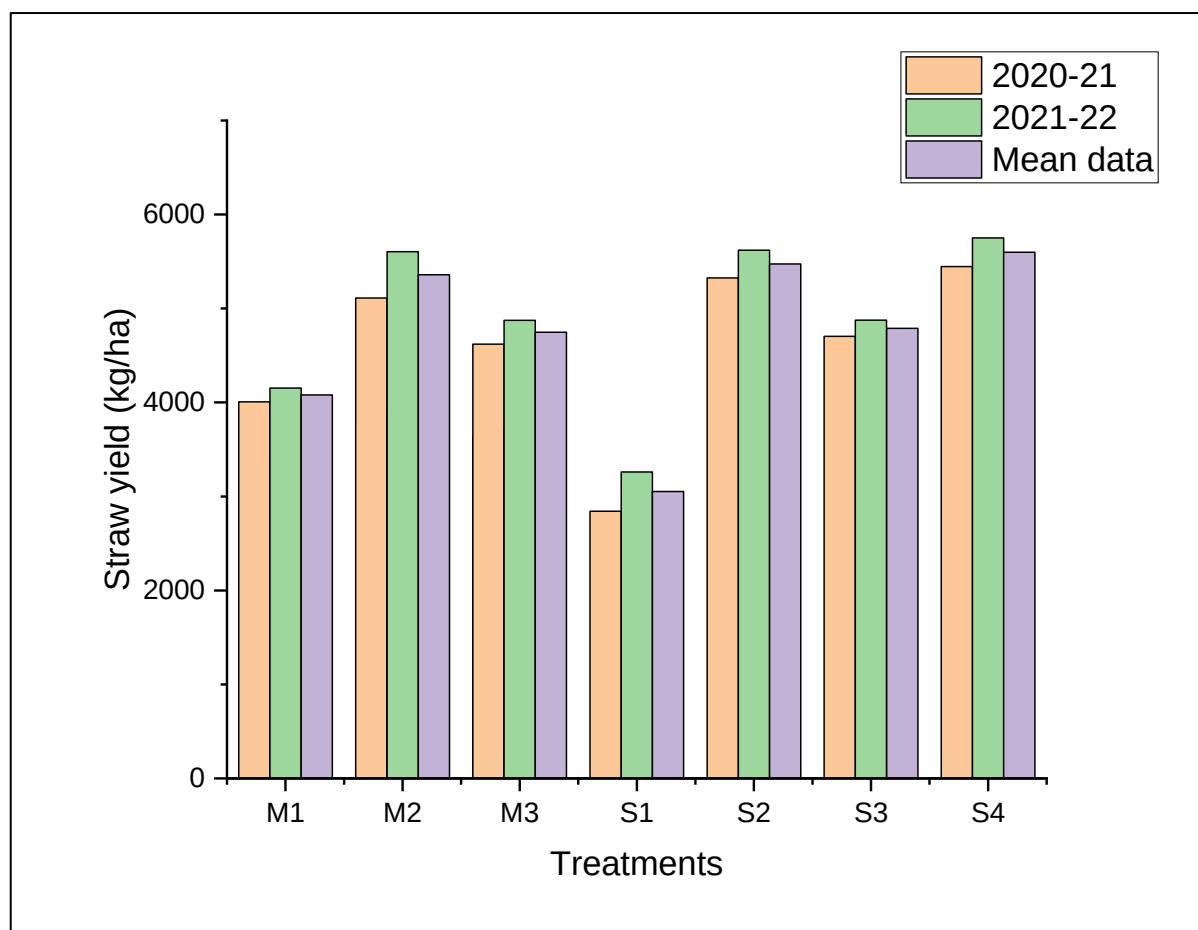


Fig.4.3.11c: Effect of the residual effect and different levels of fertilizers on the straw yield (kg/ha) of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers RDF=Recommended dose of fertilizers.

Table 4.3.11a: Interaction between residual effect of crops and different levels of fertilizer on the test weight (g) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	28.89 ^h	39.10 ^e	37.02 ^f	39.82 ^d	28.96 ^h	38.53 ^e	37.11 ^f	40.25 ^c	29.93 ⁱ	39.31 ^e	37.07 ^{fg}	40.04 ^c
M₂	36.81 ^f	43.13 ^b	41.65 ^c	44.93 ^a	36.90 ^f	43.57 ^c	41.75 ^d	45.04 ^a	36.86 ^g	43.35 ^{cd}	41.70 ^d	44.99 ^a
M₃	31.12 ^g	39.49 ^d	38.27 ^e	43.98 ^a	31.20 ^g	39.58 ^e	38.37 ^{ef}	44.42 ^b	31.16 ^h	39.53 ^e	38.32 ^{ef}	44.20 ^b
SEm (±)	0.73				0.79				0.48			
CD (P=0.05)	2.16				2.35				1.50			

Table 4.3.11b: Interaction between the residual effect of crops and different levels of fertilizer on the grain yield (kg/ha) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	1391.17 ^g	4119.00 ^b	3764.04 ^{de}	4161.03 ^b	1317.64 ^e	4336.92 ^b	3981.34 ^d	4381.39 ^b	1354.39 ^e	4227.96 ^b	3872.69 ^d	4271.21 ^b
M₂	2153.77 ^e	4534.47 ^b	3831.28 ^c	4546.25 ^a	2297.32 ^d	4709.72 ^b	4052.46 ^c	4751.66 ^a	2225.80 ^d	4622.10 ^b	3941.87 ^c	4648.95 ^a
M₃	1550.17 ^{fg}	4361.55 ^b	3766.93 ^d	4906.63 ^a	1572.06 ^e	4522.97 ^b	3951.06 ^d	5074.49 ^a	1561.12 ^e	4442.26 ^b	3859.00 ^d	4990.56 ^a
SEm (±)	138.77				157.26				148.02			
CD (P=0.05)	412.25				467.17				439.71			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.11c: Interaction between the residual effect of crops and different levels of fertilizer on the straw yield (kg/ha) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	1820.70 ^h	4826.94 ^{fg}	4402.07 ^{de}	4975.79 ^d	1875.66 ^h	4961.34 ^g	4508.75 ^e	5263.84 ^{de}	1848.18 ^h	4894.14 ^g	4455.41 ^e	5119.81 ^d
M₂	3830.57 ^f	5784.03 ^c	5043.88 ^{cd}	5788.37 ^a	4901.65 ^f	6073.02 ^c	5272.16 ^{cd}	6173.55 ^a	4366.11 ^f	5928.53 ^c	5158.02 ^{cd}	5980.96 ^a
M₃	2878.61 ^g	5364.25 ^e	4662.40 ^d	5573.81 ^b	3006.03 ^{fg}	5927.28 ^e	4844.63 ^d	5814.53 ^b	2942.32 ^{fg}	5595.76 ^e	4753.51 ^d	5694.17 ^b
SEm (±)	187.36				222.77				205.06			
CD (P=0.05)	556.60				661.77				609.19			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.2.7. Biological yield (kg/ha)

Table 4.3.12 illustrates the biological yield per hectare as impacted by different fertilizer levels, crop residue, and combined data for the *rabi* seasons of 2020–2021 and 2021–2022. Biological yield significantly responded to different fertilizer levels and residual crops effect. Plots, where mungbean was grown as a sole crop prior to wheat, produced the superior biological yield followed by plots where maize and mungbean were intercropped before wheat. While the plot with maize as the only crop cultivated before wheat had the lowest biological yield in both the seasons of 2020-2021 and 2021-2022 and in mean statistics. The observed variation in biological yield can be attributed to the residual effects of preceding crops. Plots with a history of mungbean as the sole crop created favorable conditions for biological yield enhancement. The intercropping of maize and mungbean before wheat also proved to be a beneficial practice, resulting in notable biological yield. In contrast, the inferior biological yield associated with the sole cultivation of maize before wheat indicates that this sequence may not have been conducive to optimal yield development, considering the residual effects left in the soil. Similar observations were documented by several researchers. In an experiment conducted at the University of Agriculture, Peshawar, Ali *et al.* (2018) found that the incorporation of mungbean residues led to a higher biological yield in maize compared to the control. This underscores the idea that residual effects, especially those originating from leguminous crops such as mungbean, significantly contribute to shaping the yields of subsequent crops. Mesfin *et al.* (2023) contributed to this understanding by emphasizing the significant impact of different legume crop rotations on biomass yield. Notably, the faba bean-wheat rotation demonstrated significantly higher wheat biomass yield, further emphasizing the positive residual effects of leguminous crops on succeeding crops. Awad *et al.* (2023) supported this perspective, indicating logical enhancements in biological yields following legumes. They noted that the yield components of wheat experienced increases after legume crops compared to cereal crops, reinforcing the positive influence of leguminous residues on biological yield. The findings of Zhang *et al.* (2015) emphasized the residual effect benefits of intercropping soybean with maize on subsequent wheat crops compared to monoculture of maize. This observation aligns with the concept that diversifying crop sequences can positively impact biological yield through residual effects. Zaheer *et*

al. (2015) provided insights into the nutrient supply aspect of biological yield, emphasizing the role of legume crops in directly increasing yield through residual nitrogen. The slow mineralization of root biomass and nodules left in the soil from preceding legumes contributed to the nutrient availability for the subsequent wheat crop throughout its growth period. In a similar vein, Singh and Dhillon (2021) reported a notably elevated biological yield of wheat associated with the application of mungbean residues.

In the case of different levels of fertilizer treatment, in the year 2020-2021, the plot treated with 50 % RDF +50 % Nano NPK fertilizers produced the highest biological yield followed by the plot treated with 100 % RDF and 100 % Nano NPK fertilizers. According to statistics, the control plot's biological yield was lowest in the years 2020 and 2021. However, a comparable pattern was noted in the year 2021-2022 and when data were mean (Table 4.3.11 and Fig.4.3.11a). This outcome could be attributed to the optimal nutrient balance provided by the 50 % RDF + 50 % Nano NPK treatment and potential synergistic effects arising from the interaction between conventional RDF and Nano NPK fertilizers. The slow-release properties of Nano NPK fertilizers might have played a role, ensuring a sustained nutrient supply. Additionally, soil health, including specific soil characteristics, and environmental conditions during the 2020-2021 growing seasons likely contributed to the observed differences. It is noteworthy that the control plot consistently demonstrated the lowest biological yield during this period, emphasizing the importance of fertilizer treatments in influencing crop productivity. Ghafari and Razmjoo (2013) found that foliar application of nanofertilizers increased the biological yield of wheat, aligning with the present study's findings. Ram *et al.* (2023) also reported maximum biological yield in nanofertilizers treatments, a result in accordance with Rawate *et al.* (2022), who observed increased wheat biological yield with the application of nanofertilizers. Additionally, Azimnejad *et al.* (2023) demonstrated the significant effect of nano phosphorous on biological yield. Al-Juthery *et al.* (2018) further supported these observations by showing that spraying nano-fertilizer had a substantial response compared to control and traditional fertilizer treatments in terms of biological yield and harvest index. The integrated use of nano and non-nanofertilizers, as noted by Mehta and Bharat (2019), had a significant impact on biological yield. Moreover, Al-Juthery *et al.* (2019) identified higher biological yield in wheat with the spraying of

nanofertilizers. These additional findings, combined with the present study's results, provide robust support to the overall conclusion regarding the positive impact of nanofertilizers on biological yield in wheat cultivation. The collective evidence underscores the potential of nanofertilizers as an effective approach to enhance crop productivity.

The interaction between the cropping system and levels of fertilizer in both seasons (2020-2021 and 2021-2022) and mean data was found to be significant. The plot where mungbean were grown as the sole crop before wheat combined with 50% RDF + 50% Nano NPK fertilizers noted the highest biological yield, and the plot where maize was grown as the sole crop before wheat combined with no fertilizers (control) recorded the least in both seasons (2020-2021 and 2021-2022), and in the mean data (Table 4.3.12 a).

4.1.3.2.8. Harvest index (%)

Table 4.3.12, which includes mean data, shows the impact of various fertilizer applications and the residual effects of crops on the harvest index throughout the *rabi* seasons of 2020–2021 and 2021–2022. The wheat harvest index was significantly impacted by the crop residues. The plot where maize was cultivated as the sole crop before wheat was recorded to have the highest percent of harvest index in the years 2020–2021, followed by the plot where maize and mungbean were intercropped before wheat. While in the case of the mean data and the seasons 2020–2021 and 2021–2022, the plot with mungbean as the sole crop grown before wheat had the lowest percent of harvest index (Fig.4.1.12b). This observed variation in harvest index can be attributed to the residual effects of the preceding crops. The cultivation of maize as the sole crop before wheat may have left favorable conditions in the soil, contributing to a higher percentage of harvest index. On the other hand, the lower harvest index in plots with mungbean as the sole crop suggests that the residual effects from mungbean cultivation may not have been as conducive to optimal harvest index development. Moreover, additional insights from Awopegba *et al.* (2016) indicated that the application of pigeon pea enhanced harvest index. Furthermore, the study by Zaheer *et al.* (2015) emphasized the dependence of harvest index on soil nutrient supply. Legume crops, owing to their residual nitrogen, were found to directly increase yield. This enhancement could be attributed to nitrogen fixation by preceding legumes and the slow mineralization of root biomass containing nodules left in the soil,

gradually becoming available to the subsequent wheat crop throughout its growth period. Similarly, Raghavendra *et al.* (2020) documented a significant increase in harvest index with the application of green gram residue in both maize and wheat cultivation.

The plot where 50 % RDF+ 50 % Nano NPK fertilizers were applied had the highest harvest index in the years 2020–2021, which was statistically similar to the plot treated with 100 % RDF and 100 % Nano NPK fertilizers. According to statistics, the control plot's harvest index for the years 2020–21 had the lowest value. A similar pattern was seen in the years 2021–2022 and in the mean statistics (Table 4.3.12 and Fig.4.3.12b). The balanced combination of conventional RDF and Nano NPK fertilizers likely provided an optimal nutrient profile, promoting efficient nutrient uptake by the plants. This, in turn, contributed to enhanced crop development and, ultimately, a higher harvest index. The statistical similarity between the 50 % RDF + 50 % Nano NPK treatment and the 100 % RDF and 100 % Nano NPK treatments further supports the notion that the nanofertilizers component played a crucial role in achieving comparable harvest index values. On the contrary, the control plot consistently demonstrated the lowest harvest index during the years 2020–2021, reflecting the importance of fertilization in optimizing crop yield. This outcome underscores the necessity of adequate nutrient supply for maximizing harvest index. A similar pattern observed in the years 2021–2022 and in the mean statistics emphasizes the robustness of the observed trends. The superior performance of the 50 % RDF + 50 % Nano NPK fertilizer treatment in terms of harvest index during the specified years can be attributed to the synergistic effects and balanced nutrient provision, reinforcing the positive impact of nanofertilizers on crop productivity. Al-Juthery *et al.* (2018) reported significant responses, indicating that spraying nano-fertilizer resulted in increased harvest index compared to control and traditional fertilizer treatments. The findings of Gangwar *et al.* (2022) from Mean data analysis further supported the positive impact of nanofertilizers treatment on harvest index. Abdel-Aziz *et al.* (2016) demonstrated substantial improvements in harvest index with the application of nano NPK fertilizer to wheat plants, compared to no fertilization or conventional NPK fertilization. Mahmoodzadeh *et al.* (2013) also documented analogous results in wheat crops, providing additional support to the consistency of the reported findings. The superior performance of the 50 % RDF

+ 50 % Nano NPK fertilizer treatment in terms of harvest index during the specified years can be attributed to the synergistic effects and balanced nutrient provision, reinforcing the positive impact of nanofertilizers on crop productivity, as corroborated by the cited studies.

The interaction between the crop residues and different levels of fertilizer in both seasons (2020-2021 and 2021-2022) and mean data was found to be significant. In all the growing years (2020-2021 and 2021-2022), as well as when data were average, the superior mean value of harvest index was found in the plot where maize was grown as the intercrop with mungbean prior to wheat combined with 50 % RDF + 50 % Nano NPK fertilizers. While the plot where maize and mungbean intercrop was cultivated before wheat combined with no fertilizers (control) in both seasons (2020-2021 and 2021-2022) and in the event of mean statistics, the least overall value of the harvest index was recorded (Table 4.3.12b).

Table 4.3.12.: Effect of the residual effect of crops and different levels of fertilizer on the biological yield (kg/ha) and harvest index (%) of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021		2021-2022		Mean data	
	Biological yield(kg/ha)	Harvest index (%)	Biological yield(kg/ha)	Harvest index (%)	Biological yield(kg/ha)	Harvest index (%)
A. Residual effect of crops						
M₁	7365.18 ^c	45.34 ^a	7656.71 ^c	45.18 ^a	7510.95 ^c	45.26 ^a
M₂	8878.16 ^a	41.79 ^b	9558.01 ^a	40.81 ^b	9218.08 ^a	41.30 ^b
M₃	8266.09 ^b	42.75 ^b	8653.26 ^b	42.35 ^b	8459.67 ^b	42.55 ^b
SEm (±)	171.58	0.46	149.72	0.28	160.65	0.37
CD (P=0.05)	509.71	1.79	587.78	1.10	548.74	1.44
B. Different levels of fertilizer						
S₁	4286.66 ^d	38.06 ^c	4990.28 ^d	36.03 ^c	4765.97 ^d	37.04 ^c
S₂	9663.41 ^b	44.99 ^b	10143.75 ^b	44.76 ^b	9903.58 ^b	44.88 ^b
S₃	8490.20 ^c	44.68 ^a	8870.13 ^c	45.13 ^a	8680.17 ^c	44.90 ^a
S₄	9983.96 ^a	45.45 ^b	10486.49 ^a	45.13 ^b	10235.22 ^a	45.32 ^b
SEm (±)	183.25	0.43	228.66	0.57	202.07	0.50
CD (P=0.05)	544.38	1.26	679.30	1.68	600.28	1.47
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

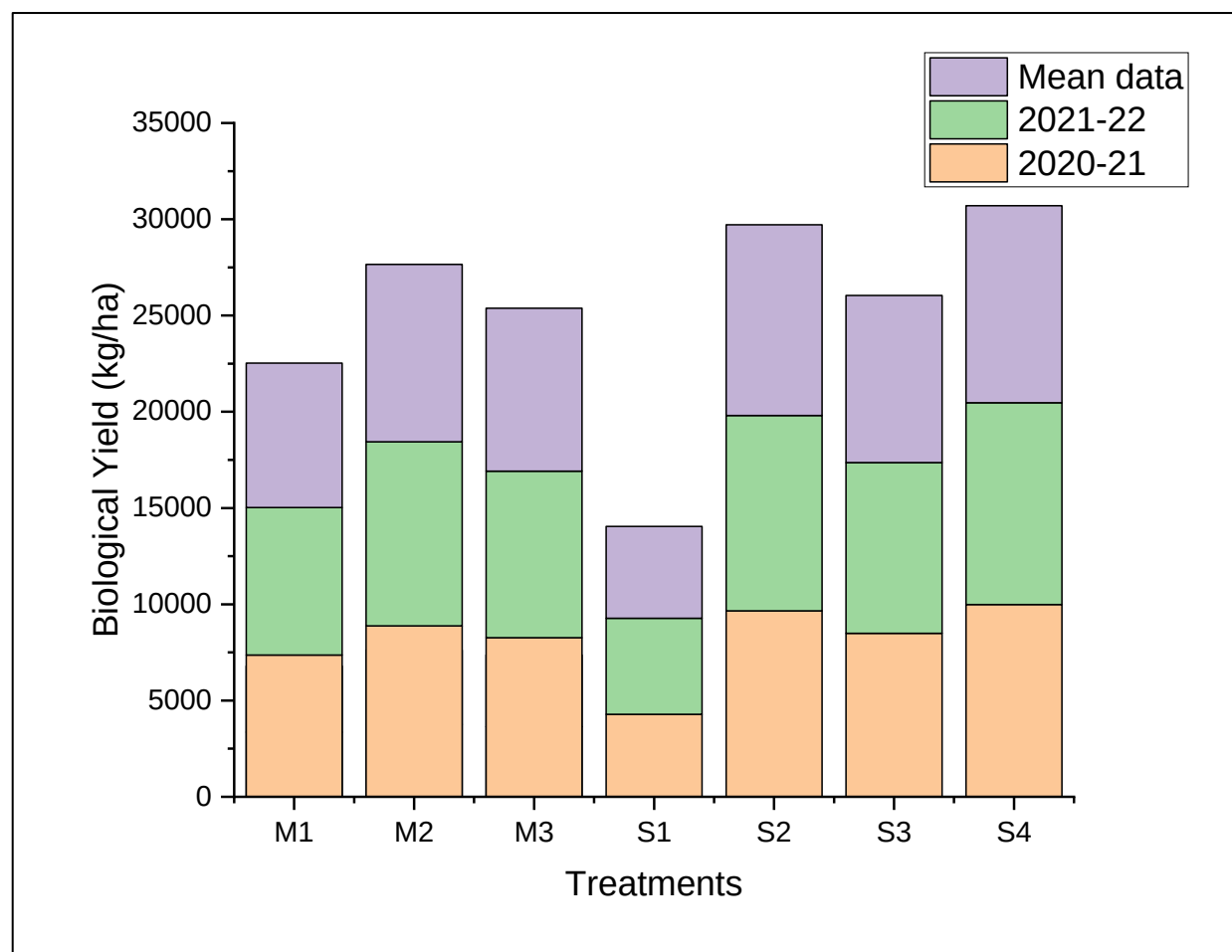


Fig.4.3.12a: Effect of the residual effect and different levels of fertilizers on the biological yield (kg/ha) of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers RDF=Recommended dose of fertilizers.

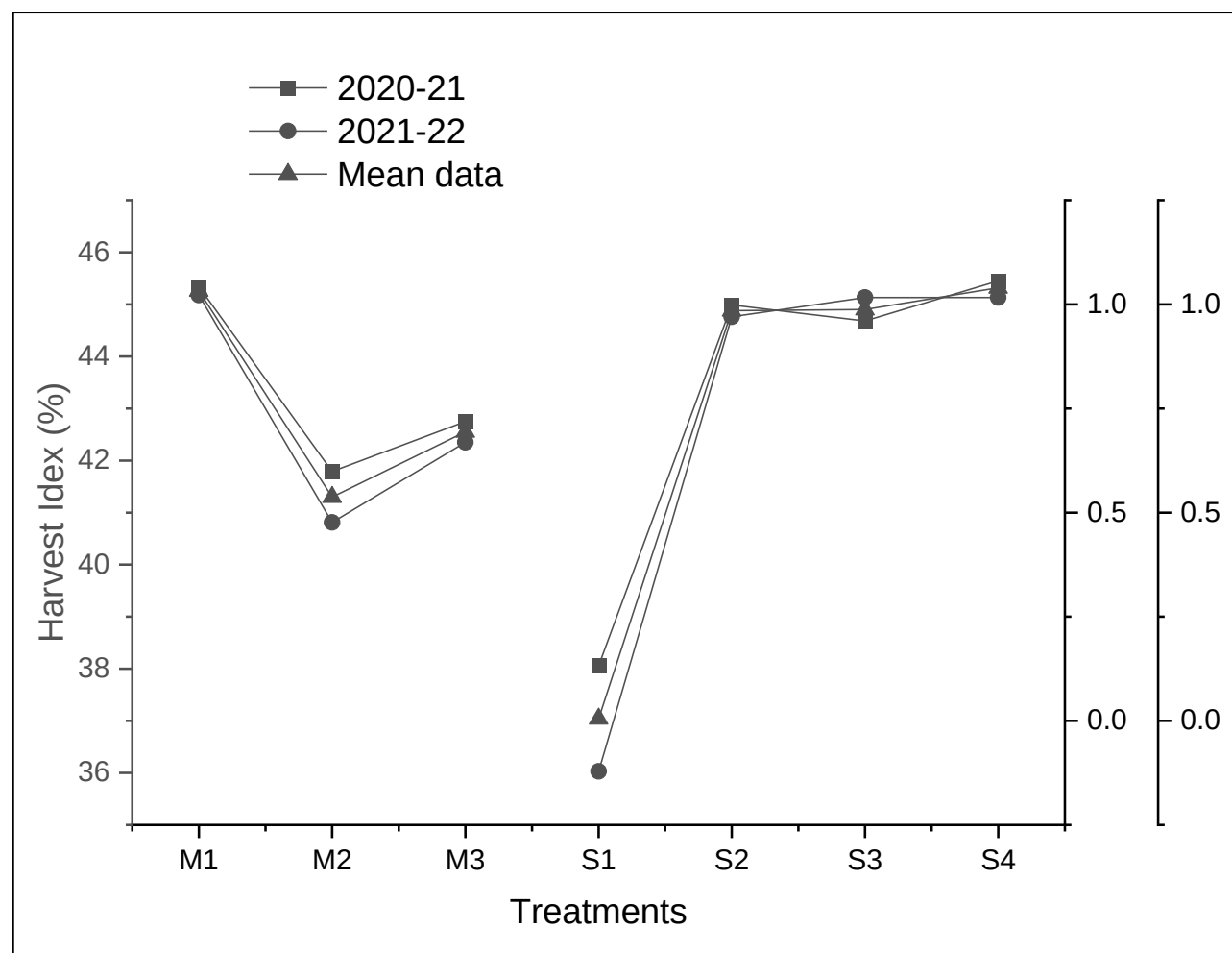


Fig.4.3.12b: Effect of the residual effect and different levels of fertilizers on the harvest index (%) of wheat during the years (2020-2021 and 2021-2022) and pooled data. M₁-Residual effect of maize on wheat, M₂- Residual effect of mungbean on wheat, M₃-Residual effect of Maize+Mungbean intercrop on wheat, S₁- Control, S₂-100% RDF, S₃-100% Nano NPK fertilizers, S₄-50% RDF+50% Nano NPK fertilizers RDF=Recommended dose of fertilizers.

Table 4.3.12a: Interaction between the residual effect of crops and different levels of fertilizer on the biological yield (kg/ha) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	3211.87 ⁱ	8945.94 ^c	8166.94 ^g	9136.83 ^b	3193.27 ⁱ	9298.26 ^c	8490.09 ^g	9645.22 ^b	3202.57 ⁱ	9122.10 ^c	8328.10 ^g	9391.03 ^b
M₂	5984.34 ^f	10318.51 ^b	8875.16 ^d	10334.62 ^a	7199.47 ^f	10782.74 ^b	9324.62 ^d	10925.21 ^a	6591.91 ^f	10550.62 ^b	9099.89 ^d	10629.91 ^a
M₃	4428.78 ^{hg}	9725.80 ^b	8429.33 ^e	10480.43 ^b	4578.09 ^g	10350.24 ^b	8795.69 ^e	10889.02 ^b	4503.44 ^g	10038.02 ^b	8612.51 ^e	10684.73 ^b
SEm (±)	297.18				396.06				346.62			
CD (P=0.05)	882.85				1176.57				1029.71			

Table 4.3.12b: Interaction between the residual effect of crops and different levels of fertilizer on the harvest index (%) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	43.25 ^b	46.21 ^a	46.17 ^a	45.72 ^a	41.36 ^b	46.81 ^a	46.96 ^a	45.59 ^a	42.33 ^b	46.51 ^a	46.58 ^a	45.66 ^a
M₂	36.08 ^c	43.93 ^a	43.17 ^b	43.98 ^{ab}	32.54 ^c	43.67 ^a	43.50 ^b	43.51 ^{ab}	34.49 ^c	43.80 ^a	43.36 ^a	43.75 ^{ab}
M₃	34.83 ^c	44.84 ^a	44.71 ^a	46.63 ^a	34.19 ^c	43.81 ^a	44.93 ^a	46.47 ^a	34.55 ^c	44.33 ^a	44.84 ^a	46.56 ^a
SEm (±)	0.74				0.98				0.86			
CD (P=0.05)	2.94				2.91				2.55			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.3 Nutrient uptake (kg/ha)

4.1.3.3.1 Nitrogen uptake in straw (kg/ha)

Table 4.3.13 shows the impact of various fertilizer levels and the crop residues on the wheat nitrogen uptake in straw during the 2020-2021 and 2021-2022 *rabi* seasons and in the mean statistics. In the year 2020-2021, the highest uptake of nitrogen in straw was observed in the plot where mungbean was cultivated as a sole crop before wheat, and this was comparable to the plots where maize and mungbean were intercropped before wheat. This treatment showed superior nitrogen uptake in straw compared to all other treatments. Conversely, the plot with maize as the sole crop cultivated before wheat exhibited the lowest uptake of nitrogen in straw in both the 2020-2021 and 2021-2022 seasons, as well as in the mean statistics. The observed differences in nitrogen uptake can be attributed to the specific crop sequences and residual effects of preceding crops. The cultivation of mungbean as a sole crop before wheat, and the intercropping of maize and mungbean, likely contributed to improved nitrogen availability in the soil, resulting in higher uptake in straw. In contrast, the sole cultivation of maize before wheat might have left the soil with lower nitrogen levels, leading to reduced nitrogen uptake in straw. This is in line with Lupwayi *et al.* (2014), who observed increased nitrogen uptake in the straw of wheat following legumes compared to wheat following barley. Additionally, Yuvaraj *et al.* (2020) emphasized that the decomposition of legume roots releases nitrogen into the soil, making it accessible for subsequent crops. Hazra and co-authors (2019) highlighted the crucial role of grain legumes in cereal-based crop rotations, asserting that integrating legumes enhances soil fertility. Janati *et al.* (2023) further demonstrated the positive impact of various legumes on plant parameters, specifically enhancing nitrogen content in the plants. Moreover, the current study aligns with the findings of Mesfin *et al.* 2023, indicating that the inclusion of legumes, such as faba bean, reduced the need for nitrogen fertilizer following the legume crop. This reduction in nitrogen fertilizer requirements is consistent with the results reported by Reckling *et al.* (2014), who stated that legumes can save significant amounts of nitrogen fertilizer for subsequent cereal crops, with reported savings ranging from 150–200 kg N ha⁻¹. The observed increase in nitrogen uptake in legumes incorporated plots can be attributed to the slow and continuous supply of nutrients, coupled with reduced nitrogen losses via denitrification or leaching. This

improved synchrony between plant nitrogen demand and soil nutrient supply is supported by research findings from Haile *et al.* (2012) and Tilahun *et al.* (2013).

The influence of various fertilizer levels had a significant impact on the nitrogen uptake of straw in both seasons i.e., 2020-2021 and 2021-2022 and in the mean statistics. In 2020-2021, the plot applied with 50 % RDF +50 % Nano NPK fertilizer noted the maximum uptake of nitrogen in straw, next to the plot treated with 100 % RDF and 100 % Nano NPK fertilizers. Conversely, the control plot had the least nitrogen uptake in straw. In the case of 2021-2022 and mean data, similar outcomes to those of 2020-2021 were observed. The significant impact of various fertilizer levels on nitrogen uptake in straw during both the 2020-2021 and 2021-2022 seasons, as well as in the mean statistics, can be elucidated by considering the recommendations put forth by Preetha and Balakrishnan (2017). They emphasized the efficacy of nanofertilizers, particularly in the form of nano fertilized nitrogen, due to their ability for slow nitrogen release, reduction in volatilization and leaching rates, and promotion of high nutrient uptake. The slow-release characteristic of nanofertilizers aligns with the observed trends, as the plot treated with 50 % RDF + 50 % Nano NPK fertilizer exhibited the highest nitrogen uptake in straw, suggesting sustained nutrient availability. Additionally, Theerthana *et al.* (2023) found increased nitrogen (N) and phosphorus (P) content in straw, supporting the notion that fertilizers play a crucial role in nutrient enrichment. Additionally, in the study conducted by Upadhyay *et al.* in 2023, it was observed that the application of nano-fertilizers significantly impacted the total nitrogen uptake in the straw of maize, wheat, and pearl millet crops. This further reinforces the notion that the use of nano-fertilizers can have a substantial influence on nitrogen uptake in grains, supporting the observed pattern in the present study.

The interaction between the various levels of fertilizer and the crop residues was significant in both the years (2020-2021 and 2021-2022) as well as when the data from both years were mean. In all seasons (2020-2021 and 2021-2022), as well as when data was mean, the superior nitrogen uptake in straw were reported in the plot where mungbean was grown as the sole crop prior to wheat combined with 50 % RDF+ 50 % Nano NPK fertilizers while the least uptake of N on straw was noted in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (control) in both seasons (2020-2021 and

2021-2022) and in the mean statistics (Table 4.3.13a).

4.1.3.3.2 Nitrogen uptake in grain (kg/ha)

Table 4.3.13 shows the impact of various fertilizer rates and the residual impact of crops on the wheat nitrogen uptake in grain during the 2020-2021 and 2021-2022 *rabi* seasons as well as mean data. The plot where mungbean was grown as the sole crop before wheat, followed by the plot where maize and mungbean were grown as an intercrop before wheat, had the highest nitrogen uptake in the grain during 2020–2021, whereas the plot where maize was grown as the sole crop before wheat had the lowest uptake. Similar results to those of the year 2020-2021 were indicated in the years 2021-2022 and mean statistics. These variations in nitrogen uptake align with the observations of Kouelo *et al.* (2013), who reported that the incorporation of legume residues, such as mungbean, increased grain nitrogen uptake compared to plots without residue incorporation. Sinha *et al.* (2018) also supported this notion, asserting that the total uptake of nutrients (N, P, K) by maize crops was higher in plots with crop residue incorporation than in those without. Moreover, research findings by Uzoh *et al.* (2019) and Abera *et al.* (2015) further substantiated this trend, confirming an increase in nitrogen uptake in subsequent wheat crops when grown after different legumes. These findings collectively suggest that the choice of preceding crops significantly influences nutrient availability in the soil, thereby impacting nitrogen uptake in wheat grain. Overall, the data, along with insights from various studies, emphasizes the intricate relationship between crop residues, nitrogen uptake, and nutrient availability in the soil. Incorporating legume residues, as observed with mungbean, proves beneficial for subsequent crops like wheat, contributing to improved nitrogen uptake in the grain.

Various levels of fertilizers had a significant impact on the nitrogen uptake of grain in both seasons i.e., 2020-2021 and 2021-2022 as well as when the data were mean. The plot fertilized with 50 % RDF + 50 % Nano NPK fertilizer in 2020–2021 had the maximum nitrogen uptake in grain, followed by 100 % RDF and 100 % Nano NPK fertilizers, in that order. The control plot experienced the lowest nitrogen uptake in grain throughout the years 2020–2021. However, a comparable tendency was seen in 2021-2022 and when data were mean. The distinct pattern observed in nitrogen uptake in grains during both the years, where the plot treated with 50 % RDF + 50 % Nano NPK fertilizer exhibited the highest

uptake, followed by 100 % RDF and 100 % Nano NPK fertilizers, aligns with findings from Bora *et al.* (2018). They documented that a combination of 50 % Recommended Dose of Nutrients (RDN), applied as a basal dose, along with foliar spray of nanofertilizers during key growth stages, resulted in increased nutrient content and uptake by grains. The enhanced nutrient uptake in the plot treated with 50 % RDF + 50 % Nano NPK fertilizer may be attributed to the larger surface area and smaller particle size of nanofertilizers, characteristics that facilitate greater penetration of nutrients into the plant, as highlighted by Bora *et al.* Furthermore, Theerthana *et al.* (2023) observed elevated levels of nitrogen in grains, supporting the notion that appropriate fertilization contributes to enhanced nutrient content in crops. The consistent trend in nitrogen uptake in grains across the years underscores the importance of fertilization practices. Moreover, Iyarin and Aravinda (2019) provided additional context by stating that nano-fertilizers containing NPK increase the absorption and utilization of nutrients by grain crops. This aligns with the overall observed trend, where the treatments involving Nano NPK fertilizers, either alone or in combination, showed increased nitrogen uptake in grains.

The interaction between the crop residues and various fertilizer levels was shown to be significant in both the years (2020-2021 and 2021-2022) as well as when the data from both years were mean. In all seasons (2020-2021 and 2021-2022), as well as when data were mean, the superior nitrogen uptake in grain was recorded in the plot where mungbean was grown as the sole crop prior to wheat combined with 50 % RDF + 50 % Nano NPK fertilizers while the least N uptake on grain was noted in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (control) in both seasons (2020-2021 and 2021-2022) and in the mean statistics.

Table 4.3.13.: Effect of the residual effect of crops and different levels of fertilizer on the nitrogen uptake in straw and grain of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021		2021-2022		Mean data	
	Nitrogen uptake(kg/ha)		Nitrogen uptake(kg/ha)		Nitrogen uptake(kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
A. Residual effect of crops						
M₁	42.33 ^c	20.28 ^b	46.34 ^c	22.16 ^c	44.34 ^c	21.22 ^c
M₂	59.14 ^a	25.27 ^a	64.74 ^a	27.62 ^a	61.94 ^a	26.44 ^a
M₃	49.51 ^b	22.25 ^a	54.20 ^b	24.31 ^b	51.86 ^b	23.28 ^b
SEm (±)	0.43	0.20	0.52	0.46	0.47	0.30
(P=0.05)	2.66	1.58	3.03	1.82	2.85	1.70
B. Different levels of fertilizer						
S₁	30.35 ^d	13.84 ^d	33.23 ^d	15.12 ^d	31.79 ^d	14.48 ^d
S₂	58.84 ^b	26.17 ^b	64.42 ^b	28.59 ^b	61.63 ^b	27.38 ^b
S₃	48.04 ^c	22.81 ^c	52.59 ^c	24.92 ^c	50.32 ^c	23.86 ^c
S₄	64.08 ^a	27.58 ^a	70.15 ^a	30.14 ^a	67.11 ^a	28.86 ^a
SEm (±)	0.42	0.14	0.47	0.45	0.32	0.28
(P=0.05)	2.29	1.05	2.41	1.33	2.35	1.19
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.13a: Interaction between the residual effect of crops and different levels of fertilizer on the nitrogen uptake (kg/ha) in grain of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	22.84 ⁱ	51.19 ^e	38.83 ^g	56.47 ^d	25.01 ^j	39.01 ^e	42.50 ^g	61.81 ^d	23.93 ^j	53.62 ^e	40.67 ^g	59.14 ^d
M₂	39.49 ^g	66.65 ^b	56.47 ^d	73.94 ^a	43.23 ^g	72.97 ^b	61.81 ^d	80.95 ^a	41.36 ^g	69.81 ^b	59.14 ^d	77.45 ^a
M₃	28.72 ^h	58.68 ^d	48.83 ^f	61.82 ^c	31.44 ^h	64.24 ^d	53.45 ^f	67.68 ^c	30.08 ^h	61.75 ^d	51.14 ^f	64.75 ^c
SEm (±)	0.75				0.82				0.78			
CD (P=0.05)	2.23				2.44				2.33			

Table 4.3.13b: Interaction between the residual effect of crops and different levels of fertilizer on the nitrogen uptake (kg/ha) in straw of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	11.83 ^h	23.76 ^e	19.72 ^f	25.80 ^c	12.93 ^h	25.96 ^e	21.54 ^f	28.19 ^c	12.38 ^h	24.86 ^e	20.63 ^f	27.00 ^c
M₂	16.83 ^g	29.43 ^a	24.27 ^d	30.57 ^a	18.39 ^g	32.16 ^a	26.52 ^d	33.40 ^a	17.61 ^g	30.79 ^a	25.39 ^d	31.98 ^a
M₃	12.84 ^h	25.32 ^{cd}	24.44 ^{de}	26.39 ^c	14.03 ^h	27.66 ^{cd}	26.70 ^{de}	28.83 ^c	13.44 ^h	26.49 ^{cd}	25.57 ^{dc}	27.61 ^c
SEm (±)	0.35				0.78				0.56			
CD (P=0.05)	1.48				2.30				1.89			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.3.3 Phosphorous uptake in straw (kg/ha)

The phosphorus uptake of stover was significantly impacted by various fertilizer levels and the residual effects of crops in both seasons (2020-2021 and 2021-2022), and in the mean data (Table 4.3.14). Higher uptake of phosphorous in straw was recorded in the plot where mungbean was grown as the sole crop prior to wheat followed by the plot where maize and mungbean were intercropped before wheat whereas a lower uptake of phosphorous in straw was recorded in the plot where maize was cultivated as the sole crop before wheat in both the seasons 2020-2021 and 2021-2022 and when both data were mean. The observed differences in phosphorus uptake can be attributed to the specific crop sequences and the residual effects of preceding crops. The cultivation of mungbean as a sole crop before wheat, and the intercropping of maize and mungbean, likely contributed to improved phosphorus availability in the soil, resulting in higher uptake in straw. Conversely, the sole cultivation of maize before wheat might have left the soil with lower phosphorus levels, leading to reduced phosphorus uptake in straw. These variations in phosphorus uptake align with findings by Jefferson *et al.* (2013) suggested that wheat grown on legume plots might develop better root systems, enabling them to explore a larger soil volume and take up greater amounts of soil phosphorus compared to wheat grown on non-legume plots. Insights from Mat Hassan *et al.* (2012) further support these observations, indicating that the maximum phosphorus uptake was substituted by legumes as a pre-crop. The incorporation of green manure enhanced the availability of phosphorus in the soil, leading to increased phosphorus uptake by the maize plant, as corroborated by Mohana Rao *et al.* (2016). Sandhya Rani *et al.* (2022) also reported that the incorporation of legume green manure crops increased phosphorus uptake in maize. Similarly, Doolette *et al.* (2019) found that phosphorus uptake was greater for wheat after legume break crops compared to continuous wheat.

In the case of different levels of fertilizer treatment, in the year 2020-2021, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest uptake of phosphorous in straw followed by the plot treated with 100% RDF, and 100% Nano NPK fertilizers respectively. According to statistics, the control plot experienced the least phosphorus uptake in straw in the years 2020–2021. A similar trend was observed in the year 2021-2022 as well when both data were mean (Table 4.3.14). The observed pattern can be contextualized and further supported

by relevant studies. The findings of Theerthana *et al.* (2023) align with the observed trend, as they documented that the application of both chemical and nanofertilizers led to a significantly higher uptake of phosphorus. This suggests that the combination of conventional and nano-fertilizers in the 50 % RDF + 50 % Nano NPK treatment likely facilitated an increase in phosphorus uptake in straw, emphasizing the importance of such integrated fertilization practices. Additionally, the study conducted by Hayyaw *et al.* in 2019 emphasized that the application of NPK nano-fertilizer resulted in elevated phosphorus levels compared to scenarios without nano-fertilizer. The presence of active microorganisms in the soil, as highlighted by Hayyaw *et al.*, and their biological activities might have played a role in enhancing the availability and uptake of phosphorus in the treated plots, especially in the case of Nano NPK fertilizers. Abdel-Aziz *et al.* (2016) proposed that nano-fertilizers contribute to nutrient supply and facilitate the transport and absorption of available nutrients, leading to improved crop growth. This aligns with the observed higher phosphorus uptake in the 50 % RDF + 50 % Nano NPK treatment, where the unique characteristics of nanofertilizers likely facilitated efficient nutrient absorption. The collective evidence from these studies supports the past-tense explanation for the observed phosphorus uptake pattern in straw during the year 2020-2021, attributing it to the balanced nutrient supply and enhanced nutrient availability facilitated by the combination of conventional and Nano NPK fertilizers.

The interaction between the crop residues and varied fertilizer levels was noted to be significant in both the years (2020-2021 and 2021-2022) as well as mean statistics. The highest phosphorous uptake in straw was recorded in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF + 50% Nano NPK fertilizers while the lowest mean value of the phosphorous uptake on straw was recorded in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (control) in both seasons (2020-2021 and 2021-2022) and in the mean statistics.

4.1.3.3.4 Phosphorous uptake in grain (kg/ha)

The impacts of various fertilizer rates and the residual effect of crops had a significant impact on the phosphorus uptake of grain in all the growing seasons (2020-2021 and 2021-2022) and mean statistics (Table 4.3.14). Maximum uptake of phosphorous in grain was recorded in the plot where mungbean was grown as

the sole crop prior to wheat followed by the plot where maize and mungbean were intercropped before wheat whereas a lower uptake of phosphorous in grain was recorded in the plot where maize was cultivated as the sole crop before wheat in both the seasons 2020-2021 and 2021-2022 and when both data were mean. These variations in phosphorus uptake align with findings by Miheguli *et al.* (2018), who reported significantly higher phosphorus uptake by wheat grain following forage legume rotations. The improved conditions for wheat growth in plots following legumes rotations, such as greater nitrogen availability, may have contributed to increased demand for, and uptake of phosphorus. Additionally, research by Jefferson *et al.* (2013) suggested that wheat grown on legume plots might develop better root systems, enabling them to explore a larger soil volume and take up greater amounts of soil phosphorus compared to wheat grown on non-legume plots. Furthermore, insights from Sinha *et al.* (2018) emphasized that the total uptake of nutrients, specifically phosphorus, by maize crops was higher in plots with crop residue incorporation than in those without, supporting the notion that residue incorporation positively influences nutrient availability, including phosphorus.

In the case of different levels of fertilizer treatment, in the year 2020-2021, the plot treated with 50% RDF + 50% Nano NPK fertilizers had the highest uptake of phosphorous in grain followed by the plot treated with 100% RDF, and 100% Nano NPK fertilizers respectively. According to statistics, the control plot experienced the least phosphorus uptake in grain in the years 2020–2021 and 2021-2022. When data were mean a similar pattern was observed (Table 4.3.14 and Fig. 4.3.14). The distinctive trend in phosphorus uptake in grains, wherein the plot treated with 50% RDF + 50% Nano NPK fertilizers displayed the highest uptake, followed by the plots treated with 100% RDF and 100% Nano NPK fertilizers, finds support in previous research. Al Juthery *et al.* (2020) documented that the synergistic effect of combining nano NPK significantly improves wheat yield and nutrient uptake. This synergistic enhancement aligns with the higher phosphorus uptake observed in the 50% RDF+50% Nano NPK treatment, indicating the efficacy of this combined fertilizer approach. The findings of Mahanta *et al.* (2019) and Elemike *et al.* (2019) further support the observed trend, as they highlighted that nanofertilizers, with their elevated surface area to volume ratio, exhibit greater effectiveness in facilitating efficient nutrient uptake by crops. The

increased surface area, attributed to the unique characteristics of nanofertilizers, likely played a role in the improved phosphorus uptake observed in the treated plots. This characteristic enhances nutrient availability, surpassing the capabilities of many traditional fertilizers. Additionally, Iyarin and Aravinda (2019) documented that the absorption of phosphorus nanoparticles from fertilizers enhances the efficacy of the solution, contributing to augmented nutrient availability. This phenomenon aligns with the observed higher phosphorus uptake in the 50% RDF + 50% Nano NPK treatment, suggesting that the unique properties of nanofertilizers contribute to a more efficient absorption and utilization of phosphorus in the grains.

The relationship between the various levels of fertilizers and the residual effect of crops was significant in both the years (2020-2021 and 2021-2022) as well as when the data from both years were mean. In all seasons (2020-2021 and 2021-2022), as well as when data were mean, the superior mean value of phosphorous uptake in grain was recorded in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF + 50% Nano NPK fertilizers while the lowest mean value of the phosphorous uptake on grain was recorded in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (control) in both seasons (2020-2021 and 2021-2022) and in the mean statistics.

Table 4.3.14.: Effect of the residual effect of crops and different levels of fertilizer on the phosphorous uptake in straw and grain of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021		2021-2022		Mean data	
	Phosphorus uptake (kg/ha)		Phosphorus uptake (kg/ha)		Phosphorus uptake (kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
A. Residual effect of crops						
M ₁	4.39 ^c	2.68 ^c	4.49 ^b	2.74 ^b	4.44 ^b	2.71 ^b
M ₂	5.29 ^a	3.32 ^a	5.41 ^a	3.40 ^a	5.35 ^a	3.36 ^a
M ₃	4.81 ^b	2.98 ^b	4.92 ^{ab}	3.04 ^{ab}	4.87 ^b	3.01 ^b
SEm (±)	0.09	0.08	0.13	0.11	0.12	0.10
(P=0.05)	0.36	0.26	0.52	0.41	0.44	0.34
B. Different levels of fertilizer						
S ₁	2.58 ^d	1.98 ^d	2.64 ^d	2.02 ^d	2.61 ^d	2.00 ^d
S ₂	5.72 ^b	3.18 ^b	5.85 ^b	3.24 ^b	5.78 ^b	3.21 ^b
S ₃	4.60 ^c	2.51 ^c	4.70 ^c	2.56 ^c	4.65 ^c	2.54 ^c
S ₄	6.42 ^a	4.32 ^a	6.56 ^a	4.41 ^a	6.49 ^a	4.37 ^a
SEm (±)	0.05	0.04	0.09	0.07	0.07	0.06
(P=0.05)	0.15	0.13	0.27	0.22	0.21	0.18
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.14a: Interaction between the residual effect of crops and different levels of fertilizer on the phosphorus uptake (kg/ha) in grain of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	2.35 ^h	5.08 ^e	3.86 ^f	6.25 ^b	2.41 ^h	5.20 ^e	3.95 ^f	6.39 ^b	2.38 ^h	5.14 ^e	3.91 ^f	6.32 ^b
M₂	2.82 ^g	6.26 ^b	5.42 ^d	6.65 ^a	2.88 ^g	6.40 ^b	5.54 ^d	6.80 ^a	2.85 ^g	6.33 ^b	5.48 ^d	6.72 ^a
M₃	2.56 ^h	5.82 ^c	4.52 ^f	6.36 ^b	2.62 ^h	5.95 ^c	4.62 ^f	6.50 ^b	2.59 ^h	5.88 ^c	4.57 ^c	6.43 ^a
SEm (±)	0.08				0.16				0.12			
CD (P=0.05)	0.25				0.47				0.36			

Table 4.3.14b: Interaction between the residual effect of crops and different levels of fertilizer on the phosphorus uptake (kg/ha) in straw of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	1.93 ⁱ	3.14 ^e	2.40 ^g	3.33 ^d	1.95 ^h	3.21	2.42 ^g	3.37 ^b	1.95 ^h	3.18 ^d	2.40 ^g	3.33 ^b
M₂	2.09 ^h	3.61 ^c	2.64 ^f	5.11 ^a	2.11 ^h	3.65 ^c	2.66 ^f	4.66 ^a	2.09 ^h	3.61 ^c	2.64 ^f	5.11 ^a
M₃	1.97 ^{hi}	2.84 ^e	2.57 ^f	4.66 ^b	1.99 ^h	2.87 ^e	2.60 ^f	4.49 ^{ab}	1.97 ^h	2.84 ^e	2.57 ^g	4.66 ^b
SEm (±)	0.04				0.06				0.05			
CD (P=0.05)	0.12				0.17				0.15			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.3.5 Potassium uptake in straw (kg/ha)

In both seasons (2020-2021 and 2021-2022), as well as in the mean data, the influence of various levels and the residual effect of crops was significant (Table 4.3.15). Higher uptake of potassium in straw was recorded in the plot where mungbean was grown as the sole crop prior to wheat followed by the plot where maize and mungbean were intercropped before wheat whereas a lower uptake of potassium in straw was recorded in the plot where maize was cultivated as the only crop before wheat in both the seasons 2020-2021 and 2021-2022 and when both data were mean. These observed variations in potassium uptake can be attributed to specific crop sequences and the residual effects of preceding crops. The cultivation of mungbean as a sole crop before wheat, as well as the intercropping of maize and mungbean, likely contributed to improved potassium availability in the soil, resulting in higher uptake in straw. On the other hand, the sole cultivation of maize before wheat may have left the soil with lower potassium levels, leading to reduced potassium uptake in straw. These stated variations in potassium uptake align with findings by Sharma *et al.* (2023), who reported that green manuring with legumes, such as mungbean, significantly increased potassium uptake in rice grain. Similarly, Hazra *et al.* (2014) found that the potassium uptake by rice and wheat crops was significantly highest when mungbean was included in the cropping system. These findings support the idea that legume inclusion, such as with mungbean, contributes to enhanced potassium availability in the soil, leading to increased uptake by subsequent crops. Insights from Sinha *et al.* (2018) further substantiate these observations, indicating that the total uptake of nutrients, including potassium, by maize crops was higher in plots with crop residue incorporation than in those without. The residue incorporation practices likely contributed to improved nutrient availability, favoring increased potassium uptake by the maize crop.

In the case of levels of fertilizer treatment, in the year 2020-2021, the plot supplied with 50% RDF +50% Nano NPK fertilizers had the highest uptake of potassium, then the plot treated with 100% RDF, and 100% Nano NPK fertilizers respectively. Statically, the lowest uptake of potassium in straw was recorded in the control plot in 2020-2021. When all sets of data were mean, a similar pattern was also seen in the years 2021 and 2022 (Table 4.3.15). The discernible pattern of potassium uptake in straw, with the plot supplied with 50% RDF + 50% Nano

NPK fertilizers exhibiting the highest uptake, followed by the plots treated with 100% RDF and 100% Nano NPK fertilizers respectively, can be comprehended in light of various corroborating studies. Bora *et al.* (2018) documented that the combination of 50 % Recommended Dose of Nutrients (RDN), applied as a basal dose, along with foliar spray of nanofertilizers led to increased nutrient content and uptake by straw. This integrated fertilization approach aligns with the observed trend, emphasizing the efficacy of combining conventional and nano fertilizers in promoting optimal potassium assimilation in straw. Furthermore, Rojas-Velazquez *et al.* (2023) asserted that nanofertilizers, due to their potential for slow release, have the capacity to enhance nutrient efficiency when compared to conventional fertilizers. This characteristic aligns with the sustained release of nutrients likely facilitated by the 50 % RDF + 50 % Nano NPK treatment, contributing to increased potassium uptake in straw. The findings of Solanki *et al.* (2015), uncovering that nutrient uptake of nanofertilizers is more compared to conventional fertilizers, provide additional support to the observed trend. The increased potassium uptake in the plot treated with Nano NPK fertilizers suggests that nanofertilizers contribute to more efficient nutrient absorption. Moreover, Abdel-Aziz *et al.* (2016) proposed that nano-fertilizers can supply nutrients to plants or facilitate the transport and absorption of available nutrients, leading to improved crop growth. The foliar application of nano-fertilizers, in conjunction with traditional fertilizers, resulted in the release and enhanced uptake of nutrients in crops. This aligns with the enhanced potassium uptake observed in the 50% RDF + 50% Nano NPK treatment, highlighting the effectiveness of nanofertilizers in optimizing nutrient assimilation in straw.

In both the years (2020-2021 and 2021-2022) as well as in the mean data, it was found that there was a significant interaction between the residual effect of crops and different fertilizers levels. The peak potassium uptake in straw was recorded in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF + 50% Nano NPK fertilizers while the lowest mean value of the potassium uptake on straw was recorded in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (control) in both seasons (2020-2021 and 2021-2022) and in the mean data.

4.1.3.3.6 Potassium uptake in grain (kg/ha)

The residual impacts of crops and varying fertilizer levels had a significant impact on the potassium uptake of grain in both seasons (2020–2021 and 2021–2022) and mean data (Table 4.3.15). Higher uptake of potassium in grain was recorded in the plot where mungbean was grown as the sole crop prior to wheat followed by the plot where maize and mungbean were intercropped before wheat whereas a lower uptake of potassium in grain was recorded in the plot where maize was cultivated as the sole crop before wheat in both the seasons 2020-2021 and 2021-2022 and when both data were mean. These observed variations in potassium uptake can be attributed to specific crop sequences and the residual effects of preceding crops. The cultivation of mungbean as a sole crop before wheat, as well as the intercropping of maize and mungbean, likely contributed to improved potassium availability in the soil, resulting in higher uptake in the grain. On the other hand, the sole cultivation of maize before wheat may have left the soil with lower potassium levels, leading to reduced potassium uptake in the grain. This process is supported by findings from Thilakarathna *et al.* (2016) and Islam and Adjesiwor (2017), who have provided similar justifications for enhanced nutrient availability following legume cultivation. Additionally, the research aligns with the findings of Makoi *et al.* (2013), who reported elevated nutrient uptake after legume inoculation. The presence of legumes in the crop rotation sequence appears to enhance the overall nutrient dynamics in the soil, positively influencing the subsequent crops. Furthermore, the work of Desta *et al.* (2015) supports the notion that inoculating legume crops can increase nodulation potential and nitrogen fixation, thereby improving the overall nutrient uptake of succeeding crops.

In the case of different levels of fertilizer treatment, in the year 2020-2021, the plot applied with 50% RDF + 50% Nano NPK fertilizers had the maximum uptake of potassium in grain followed by the plot treated with 100% RDF, and 100% Nano NPK fertilizers respectively. Statically, the lowest uptake of K in grain was recorded in the control plot in 2020-2021. A similar tendency was noticed in the year 2021-2022 as well when data were average (Table 4.3.15). The discernible pattern of potassium uptake in grains, where the plot treated with 50 % RDF + 50 % Nano NPK fertilizers exhibited the highest uptake, followed by the plots treated with 100% RDF and 100% Nano NPK fertilizers, can be

comprehended through a synthesis of relevant studies. Iyarin and Aravinda (2019) emphasized that nano-fertilizers containing NPK enhance the absorption and utilization of nutrients by grain crops. This assertion aligns with the observed trend, highlighting the increased potassium uptake in the plot treated with Nano NPK fertilizers, suggesting enhanced nutrient absorption. Bora *et al.* (2018) further support the observed enhancement in nutrient uptake. Their documentation of increased nutrient content and uptake by grain crops through the combination of traditional fertilizers applied as a basal dose, along with foliar spray of nanofertilizers, aligns with the strategy applied in the 50% RDF + 50% Nano NPK treatment. The larger surface area and smaller particle size of nanofertilizers likely facilitated greater penetration of nutrients into the plant, contributing to the observed higher potassium uptake in the treated plots. The findings of Al-Juthery *et al.* (2020) contribute to the understanding of the observed trend. They documented that the synergistic effect of combining nano NPK significantly improves wheat yield and nutrient uptake, reinforcing the idea that the combination of conventional and nano fertilizers can lead to optimal nutrient assimilation in grains. Elemike *et al.* (2019) added to the explanation by documenting that nanofertilizers, owing to their elevated surface area to volume ratio, exhibit greater effectiveness in facilitating efficient nutrient uptake by crops. This characteristic aligns with the enhanced potassium uptake observed in the 50% RDF + 50% Nano NPK treatment, emphasizing the efficiency of nanofertilizers in nutrient absorption.

The relations between the different fertilizer's doses and the residual effect of crops were significant in both the years (2020-2021 and 2021-2022) as well as when the data from both years were mean. In all seasons (2020-2021 and 2021-2022), as well as when data were mean, the highest uptake of potassium in grain was noted in the plot where mungbean was grown as the sole crop prior to wheat combined with 50% RDF +50 % Nano NPK fertilizers while the lowest mean value of the phosphorous uptake on grain was recorded in the plot where maize was grown as the sole crop prior to wheat combined with no fertilizers (control) in both seasons (2020-2021 and 2021-2022) and in the mean statistics (Table 4.3.15a).

Table 4.3.15.: Effect of the residual effect of crops and different levels of fertilizer on the potassium uptake in straw and grain of wheat during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021		2021-2022		Mean data	
	Potassium uptake(kg/ha)		Potassium uptake(kg/ha)		Potassium uptake(kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
A. Residual effect of crops						
M₁	14.70 ^b	51.16 ^b	15.01 ^b	52.81 ^b	14.85 ^b	51.99 ^b
M₂	18.19 ^a	58.44 ^a	18.58 ^a	60.33 ^a	18.38 ^a	59.38 ^a
M₃	15.79 ^b	53.28 ^b	16.13 ^b	55.00 ^b	15.96 ^b	54.14 ^b
SEm (±)	0.32	1.00	0.52	1.03	0.42	1.02
(P=0.05)	1.27	3.93	1.53	4.05	1.40	3.99
B. Different levels of fertilizer						
S₁	9.83 ^d	27.12 ^d	10.04 ^d	27.99 ^d	9.94 ^d	27.55 ^d
S₂	18.86 ^b	64.83 ^b	19.27 ^b	66.92 ^b	19.06 ^b	65.88 ^b
S₃	15.39 ^c	54.38 ^c	15.72 ^c	56.13 ^c	15.56 ^c	55.25 ^c
S₄	20.82 ^a	70.85 ^a	21.27 ^a	73.14 ^a	21.04 ^a	72.00 ^a
SEm (±)	0.27	0.98	0.33	1.01	0.30	1.00
(P=0.05)	1.06	2.90	1.30	2.99	1.18	2.95
Interaction (A x B)	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.15a: Interaction between the residual effect of crops and different levels of fertilizer on the potassium uptake (kg/ha) in grain of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	8.39 ^h	16.43	15.10 ^{ef}	18.87 ^{de}	8.57 ^h	16.78 ^f	15.42 ^{ef}	19.27 ^{de}	8.48 ^h	16.60 ^f	15.26 ^{ef}	19.07 ^{de}
M₂	11.10 ^g	21.29 ^b	17.21 ^{cd}	23.17 ^a	11.34 ^g	21.75 ^{bc}	17.57 ^{cd}	23.66 ^a	11.22 ^g	21.52 ^{bc}	17.39 ^{cd}	23.41 ^a
M₃	10.00 ^g	18.87 ^d	13.88 ^f	20.42 ^b	10.22 ^g	19.27 ^d	14.17 ^f	20.86 ^b	10.11 ^g	19.07 ^d	14.02 ^f	20.64 ^b
SEm (±)	0.49				0.50				0.25			
CD (P=0.05)	1.47				1.50				0.73			

Table 4.3.15b: Interaction between the residual effect of crops and different levels of fertilizer on the potassium uptake (kg/ha) in straw of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	24.48 ^e	64.19 ^c	48.96 ^b	67.01 ^a	25.27 ^e	66.26 ^c	50.54 ^b	69.18 ^a	24.88 ^e	65.23 ^c	49.75 ^b	68.10 ^a
M₂	31.02 ^d	65.15 ^b	62.48 ^a	75.11 ^a	32.02 ^d	67.25 ^b	64.50 ^a	77.54 ^a	31.52 ^d	66.20 ^b	63.49 ^a	76.32 ^a
M₃	25.84 ^e	69.15 ^c	51.69 ^b	70.44 ^a	26.68 ^e	67.25 ^c	53.36 ^b	72.71 ^a	26.26 ^e	66.20 ^c	52.52 ^b	71.57 ^a
SEm (±)	1.69				1.74				1.72			
CD (P=0.05)	5.02				5.18				5.10			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.4 Correlation Analysis

Simple correlation analysis to study the degree of association between the growth and yield component with the grain yield was carried out for each season (2020-2021, 2021-2022 and mean data). In the 2020-2021 *rabi* season, the relationship between yield, growth, and yield characteristics of wheat is presented in Table 4.3.16. Grain yield and yield attributes including plant height, no. of leaves, leaf area, shoot dry weight, CGR, RGR, days to 50% flowering, days to 90% maturity, no. of effective tillers, no. of grains/spike, and test weight showed a positive and highly significant correlation. The relationship between the plant height and the other growth and yield parameters was favorable and significant. A positive and significant exist between the leaf area, growth, and yield parameters. All the growth and yield metrics showed a significant correlation with shoot dry weight, CGR, RGR, days to 50% flowering, days to 90% maturity, no. of effective tillers, no. of grains per spike, and test weight.

The relationship between wheat grain yield, growth, and yield characteristics for the *rabi* season of 2021–2022 is shown in Table 4.3.17. In the years 2021–2022, there was a significant and positive relationship between grain yield, growth, and yield parameters. The parameters relating to plant height, growth, and yield also showed a positive and significant correlation. All the growth and yield characteristics, including the no. of leaves, leaf area, shoot dry weight, CGR, RGR, days to 50% flowering, days to 90% maturity, no. of effective tillers, no. of grains/spike, and test weight, were all found to be significantly correlated with one another.

The correlation between wheat grain yield, growth, and yield attributes in mean data is shown in Table 4.3.18. Grain yield and growth as well as yield characteristics likewise showed a positive and highly significant correlation in the mean data. Additionally, a positive and significant correlation was seen between the plant height, growth, and yield components. Furthermore, all the growth and yield metrics were found to be significantly correlated with each other. The coherence among these variable can be attributed to the intricate interplay of physiological processes within the plant. Physiological synchronization was evident, wherein an increase in one variable corresponded to an increase in others, indicating a harmonious response to optimal growth conditions. The positive correlations underscored the effective allocation and utilization of resources by the

plants, with a healthier and well-nourished plant exhibiting higher tiller numbers, grains/spike, and better test weight. The stability of these correlations over the study period suggested adaptability to prevailing environmental conditions, further highlighting the intricate relationship between various yield attributes and overall crop productivity. The degree of these correlations were meticulously examined through correlation coefficient analysis, as highlighted by Schober *et al.* (2018). The significance of understanding the intricate relationship between grain yield and yield-attributing traits was underscored in the literature, with Baye *et al.* (2020) emphasizing the efficacy of selection based on yield components over yield alone. The observed positive and substantial correlations between growth and yield parameters and grain yield have implications for agronomists, emphasizing the importance of these characteristics in optimizing production. Notably, the positive links between shoot dry weight and grain yield, as well as the positive correlation between LAI, CGR and RGR, were highlighted. This may be attributed to the contribution of high specific leaf weight to leaf photosynthesis and overall yield. Additionally, the substantial positive correlation between test weight and grain yield indicated effective photosynthesis from source to sink. These findings resonated with the work of Sokoto *et al.* (2012), supporting the positive correlation between growth and yield components and grain yield. Furthermore, the study's results aligned with those of Kaur *et al.* (2016), Bhutto *et al.* (2016), and Kaur *et al.* (2017), showcasing positive correlations between wheat yield and LAI, seed index, and the no. of tillers/plant, respectively. The consistent recurrence of positive and highly significant correlations between grain yield and various yield factors, as noted by Ayer *et al.* (2017), Kandel *et al.* (2018), Ojha *et al.* (2019), Khanala *et al.* (2020), Maurya *et al.* (2020), Upadhyay (2020), and Dayem *et al.* (2021), underscored the robustness of these relationships across different studies. The cumulative findings stress the magnitude of each trait in influencing grain yield, providing valuable insights for the selection of wheat genotypes with high yield potential. It is inferred from the observations that each growth and yield parameter significantly contribute to augmenting grain yield per hectare, and prioritizing selection efforts toward enhancing these characteristics is likely to yield more productive outcomes.

Table 4.3.16: Matrix of the correlation coefficient between growth and yield attributes of wheat during the year 2020-2021 *rabi* season in Punjab.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.808*)	1.000										
3	(0.819*)	(0.769*)	1.000									
4	(0.824*)	(0.890*)	(0.929*)	1.000								
5	(0.859*)	(0.858*)	(0.834*)	(0.912*)	1.000							
6	(0.846*)	(0.884*)	(0.834*)	(0.935*)	(0.993*)	1.000						
7	(0.763*)	(0.885*)	(0.754*)	(0.892*)	(0.818*)	(0.858*)	1.000					
8	(0.800*)	(0.867*)	(0.751*)	(0.874*)	(0.950*)	(0.957*)	(0.829*)	1.000				
9	(0.812)	(0.737*)	(0.811*)	(0.828*)	(0.917*)	(0.889*)	(0.715*)	(0.833*)	1.000			
10	(0.591*)	(0.587*)	(0.655*)	(0.680*)	(0.756*)	(0.726*)	(0.552*)	(0.683*)	(0.676*)	1.000		
11	(0.713*)	(0.756*)	(0.682*)	(0.830*)	(0.759*)	(0.792*)	(0.804*)	(0.761*)	(0.683*)	(0.559*)	1.000	
12	(0.820*)	(0.871*)	(0.841*)	(0.914*)	(0.824*)	(0.851*)	(0.851*)	(0.801*)	(0.728*)	(0.661*)	(0.864*)	1.000

1. Grain yield

2. Plant height

3. Number of leaves

4. Leaf area

5. Shoot dry weight

6. Crop growth rate

*= Significant at 5% level of probability

7. Days to 50% flowering

8. Relative growth rate

9. Days to 90% maturity

10. No. of effective tillers

11. No. of grains/spike

12. Test weight

Table 4.3.17.Matrix of the correlation coefficient between growth and yield attributes of wheat during the year 2021-22 *rabi* season in Punjab.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.798*)	1.000										
3	(0.799*)	(0.815*)	1.000									
4	(0.815*)	(0.927*)	(0.917*)	1.000								
5	(0.858*)	(0.862*)	(0.832*)	(0.912*)	1.000							
6	(0.841*)	(0.890*)	(0.830*)	(0.936*)	(0.993*)	1.000						
7	(0.779*)	(0.868*)	(0.750*)	(0.897*)	(0.834*)	(0.870*)	1.000					
8	(0.798*)	(0.851*)	(0.746*)	(0.875*)	(0.950*)	(0.956*)	(0.834*)	1.000				
9	(0.765*)	(0.807*)	(0.817*)	(0.809*)	(0.895*)	(0.868*)	(0.704*)	(0.835*)	1.000			
10	(0.638*)	(0.607*)	(0.671*)	(0.692*)	(0.768*)	(0.737*)	(0.576*)	(0.683*)	(0.685*)	1.000		
11	(0.748*)	(0.882*)	(0.745*)	(0.875*)	(0.837*)	(0.864*)	(0.826*)	(0.862*)	(0.727*)	(0.608*)	1.000	
12	(0.825*)	(0.895*)	(0.827*)	(0.906*)	(0.823*)	(0.847*)	(0.836*)	(0.799*)	(0.742*)	(0.661*)	(0.905*)	1.000

1. Grain yield

2. Plant height

3. Number of leaves

4. Leaf area

5. Shoot dry weight

6. Crop growth rate

*= Significant at 5% level of probability

7. Days to 50% flowering

8. Relative growth rate

9. Days to 90% maturity

10. No. of effective tillers

11. No. of grains/spike

12. Test weight

Table 4.3.18. Matrix of the correlation coefficient between growth and yield attributes of wheat (Mean data).

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	(0.803*)	1.000										
3	(0.809*)	(0.792*)	1.000									
4	(0.820*)	(0.910*)	(0.923*)	1.000								
5	(0.859*)	(0.860*)	(0.833*)	(0.912*)	1.000							
6	(0.843*)	(0.887*)	(0.832*)	(0.935*)	(0.993*)	1.000						
7	(0.771*)	(0.877*)	(0.752*)	(0.895*)	(0.826*)	(0.864*)	1.000					
8	(0.800*)	(0.859*)	(0.749*)	(0.875*)	(0.950*)	(0.956*)	(0.831*)	1.000				
9	(0.789*)	(0.772*)	(0.814*)	(0.819*)	(0.906*)	(0.878*)	(0.710*)	(0.834*)	1.000			
10	(0.615*)	(0.597*)	(0.663*)	(0.686*)	(0.762*)	(0.731*)	(0.564*)	(0.683*)	(0.681*)	1.000		
11	(0.731*)	(0.819*)	(0.714*)	(0.852*)	(0.798*)	(0.828*)	(0.815*)	(0.812*)	(0.705*)	(0.584*)	1.000	
12	(0.823*)	(0.883*)	(0.834*)	(0.910*)	(0.823*)	(0.849*)	(0.844*)	(0.800*)	(0.735*)	(0.661*)	(0.885*)	1.000

1. Grain yield

2. Plant height

3. Number of leaves

4. Leaf area

5. Shoot dry weight

6. Crop growth rate

*= Significant at 5% level of probability

7. Days to 50% flowering

8. Relative growth rate

9. Days to 90% maturity

10. No. of effective tillers

11. No. of grains/spike

12. Test weight

4.1.3.5. Economics of wheat

Table 4.3.19 shows the influences of various fertilizer levels and crop residues on the economics of wheat (2020-2021, 2021-2022 and mean data). Considering 2020-2021, 2021-2022, and mean data, the plot with maize cultivated as the sole crop prior to wheat provided better economics than a plot followed by the plot where maize and mungbean intercrop were grown before wheat. Whereas the plot where maize was grown as the sole crop before wheat produced lower values of economics. Considering the B:C ratio in all the situations exceeded 1, this research is anticipated to add value (Table 4.3.19). The superior economics observed in the sole maize crop plot can be attributed to factors such as crop productivity, resource utilization efficiency, or market demand dynamics associated with the specific cropping arrangement. Conversely, the intercropped maize and mungbean plot, despite providing some economic returns, did not match the economic performance of the sole maize crop plot. The consistently lower economic values in the sole maize crop plot suggest that intercropping with mungbean may have influenced resource allocation or crop interactions in a way that impacted overall economic returns. These observations were consistent across both the 2020-2021 and 2021-2022 growing seasons, and the mean data further support the robustness of these findings. The fact that the B:C ratio consistently exceeded 1 across all situations underscores the positive economic viability of the research. This suggests that, regardless of the specific cropping sequence, the research is anticipated to add value and provide a positive return on investment. This result can be attributable to the advantage of using legume residues, which increased overall grain production in comparison to other crops cultivated before wheat. Related outcomes were reported by Meena *et al.* (2015), who stated that residue retention of green gram considerably boosted the benefit-cost ratio of maize. Both Parihar *et al.* (2016) and Prasai *et al.* (2018) observed the same results, such that mungbean residue retention led to the highest net returns in the case of the maize-wheat-mungbean cropping approach. Padma *et al.* (2018) also reported an analogous pattern and stated that legume crop residues raise the succeeding maize crop's economics. Jat *et al.* (2013) recounted parallel outcomes in both years of their study, showing that the incorporation of mungbean residues before planting wheat resulted in the highest economics. Meena *et al.* 2015 reported that residue retention of green gram significantly increased the benefit-cost

ratio in maize-based cropping systems. Prabhamani and Babalad, 2017 concluded that surface retention of crop residues with no tillage and flatbed method resulted in the higher net profit. Prasai *et al.* 2018 concluded that retention of crop residues under no tillage gave 114 % higher net returns under maize-based cropping systems. Padma *et al.* 2019 incorporation or mulching of legume crop residues also resulted in higher net returns and a benefit-cost ratio. Mesfin *et al.* 2023, the results revealed that the highest net benefit was obtained in the full faba bean-wheat rotation plot. However, the lowest net benefit was obtained in the wheat-wheat rotation plot. Kiran Kumar *et al.* 2019, the maximum gross and net returns and benefit-cost ratio were recorded under groundnut-wheat cropping. Sandhya Rani *et al.* 2022, economic analysis of maize indicated significantly higher net returns and higher B:C ratio in the treatments receiving 75 % RDF and incorporation.

The plot treated with 50% RDF + 50% Nano NPK fertilizers, however, produced the economics among the various fertilizer treatments followed by the plot applied with 100% Nano NPK fertilizers and 100% RDF respectively. As opposed to the control plot, which had the lowest gross returns per hectare, cultivation costs per hectare, net benefits per hectare, and benefit-cost ratio. This research is expected to be valuable because all different fertilizer application levels yielded BCR values higher than 1(2020-2021, 2021-2022, and mean data). The higher net return observed in the study can be attributed to the prudent management of cultivation costs, facilitated by the effective utilization of foliar nanofertilizers and the application of 50 % RDF in the soil. The judicious combination of these practices resulted in lower costs associated with both the 50% NPK and nano fertilizer applications, leading to increased production and subsequently higher net returns. This outcome aligns with the findings of Manikandan *et al.* (2016), and Kumar *et al.* (2020). Similar results were also reported by Kanno *et al.* (2022), who emphasized the economic benefits of incorporating nano spray alongside conventional urea fertilizer treatments. Sankar *et al.* (2020) observed an enhancement in baby corn economics attributed to the use of Nano NPK and conventional fertilizers. Additionally, Panda *et al.* (2020) suggested that an increase in yield, coupled with higher market prices, contributed to the improved Benefit-Cost (B: C) ratio and overall economic performance. In contrast, the absolute control plot exhibited the lowest B: C ratio, likely influenced by changes in cultivation costs and net returns. This echoes findings by Ajaz *et al.* (2019) and

Rakesh Kumar *et al.* (2015), who reported similar outcomes in their research. Mehta and Bharat (2019) emphasized the economic efficacy of combining conventional fertilizer with nanofertilizers, resulting in the highest benefit-cost ratio for wheat. The enhanced solubility and dispersion of insoluble nutrients in the soil, along with mitigated soil fixation and increased bioavailability, were attributed to nanofertilizers nutrition. These improvements played a crucial role in enhancing nutrient availability, seed setting percentage, test weight, and reducing percent chaffiness, collectively contributing to a higher economic yield. These findings are consistent with the results reported by Goudar *et al.* (2018), Hanumanthappa *et al.* (2019), and Merghany *et al.* (2019). Khan *et al.* (2019) definitively concluded that the economic evaluation of nanofertilizers indicates the potential for achieving additional benefits from the same land and resources. The cumulative evidence from various studies supports the notion that the incorporation of nanofertilizers, especially in combination with conventional fertilizers, holds promise for optimizing agricultural productivity and economic returns.

The interaction between residual crop effects and different fertilizer levels was found to be significant in both the years (2020-2021 and 2021-2022), and this observation held true when consolidating data from both years. Across all seasons (2020-2021 and 2021-2022), and when the data were mean, the plot where mungbean was cultivated as the sole crop before wheat, along with a combination of 50% RDF + 50% Nano NPK fertilizers, exhibited the highest gross return, net return, and B:C ratio. Conversely, the lowest gross return, net return, and B:C ratio were documented in the plot where maize was grown as the sole crop prior to wheat, without any fertilizers (control), in both seasons (2020-2021 and 2021-2022) and in the mean statistics (Table 4.3.19a, 4.3.19b, and 4.3.19c).

Table 4.3.19.: Economics of wheat as influenced by the residual effect of crops and different fertilizer levels during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-21			2021-22			Mean data		
	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
A –Cropping system									
M₁	97284.48 ^b	54090.69 ^b	1.189 ^b	101361.20 ^b	56959.60 ^b	1.215 ^b	99322.84 ^b	55525.15 ^b	1.202 ^b
M₂	112186.80 ^a	68993.00 ^a	1.560 ^a	118942.51 ^a	74540.92 ^a	1.649 ^a	115564.65 ^a	71766.96 ^a	1.605 ^a
M₃	106964.19 ^a	63770.40 ^a	1.410 ^a	111308.91 ^a	66907.31 ^a	1.442 ^a	109136.55 ^a	65338.85 ^a	1.428 ^a
SEm (±)	2072.31	1916.55	0.046	1947.80	2115.12	0.044	2010.06	2015.83	0.045
(P=0.05)	8135.67	7524.15	0.181	7646.85	8303.74	0.174	7690.85	7913.94	0.177
B-Different levels of fertilizer									
S₁	53279.01 ^d	18838.41 ^d	0.547 ^c	56076.32 ^c	20427.92 ^d	0.573 ^d	54677.67 ^c	19633.17 ^d	0.560 ^c
S₂	126407.20 ^b	76331.08 ^b	1.524 ^b	132136.39 ^a	80852.50 ^b	1.577 ^c	129271.80 ^b	78591.78 ^b	1.551 ^b
S₃	110624.48 ^c	68284.38 ^c	1.613 ^b	116259.80 ^b	72711.90 ^c	1.670 ^b	113442.14 ^b	70498.14 ^c	1.642 ^b
S₄	131603.26 ^a	85684.90 ^a	1.866 ^a	137677.66 ^a	90551.50 ^a	1.921 ^a	134640.46 ^a	88118.20 ^a	1.894 ^a
SEm (±)	1704.28	1979.66	0.039	1964.47	1972.09	0.043	1834.37	1975.87	0.041
(P=0.05)	5062.91	5880.98	0.117	5835.86	5858.49	0.127	5449.39	5869.74	0.122
Interaction (AxB)	S	S	S	S	S	S	S	S	S

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table.4.3.19a: Interaction between residual effect of crop and different level of fertilizers on the Gross return (Rs/ha) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	41100 ^b	118872 ^a	108583 ^{ab}	120583 ^a	39683 ^b	124556 ^a	114114 ^{ab}	127091 ^a	40392 ^b	121714 ^a	111349 ^{ab}	123837 ^a
M₂	68690 ^b	133213 ^a	113339 ^a	133506 ^a	77358 ^b	138689 ^a	119567 ^a	140156 ^a	73024 ^b	135951 ^a	116453 ^a	136831 ^a
M₃	50047 ^b	127137 ^a	109951 ^a	140721 ^a	51188 ^b	133165 ^a	115098 ^a	145786 ^a	50617 ^b	130151 ^a	112524 ^a	143254 ^a
SEm (±)	2952				3403				3077			
CD (P=0.05)	8769				10108				9141			

Table.4.3.19b: Interaction between residual effect of crop and different level of fertilizers on the Net return (Rs/ha) of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	6660 ^g	68795 ^c	66243 ^d	74664 ^b	4035 ^g	73272 ^d	70567 ^d	79965 ^b	5347 ^f	71034 ^{de}	68405 ^e	77315 ^c
M₂	34249 ^e	83137 ^b	70999 ^c	87587 ^a	41710 ^e	87405 ^{bc}	76019 ^d	93030 ^{ab}	37979 ^f	85271 ^{bc}	73509 ^d	90308 ^{ab}
M₃	15606 ^f	77061 ^{bc}	67611 ^{cd}	94803 ^a	15539 ^f	81881 ^c	71550 ^d	98660 ^a	15573 ^f	79471 ^{cd}	69580 ^e	96731 ^a
SEm (±)	3416				3429				3422			
CD (P=0.05)	10147				10186				10167			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table.4.3.19c: Interaction between residual effect of crop and different level of fertilizers on the B:C ratio of wheat.

	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M₁	0.19 ^f	1.37 ^c	1.56 ^b	1.63 ^b	0.11 ^g	1.43 ^d	1.62 ^c	1.70 ^c	0.15 ^g	1.40 ^d	1.59 ^c	1.66 ^c
M₂	0.99 ^d	1.66 ^b	1.68 ^b	1.91 ^a	1.17 ^e	1.70 ^c	1.75 ^{bc}	1.97 ^{ab}	1.08 ^e	1.68 ^c	1.71 ^{bc}	1.94 ^a
M₃	0.45 ^e	1.54 ^{bc}	1.60 ^b	2.06 ^a	0.44 ^f	1.60 ^{cd}	1.64 ^c	2.09 ^a	0.44 ^f	1.57 ^c	1.62 ^c	2.08 ^a
SEm (±)	0.07				0.07				0.07			
CD (P=0.05)	0.20				0.22				0.21			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.6. Post-harvest soil analysis

In 4.3.20 and 4.3.21, specifics of the chemical study of soil following the harvest of the wheat crop in the years 2021 and 2022 are presented along with the average results.

4.1.3.6.1. pH

The pH of the soil where wheat was grown earlier in both seasons, i.e., 2020-2021 and 2021-2021, and when both the data were mean was significantly impacted by the various fertilizer levels and crop residues. The maximum pH was reported in the plot where maize and mungbean were grown as intercrop before wheat which was comparable with the plot where maize was cultivated as sole crop before wheat whereas the lowest pH was recorded in the plot where mungbean was grown as a sole crop prior to wheat in both the seasons. A comparable tendency was recorded in mean statistics (Table 4.3.20). This could be attributed to factors such as root interactions, nutrient uptake dynamics, or specific biochemical processes associated with the selected crops. Conversely, the consistently lowest pH levels in the sole mungbean crop plot imply that mungbean cultivation alone, without the mitigating influence of intercropping or the presence of a preceding crop like maize, resulted in more acidic soil conditions. The analysis underscores that these observations were consistent across both the growing seasons, reflecting the impact of specific agronomic practices during this period. Additionally, Yuvaraj *et al.* (2020) contended that soil pH is affected by leguminous crops, attributing it to the fact that legumes obtain nitrogen from the air in the form of diatomic nitrogen, leading to a decrease in soil pH. Shi and colleagues (2023) noticed that the inclusion of legume rotation in the cropping system led to a reduction in soil pH levels. They similarly reported that legumes contribute to a decrease in pH, suggesting that this effect could be attributed to the accumulation of organic acids derived from the decomposition of biomass. Furthermore, according to Wang *et al.* (2023), the rotation of legumes and potatoes significantly decreased soil pH, providing additional scientific support to the observed trends in soil pH and highlighting the impact of specific crop rotations on soil acidity levels.

In the case of different levels of fertilizer treatment, in the years 2021 and 2022, the control plot had the highest pH which was comparable with the plot supplied with 100% Nano NPK fertilizers and 100% RDF respectively. Statically

lowest pH was recorded in the plot where 50% RDF + 50% Nano NPK fertilizers were applied. The mean data showed a similar pattern (Table 4.3.20). The observed variations in soil pH across different fertilizer treatments in 2021, 2022, and mean data align with findings from comparable studies. Pide *et al.* (2023) reported similar conclusions, indicating that the application of nanofertilizers and nano plant hormones resulted in a significant decrease in soil pH. This aligns with the trends observed in the control plot and plots treated with 100 % Nano NPK fertilizers and 100 % RDF, where pH levels were relatively high. Rajonee *et al.* (2017) documented positive after-effects of applying nano fertilizer to the soil, noting improvements in pH compared to conventional fertilizer treatment. These findings resonate with the elevated pH observed in the control plot and plots treated with 100 % Nano NPK fertilizers and 100 % RDF. Sahar *et al.* (2020) highlighted that the minimum soil pH was achieved by the application of NPK nano-fertilizers combined with NPK. This observation corresponds with the lowest pH recorded in the plot where 50 % RDF + 50 % Nano NPK fertilizers were applied. The reduction in soil pH values was attributed to residual organic compounds, microbial activity, and the release of organic acids, consistent with the acidifying effect observed in the specific fertilizer combination. Furthermore, El-Ghamry *et al.* (2018) suggested that the use of nano-fertilizers on soil led to an improvement in soil pH, reflecting the production of organic matter and enhanced biological activity. This supports the notion that the unique combination of 50% RDF + 50% Nano NPK fertilizers could have influenced soil pH levels through the release of organic compounds and microbial activity. The observed pH variations in the specified years and mean data, as influenced by different fertilizer treatments, resonate with the documented effects of nanofertilizers and conventional fertilizers on soil pH in related studies. The findings underscore the multifaceted impact of fertilizer choices on soil chemistry and highlight the importance of considering these factors in sustainable agricultural practices.

The residual impact of crops and various fertilizer levels were shown to interact significantly in 2020-21 and 2021-22 and in the mean statistics.

4.1.3.6.2. Electric conductivity (EC)

When wheat was planted earlier in both seasons (2021 and 2022) and when statistics were average, the impact of varied fertilizer levels and crop residues had a significant impact on soil EC (Table 4.3.20). The plot where mungbean

was planted as the sole crop before wheat had the highest EC value, which was comparable to the plot where maize and mungbean were intercropped together prior to wheat and the plot where maize was cultivated as a sole crop prior to wheat. The plot where maize was cultivated as the sole crop before wheat in both the seasons 2021 and 2022 had the lowest EC. A similar pattern was seen in the mean data. This could be attributed to factors such as root interactions, nutrient dynamics, or specific biochemical processes associated with the selected crops. Conversely, the consistently lowest EC values in the sole maize crop plot imply that maize cultivation alone, without the presence of a preceding leguminous crop like mungbean, resulted in lower electrical conductivity of the soil. The analysis underscores that these observations were consistent across both the growing seasons, reflecting the impact of specific agronomic practices during this period. The mean data further solidifies the reliability of the identified trends, highlighting the enduring influence of the cropping sequence on soil electrical conductivity. Moreover, Kabirinejad *et al.* (2014) proposed that the rise in EC resulting from the inclusion of legumes could potentially be attributed to higher concentrations of nutrients released during the decomposition of biomass. Kandel and colleagues (2019) observed an elevation in EC through the incorporation of legumes, providing additional insights into the potential mechanisms influencing soil EC in response to specific crop sequences.

In the years 2021 and 2022, the plot treated with 50 % RDF and 50 % Nano NPK fertilizers had the highest EC and was statistically comparable to the plot treated with 100 % RDF and 100 % Nano NPK fertilizers respectively. Nonetheless, the control plot had the lowest EC. Likewise a similar trend was reported when the data were mean (Table 4.3.20). The elevated EC observed in the plot treated with 50 % RDF and 50 % Nano NPK fertilizers suggests that this specific combination had a notable impact on the electrical conductivity of the soil. The integration of these fertilizers likely influenced the ion concentration in the soil solution, leading to an increase in EC. The statistical comparability of EC levels between the 50 % RDF + 50 % Nano NPK treatment and the 100 % RDF and 100 % Nano NPK treatments indicates that, in terms of electrical conductivity, the combined application of 50 % RDF and 50 % Nano NPK had a similar effect to the singular application of recommended doses of these fertilizers. This may be attributed to the synergistic effects of combining organic and nano fertilizers.

Conversely, the control plot, with the absence of additional fertilizers, consistently exhibited the lowest EC levels. This could be attributed to the lack of supplementary nutrient inputs in the control condition, resulting in lower ion concentration and electrical conductivity. When examining the mean data, the consistent trend further supports the notion that the choice of fertilizer treatments has a lasting impact on soil electrical conductivity. The cumulative effect of these treatments on EC emphasizes the need to consider the specific characteristics of different fertilizer combinations for sustainable soil management practices. In retrospect, the variations in soil electrical conductivity across different fertilizer treatments in 2021, 2022, and the mean data provide valuable insights into the dynamic nature of soil response to diverse nutrient applications. These findings underscore the importance of understanding and optimizing soil conductivity for sustainable agricultural practices. Furthermore, nanomaterials hold significant potential to enhance soil quality and crop productivity by influencing various soil processes and properties. Nanoparticles can serve as nano-fertilizers or nano-carriers for agrochemicals, increasing the availability of essential nutrients like nitrogen, phosphorus, potassium, and micronutrients (Baig *et al.* 2022). Additionally, nanomaterials in nanofertilizers can modify soil pH and EC by interacting with soil ions and organic matter (Kumari *et al.* 2020). Notably, nanomaterials in nanofertilizers have been shown to release metal ions into the soil solution, leading to an increase in soil pH and EC. Studies by Sahar *et al.* (2020) concluded that compost or nano-NPK fertilizer applications decreased soil pH and EC while increasing soil organic matter and the contents of N, P, and K. Their results indicate that nano-fertilizers release nutrients slowly, enhancing soil fertility and improving nutrient levels in grains. Rathore *et al.* (2022) found significant effects on EC with the application of conventional fertilizer and nano urea, along with improvements in soil physio-chemical properties and yield. Together, these studies emphasize the multifaceted impact of different fertilizers on soil properties and agricultural outcomes.

According to results, the interactions between different fertilizer levels and crop residues were non-significant in 2021 or 2022. When the data were mean, similar trends were recorded.

4.1.3.6.3. Organic carbon (%)

The residual effect of crops and different levels of fertilizers had no significant effect on the wheat in the growing seasons of 2021 and 2022 had the lowest level of organic carbon. Whereas the mean data was comparable to the observation made in 2021 and 2022 (Table 4.3.20).

The interaction between crop residues and different fertilizer levels was recorded to be non-significant in both the growing years (2021 and 2022) and mean data.

Table 4.3.20.: Effect of the residual effect of crops and different levels of fertilizer on physiochemical properties of wheat-grown soil during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021			2021-2022			Mean data		
	pH	EC (dsm ⁻¹)	Organic Car-bon (%)	pH	EC (dsm ⁻¹)	Organic Car-bon (%)	pH	EC (dsm ⁻¹)	Organic Car-bon (%)
A. Residual effect of crops									
M ₁	8.00 ^a	0.497 ^b	0.530	7.96 ^a	0.509 ^b	0.537	7.98 ^a	0.503 ^b	0.534
M ₂	7.77 ^b	0.592 ^a	0.544	7.49 ^c	0.604 ^a	0.552	7.63 ^b	0.597 ^a	0.548
M ₃	7.97 ^a	0.540 ^{ab}	0.536	7.70 ^b	0.552 ^{ab}	0.544	7.83 ^a	0.546 ^b	0.540
SEm (±)	0.06	0.017	0.010	0.04	0.019	0.012	0.05	0.018	0.011
CD (P=0.05)	0.16	0.052	NS	0.15	0.057	NS	0.16	0.054	NS
B. Different levels of fertilizer									
S ₁	8.06 ^a	0.479 ^b	0.520	7.86 ^a	0.493 ^b	0.526	7.96 ^a	0.486 ^b	0.523
S ₂	7.93 ^a	0.561 ^a	0.544	7.74 ^a	0.573 ^a	0.551	7.84 ^a	0.566 ^a	0.548
S ₃	7.97 ^a	0.548 ^a	0.531	7.78 ^a	0.559 ^a	0.537	7.87 ^a	0.552 ^a	0.534
S ₄	7.69 ^b	0.583 ^a	0.552	7.50 ^b	0.595 ^a	0.562	7.60 ^b	0.588 ^a	0.557
SEm (±)	0.04	0.009	0.016	0.03	0.012	0.017	0.04	0.010	0.016
CD (P=0.05)	0.14	0.036	NS	0.13	0.046	NS	0.13	0.041	NS
Interaction (A x B)	S	NS	NS	S	NS	NS	S	NS	NS

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

4.1.3.6.4. Available nitrogen (kg/ha)

The effects of various levels of fertilizers and the residual effect of crops significantly impacted the available nitrogen of the soil when wheat was grown prior in both seasons, i.e., 2021 and 2022, and in mean statistics. In 2020-2021 and 2021-2022, the plot where mungbean was grown as the sole crop before wheat recorded the highest mean value of N that was available; this value was statistically comparable to that of the plot where maize and mungbean were intercropped before wheat but was relatively higher than all other treatments. The plot with maize as the sole crop prior to wheat throughout the growing seasons of 2021 and 2022 had the lowest mean value of available N. Similar results were obtained when the data were mean (Table 4.3.21). The analysis suggests that, during the specified growing periods, the choice of cropping sequence had a substantial impact on the availability of nitrogen in the soil. The highest nitrogen levels associated with the mungbean sole-crop plot imply that mungbean, through its nitrogen-fixing abilities or other related mechanisms, contributed significantly to enriching the soil with nitrogen. The comparable N levels in the intercropped maize and mungbean plot indicate the potential synergistic effects of this crop combination on N availability. In contrast, the lowest nitrogen levels in the maize sole-crop plot suggest that maize cultivation alone, without the beneficial influence of a preceding legume crop like mungbean, resulted in diminished N content in the soil. The maximum N content in the soil after mungbean crops are harvested may be attributed to the mineralization of N from organic wastes and atmospheric nitrogen fixation by rhizobium bacteria in nodules on their roots, as suggested by Yuvraj *et al.* (2020). This observation finds support in the works of Sheoran *et al.* (2021) and Kumar *et al.* (2017), both of whom have put forth comparable assumptions regarding the enhanced N levels following the cultivation of N fixing legumes like mungbean. Furthermore, the augmentation of biological nitrogen fixation facilitated by rhizobia inoculants contributes to the enhancement of available N and P in the soil post-harvest, thereby making these nutrients accessible for utilization by subsequent crops (Matse *et al.* 2020). According to Murphy-Bokern *et al.* (2017), the N-rich root, shoot, and leaf biomass produced by legumes, facilitated by biological nitrogen fixation, enhances the accessibility of nitrogen for neighboring or subsequent non-legume crops. This occurs through the release of exudates, as well as the contribution of living and senescent biomasses,

providing an additional input of nitrogen-enriched material to the soil below-ground. A segment of the nitrogen fixed symbiotically in legumes becomes available to succeeding crops through the decomposition and mineralization of legume residues (Thilakarathna *et al.* 2016; Islam and Adjewor, 2017). Additionally, as asserted by Louarn *et al.* (2015), the residues of legumes can serve as a richer source of mineral N for subsequent crops compared to cereal residues. This is attributed to the relatively higher. Moreover, Ghosh *et al.* (2020) reported a similar legume effect on soil available N, emphasizing the role of biological N fixation by legumes. In both lowland and upland conditions, significant correlations were noted between soil variables and base crop grain yield, indicating that increased soil fertility with the inclusion of legumes influenced the productivity of the base crop. Hazra *et al.* (2014) and Venkatesh *et al.* (2017) further supported these findings, reporting that legume-inclusive rotations maintained a positive balance of N and P, thus accepting the hypothesis that changes in soil fertility directly influence base crop productivity in the long term. These collective findings emphasize the positive impact of legumes on soil fertility, particularly in terms of N availability, and the consequential benefits for subsequent crops.

The plot treated with 50 % RDF + 50 % Nano NPK fertilizers recorded the maximum available N in the case of different levels of fertilizer treatment in the years 2021 and 2022, and it was comparable with the plot applied with 100 % Nano NPK fertilizers and 100% RDF. Statistically, the least mean value of available N was obtained on the control. A similar pattern was noticed in the mean data (Table 4.3.21). The findings align with previous research conducted by Rajonee *et al.* (2016), which emphasized that the available N content was notably higher in the nano fertilizer treatment compared to other treatments. This disparity is likely attributable to the residual presence of fertilizer in the soil, with the nano fertilizer retaining a higher quantity of inorganic N compared to conventional counterparts. This supports the observed higher levels of available N in the plot treated with 50 % RDF + 50 % Nano NPK fertilizers in the years 2021 and 2022. Mala *et al.* (2017) further supported the notion that the use of nanofertilizers resulted in an elevated nitrogen content in the soil following the harvest of the crops. The rise in N concentration was ascribed to the slow release of nitrogen, coupled with its fixation by the root-nodule-inhabiting *Rhizobium*. This insight provides additional context to the higher available N levels observed in the plot treated

with 50 % RDF + 50 % Nano NPK fertilizers. Moreover, Mehta and Bharat (2019) disclosed that the foliar application of nano urea during critical stages, specifically tillering and panicle initiation, resulted in an adequate supply of N. This emphasizes the potential impact of nanofertilizers on N availability at different growth stages, contributing to the overall nutrient content in the soil. Shantappa (2014) and Naveen (2022) both conveyed that the foliar spray of nano fertilizers facilitated the rapid and timely availability of nutrients to the plants. This supports the idea that the balanced combination of 50 % RDF + 50 % Nano NPK fertilizers in the plot contributed to higher nitrogen availability, in line with the observed outcomes in 2021, 2022, and the mean data.

In the two following years, as well as when the data were mean, there was a significant interaction between the crop residues and the various fertilizer levels. The highest mean value available N was obtained in the plot where mungbean was cultivated as the only crop prior to wheat in conjunction with 50 % RDF + 50 % Nano NPK fertilizers while the least available N was obtained in the plot where maize was grown as sole crop prior to wheat in combination with control in both year i.e., 2021 and 2022. However, the tendency was identical when the data were mean (Table 4.3.21a).

4.1.3.6.5. Available phosphorous (kg/ha)

Table 4.1.21 depicts the outcome of different fertilizer levels as well as the crop's residual effect on available phosphorus (2021, 2022 and mean data). The plot with mungbean as the sole crop before wheat recorded the highest percentage of available P followed by the plot with maize and mungbean intercropped before wheat in both years (2021 and 2022). Also, in the growing seasons of 2021 and 2022, the plot with maize as the sole crop before wheat had the lowest accessible P content in the soil. In a similar manner, the mean data were comparable to the observation made in 2021 and 2022. The analysis indicates that the choice of cropping sequence significantly influenced the availability of P in the soil during the specified growing periods. The highest percentage of available P observed in the mungbean sole-crop plot suggests that mungbean cultivation, either through its root exudates or other mechanisms, contributed to an increased release or mineralization of P in the soil. The comparable P levels in the intercropped maize and mungbean plot indicate potential synergistic effects in P availability resulting from this crop combination. Moreover, the increased availability

of P with the inclusion of legumes, as observed in this study, aligns with findings from Venkatesh *et al.* (2019). This enhanced availability may be attributed to induced phosphorus solubilization. Additionally, the higher available P in pulse-included rotations can be attributed to the release of organic acids and root exudates, as indicated by Hazra *et al.* (2018). Legumes' ability to release organic acids and H⁺ ions, acidifying the rhizosphere, is recognized as a mechanism for improving phosphorus availability, as highlighted by Nandwa *et al.* (2011). Furthermore, the rise in available phosphorous content in the soil following mungbean crop harvest may be due to mungbean crops releasing more acid phosphatases from their roots into the soil than maize. This mechanism contributes to an increase in the status of accessible P₂O₅ in the soil. A comparable outcome was reported by Girijesh *et al.* (2015), who found maximum available phosphorous status in soil following crop harvest in sole intercrops (legumes) followed by intercropping treatments compared to sole maize. These findings collectively provide a scientific basis for the observed trends in phosphorus availability, emphasizing the role of legumes and specific crop sequences in enhancing soil phosphorus content.

In the years 2021 and 2022, the plot treated with 50% RDF + 50% Nano NPK fertilizers consistently exhibited the highest concentration of available phosphorus, followed by the plots treated with 100% RDF and 100% Nano NPK fertilizers. Statistically, the control plot consistently displayed the lowest percentage of available P in both seasons (2021 and 2022). The results obtained from the mean data were comparable to those observed in 2021 and 2022, as indicated in Table 4.1.21. The heightened levels of available phosphorus in the plot treated with 50% RDF + 50% Nano NPK fertilizers can be attributed to the balanced combination of these fertilizers. The synergistic effects of integrating both organic and nano fertilizers likely played a significant role in optimizing phosphorus availability in the soil. The comparable phosphorus levels observed in the plot treated with 100 % RDF and 100 % Nano NPK further support the effectiveness of the 50 % RDF + 50 % Nano NPK combination. Furthermore, studies by Soliman *et al.* (2016) support the positive impact of nanofertilizers on phosphorus availability. They affirmed that foliar application of nano phosphorous, in conjunction with traditional phosphorous fertilizer, satisfied the phosphorous needs of plants across various stages in the soil cycle. Additionally, they noted that

nanofertilizers application through spraying enhanced nutrient status in the soil following crop harvesting. El-Azizy *et al.* (2021) documented a noteworthy increase in the levels of available macronutrients, including nitrogen, phosphorus, and potassium, in the soil after the harvesting process, correlating with escalating foliar application of nano-fertilizers on broad beans. Similarly, Prathyusha *et al.* (2014) reported a notable positive impact of nano fertilizer on available phosphorus. These findings align with earlier studies by Han *et al.* (2016) and Pawar *et al.* (2017). Additionally, Nibin (2019) found that higher nutrients on post-harvest soil were provided by foliar nano NPK application in Okra. Conversely, the control plot, lacking additional fertilizers, consistently exhibited the lowest percentage of available phosphorus. The absence of supplementary nutrient inputs in the control condition resulted in limited phosphorus availability. When analyzing the mean data, the consistent trend across different fertilizer treatments further substantiates the notion that the choice of fertilizers has a lasting impact on phosphorus availability in the soil. This cumulative effect emphasizes the importance of considering specific fertilizer combinations to promote optimal nutrient levels in the soil for sustainable agricultural practices. In retrospect, the observed variations in available phosphorus across different fertilizer treatments in 2021, 2022, and the Mean data provide valuable insights into the historical dynamics of soil response to diverse nutrient applications.

It was found that there was significant interaction between the crop residues and the various fertilizer levels in 2021, and 2022, or when the data were mean. The plot where mungbean was grown as a sole crop before wheat in combination with 50 % RDF + 50 % Nano NPK fertilizers had the highest mean value of available P. However, the plot where maize was planted as the sole crop prior to wheat and with no fertilization (control) had the least available P in both the years and mean statistics (Table 4.3.21b).

4.1.3.6.6. Available potassium (kg/ha)

The effects of various fertilizer levels and residual effects of crops had a significant impact on the available potassium of soil when wheat was grown earlier in both seasons, i.e., 2021 and 2022, or when the data was mean (Table 4.3.21). The highest mean value of K that was accessible was found in the plot where mungbean was grown as the sole crop prior to wheat in 2021 and 2022, followed by the plot where maize and mungbean were intercropped. The least

mean value of available K was obtained on the plot where maize was the only crop grown before wheat. A similar trend to that of data recorded in 2021 and 2022 was observed when the data were mean. The analysis suggests that, during the specified growing periods, the choice of cropping sequence played a crucial role in influencing the availability of potassium in the soil. The highest accessible potassium levels in the mungbean sole-crop plot imply that mungbean cultivation, either through its root exudates or other mechanisms, significantly contributed to enhancing the soil's potassium content. The comparable potassium levels in the intercropped maize and mungbean plot indicate potential synergistic effects in potassium availability resulting from this specific crop combination. Conversely, the consistently lowest potassium levels in the maize sole-crop plot suggest that maize cultivation alone, without the beneficial influence of a preceding legume crop like mungbean, led to diminished potassium content in the soil. The analysis underscores that these observations were consistent across both the 2021 and 2022 growing seasons, reflecting the impact of specific agronomic practices during this period. Moreover, the deep root systems of mungbean, capable of extracting potassium from deeper soil levels, and increased biological and chemical activity in the rhizosphere, may be attributed to the highest available K_2O content in the soil under sole mungbean. This explanation aligns with similar inferences provided by Girijesh *et al.* (2015), and Balemi and Tufa (2019), who have reported the positive impact of deep-rooted legumes on soil potassium availability. Additionally, according to Latati *et al.* (2016), the intercropping of corn with legumes, such as peanuts, leads to elevated soil microorganism levels. This agricultural practice enhances nutrient availability in the soil by boosting the activity of soil urease and phosphate monoesterase. Consequently, it results in an increase in chlorophyll levels and microorganisms on corn plants. Although the intercropping dynamics described by Latati *et al.* focus on corn and peanuts, the principles of increased microorganism levels and enhanced nutrient availability through intercropping align with the potential benefits observed in the maize and mungbean intercropped plot in this study. The resemblance of the mean data to the individual year observations further strengthens the reliability of the identified trends, highlighting the enduring influence of the cropping sequence on soil potassium availability.

In the case of different levels of fertilizer treatment, in the years 2021 and 2022, the plot treated with 50% RDF + 50% Nano NPK fertilizers recorded the highest mean value of available K followed by the 100% RDF and 100 % Nano NPK fertilizers. The statically lowest available K was recorded in the control. A similar pattern was seen in the mean statistics. These outcomes resonate with the findings of Rajonee and collaborators (2017), who observed beneficial effects following the application of nano-fertilizer to the soil. Their research demonstrated an enhancement in potassium availability compared to conventional fertilizer treatments. Moreover, Abdel-Hakim and co-authors (2023) emphasized that the improvement in soil content, whether treated with nano-fertilizers independently or in conjunction with conventional fertilizers, can be attributed to the unique chemical and physical characteristics of nanofertilizers. These characteristics, such as slow release, precise targeting, rapid absorption by roots, penetration of living membranes, and protection against adsorption and sedimentation reactions, set nanofertilizers apart from their conventional counterparts. These findings align with earlier research by various groups, including Jyothi and Heb-sur (2017), Al-Juthery and Saadoun (2018), Mahgoub *et al.* (2017), Subramanian and Thirunavukkarasu (2017), and Al-Uthery and Al-Shami (2019). Collectively, these studies underscore the potential of nano-fertilizers to promote sustainable agricultural practices by improving nutrient availability and reducing environmental impacts. Additionally, Kubavat *et al.* (2020) documented that Nano-K nanofertilizers specifically have demonstrated the ability to maintain soil health and improve water quality. This is achieved by minimizing potassium losses in the soil and contributing to enhanced physiological and yield characteristics. The findings of Kubavat *et al.* complement the observed trend of increased available potassium levels in the plot treated with Nano NPK fertilizers, reinforcing the positive impact of nanofertilizers on soil health and crop productivity.

It was found that there was no considerable interaction between the crop residues and the various fertilizer levels on the available potassium in 2021, and 2022, and when the data were mean.

Table 4.3.21.: Effect of the residual effect of crops and different levels of fertilizer on the available nitrogen, phosphorous and potassium content of wheat -grown soil during the years (2020-2021 and 2021-2022) and mean data.

Treatments	2020-2021			2021-2022			Mean data		
	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)
A. Residual effect of crops									
M₁	244.73 ^b	28.57 ^c	283.63 ^a	254.06 ^b	30.62 ^c	296.733 ^b	247.96 ^b	29.59 ^c	290.18 ^b
M₂	356.65 ^a	34.08 ^a	317.92 ^a	363.83 ^a	36.62 ^a	332.82 ^a	360.24 ^a	35.35 ^a	325.37 ^a
M₃	323.41 ^{ab}	31.68 ^b	295.74 ^a	329.91 ^{ab}	33.98 ^b	309.94 ^{ab}	326.66 ^{ab}	32.83 ^b	302.84 ^{ab}
SEm (±)	3.91	0.56	6.46	3.56	0.59	4.71	3.74	0.57	5.59
CD (P=0.05)	15.35	1.65	25.37	13.98	1.75	18.50	14.67	1.70	21.93
B. Different levels of fertilizer									
S₁	243.71 ^c	19.93 ^d	205.26 ^d	250.35 ^c	20.88 ^d	211.96 ^d	247.03 ^c	20.41 ^d	208.61 ^d
S₂	318.10 ^{ab}	34.82 ^b	338.11 ^b	327.40 ^{ab}	37.53 ^b	355.02 ^b	322.76 ^{ab}	36.18 ^b	346.56 ^b
S₃	299.46 ^{bc}	30.69 ^c	309.51 ^c	306.84 ^{bc}	33.07 ^c	324.99 ^c	303.15 ^{bc}	31.88 ^c	317.25 ^c
S₄	371.80 ^a	40.33 ^a	343.51 ^a	379.15 ^a	43.46 ^a	360.69 ^a	375.45 ^a	41.90 ^a	352.10 ^a
SEm (±)	3.55	0.32	5.82	4.06	0.33	10.03	3.80	0.32	7.92
CD (P=0.05)	10.54	1.25	17.29	12.05	1.30	29.79	11.65	1.27	23.54
Interaction (A x B)	S	S	NS	S	S	NS	S	S	NS

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

Table 4.3.21a: Interaction between residual effect of crops and different levels of fertilizers on the available nitrogen of soil during the years (2020-21 and 2021-22) and mean data.

Kg/ha	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	218.35 ^g	242.28 ^f	224.12 ^g	302.85 ^e	227.98 ^g	246.90 ^f	232.71 ^g	308.63 ^e	223.17 ^g	240.26 ^f	228.41 ^g	305.74 ^e
M ₂	263.82 ^f	381.60 ^{bc}	364.76 ^c	416.44 ^a	269.11 ^f	389.26 ^{bc}	372.08 ^c	424.87 ^a	266.46 ^f	385.43 ^{bc}	368.42 ^c	420.66 ^a
M ₃	248.95 ^f	339.20 ^d	309.52 ^e	395.99 ^b	253.95 ^f	346.01 ^d	315.73 ^e	403.94 ^b	251.45 ^f	342.60 ^d	312.63 ^e	399.96 ^b
SEm (±)	6.15				7.02				6.59			
CD (P=0.05)	18.26				20.87				19.57			

Table 4.3.21b: Interaction between residual effect of crops and different levels of fertilizers on the available phosphorous of soil during the years (2020-21 and 2021-22) and mean data.

Kg/ha	(2020-2021)				(2021-2022)				Mean data			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
M ₁	15.04 ^g	30.34 ^d	26.50 ^e	34.38 ^b	14.22 ^g	34.26 ^d	29.92 ^e	38.82 ^b	14.63 ^g	32.30 ^d	28.21 ^e	36.60 ^b
M ₂	21.18 ^f	34.42 ^b	30.49 ^{cd}	40.39 ^a	21.96 ^f	39.34 ^b	34.85 ^{cd}	46.16 ^a	21.57 ^f	36.88 ^b	32.67 ^{cd}	43.27 ^a
M ₃	19.39 ^f	32.39 ^{bc}	28.62 ^{de}	33.41 ^b	19.25 ^f	36.67 ^{bc}	32.40 ^{de}	37.82 ^b	19.32 ^f	34.53 ^{bc}	30.51 ^{de}	35.62 ^b
SEm (±)	0.89				0.99				0.93			
CD (P=0.05)	2.63				2.95				2.76			

Means followed by different letters (a ,b, c and d) are statically different at 0.05%, S= Significant at P=0.05, NS=Non-significant at P=0.05, SEm (±)= Standard error mean, CD=Critical difference, RDF= Recommended dose of fertilizers, A x B= Interaction between cropping system and different levels of fertilizer, M₁= Residual effect of maize on wheat, M₂= Residual effect of mungbean on wheat , M₃= Residual effect of Maize+ Mungbean on wheat , S₁=Control, S₂=100 % RDF, S₃=100 % Nano NPK fertilizers, S₄= 50 % RDF+50 % Nano NPK fertilizers.

SUMMARY

The study entitled “ **Nanofertilizers for sustainable crop production under changing climate and impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean and wheat cropping system**” was conducted at the agricultural Farm of the Lovely Professional University, Phagwara, Punjab during the *kharif* and *rabi* seasons (2020 -2022). The study involved the cultivation of maize + mungbean intercropping during the *kharif* season of 2020 and 2021. The experiment included three types of cropping systems in the main plot: 1) Sole mungbean, 2) Sole maize, and 3) Maize + Mungbean (1:1). The subplot consisted of four different levels of fertilizers, including a control, 100% recommended dose of fertilizers (RDF), 100% Nano NPK fertilizers, and 50% RDF + 50% Nano NPK fertilizers. For the wheat cropping, which was grown during the *rabi* season of 2020-2021 and 2021-2022, the residual effect of previously grown crops was used as treatments in the main plot, which included crop residues of maize and mungbean intercropping.

The objective of the research was to identify the best appropriate combination of cropping system and fertilizer levels for maize and mungbean, as well as determine the optimal residual effect of crops and fertilizer levels for wheat. During the experiment, various growth and yield parameters were measured at various phases of crop growth, including the equivalent yield of maize and mungbean, the impact of nanofertilizers on the infestation of fall armyworm, the economics of the crops, nutrient uptake, correlation, and soil fertility status both before and after harvest. The findings of the trials are outlined below: -

5.1. Maize

5.1.1. Cropping systems

1. The growth components of both sole maize and intercropped maize were influenced by the cropping system at all sampling stages in both growing years (2020 and 2021), as well as when the data were mean. In most growth parameters, the

plot where maize was intercropped with mungbean showed better performance than the plot where sole maize was grown.

2. The phenological components, such as days to 50 % tasseling, days to 50 % silking, and 90% maturity stage were higher in intercrop maize in both growing years and in mean data.
3. The cropping approach significantly affected the yield and yield components of sole maize and intercropped maize. In both growing seasons and when the data were mean, the plot with maize and mungbean intercropped had the highest mean values of yield and yield components, while the plot with sole maize was found to have the lowest.
4. The plot where maize was intercropped with mungbean had a higher maize equivalent yield, whereas the yield was lower in the plot where sole maize was grown in two growing years, as well as when the statistics were mean.
5. The incidence of fall armyworm (FAW) infestation was higher in the plot where only maize was grown, compared to the plot where maize was intercropped with mungbean in 2020, 2021 and when the sets of data were mean.
6. The intercropped mungbean plot had better economics than the monoculture maize plot when both growing years and the mean data were considered. Yet, it was noted that the economy improved from the first to the second year.
7. The absorption of NPK in both the grain and straw of maize was greater in the plot where maize was intercropped with mungbean compared to the plot where only maize was grown, in both growing years and when the data were mean.
8. The pH, electrical conductivity (EC) and available NPK of the soil where maize and mungbean were cultivated were significantly influenced by the cropping system. The soil physicochemical properties were greater in the plot where only mungbean was grown, except for pH, which was higher in the soil where only maize was grown.

5.1.2. Different levels of fertilizers

1. Different fertilizer levels were found to influence the growth components of both sole maize and intercrop maize, including plant height, leaf number, LA, LAI, CGR, RGR, and shoot dry weight at all sampling stages in both the 2020 and 2021 growing years, as well as when the data were mean. Among all the

treatments, the plot treated with 50 % RDF+50 % Nano NPK fertilizers showed the best performance in terms of growth parameters.

2. The plot treated with 50 % RDF+50 % Nano NPK fertilizers exhibited the highest phenological components, such as the number of days to 50 % tasseling, days to 50 % silking and days to 90 % maturity in both growing years and when the data were mean.
3. For both sole and intercrop maize, the yield and yield components were significantly impacted by different fertilizer levels. The plot that was fertilized with 50 % RDF and 50 % Nano NPK fertilizers had the greatest mean values for yield and yield components. While the control plot had the lowest values in both growing seasons and when the data were mean.
4. The plot treated with 50 % RDF+ 50 % Nano NPK fertilizers had the highest maize equivalent yield, while the control plot had the lowest in both the 2020 and 2021 growing years, as well as when the data were mean.
5. The control plot had a higher infestation of fall armyworm (FAW), while the plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the lowest infestation in both the 2020 and 2021 growing years, as well as when the data were average.
6. In both the 2020 and 2021 growth seasons, as well as when the data were mean, the plot treated with 50 % RDF + 50 % Nano NPK fertilizers had better economics than all other treatments. However, it was found that the economy was better in the second year than in the first.
7. The plot treated with 50 % RDF +50 % Nano NPK fertilizers had the highest uptake of N, P, and K in both grain and straw of maize, while the control plot had the lowest uptake in both the 2020 and 2021 growing years, as well as when the data were mean.
8. The various fertilizer treatments had a significant impact on the pH, EC, and available NPK levels of the soil where maize and mungbean were cultivated. The plot treated with 50 % RDF + 50 % Nano NPK fertilizers had the highest levels of these soil physiochemical properties, except for pH, which was highest in the control plot, in both the 2020 and 2021 growing seasons and when the data were mean.
9. The cropping system and various fertilizer levels were found to interact significantly in both the growing seasons (2020 and 2021) as well as when the data were mean. The intercrop maize fertilized with 50 % RDF + 50 % Nano NPK fertilizers

showed the highest Mean values for the majority of growth, yield, and yield components.

10. In both growing seasons, as well as when the data were Mean, there were statistically significant and positive relationships between maize grain yield, growth, and yield components.

5.2. Mungbean

5.2.1. Cropping systems

1. Both sole mungbean and intercropped mungbean growth traits were positively impacted by the cropping system. Parameters such as plant height, no. of leaves, no. of branches per plant, leaf area, LAI, CGR, RGR, and total dry weight exhibited noticeable improvements throughout all stages of sampling in both the years of study (2020 and 2021) as well as when the data was mean. However, in most growth parameters, the plot where mungbean was grown solely performed better than the plot where it was intercropped with maize.
2. The phenological attributes, including days to 50% flowering and days to 90% maturity showed higher values in the sole mungbean plot, while days were shorter in the intercrop mungbean plot. This trend was consistent across both growing years as well as when the data was mean.
3. Both sole mungbean and intercropped mungbean yields and their numerous components were significantly influenced by the cropping system. The intercropped mungbean plot showed the lowest mean values of yield and its constituent parts, whereas the sole mungbean plot showed the maximum mean values. This trend was consistent across both growing seasons as well as when the data was mean.
4. The sole mungbean plot produced greater economics than the intercropped mungbean plot during 2020, 2021 and when the sets were mean. Notably, the economy was observed to be more favorable in the second year than in the first.
5. The assimilation of nutrients in grain and straw of mungbean was greater in the sole mungbean plot than in the intercropped mungbean and maize plot. This trend was consistent across both growing seasons as well as when the data was mean.

5.2.2. Different levels of fertilizers

1. The growth components of both sole mungbean and intercropped mungbean, including plant height, no. of leaves, no. of branches per plant, LA, LAI, CGR, RGR, and total dry matter, demonstrated improvement with the application of

different fertilizer levels throughout all stages of sampling in both 2020 and 2021. The plot treated with a combination of 50 % RDF and 50 % Nano NPK fertilizers exhibited the highest performance among all other treatments in terms of growth parameters.

2. The phenological components, specifically the days to 50 % flowering and 90% maturity exhibited the highest value in the plot treated with 50% RDF + 50 % Nano NPK fertilizers, whereas the control plot recorded the lowest during both growing years, as well as when the data was mean.
3. The yield and yield-related characteristics of sole mungbean and intercrop mungbean were significantly impacted by the application of various fertilizer levels. The plot with the highest Mean values of yield and yield components was treated with 50% RDF and 50% Nano NPK fertilizers. While the control plot exhibited the lowest mean values in both growing seasons, as well as when the data was mean.
4. The plot treated with 50 % RDF + 50 % Nano NPK fertilizers showed higher gross returns, net benefits, and benefit-cost ratios compared to all other treatments in both growing seasons and when the data were mean. Nevertheless, it was observed that the economy was more favorable in the second year than in the first.
5. The plot treated with 50 % RDF + 50 % Nano NPK fertilizers recorded the highest uptake of N, P, and K in grain and straw of mungbean, while the lowest was observed in the control plot in both growing years as well as when the data were mean.
6. In both the growing years (2020 and 2021) and when the data were mean, a substantial interaction between the cropping system and various fertilizer levels was seen. The sole mungbean plot that used 50 % RDF + 50 % Nano NPK fertilizers had the highest Mean values for most of the growth, yield, and yield components.
7. Positive correlations that were statistically significant ($P=0.05$) were observed between mungbean seed yield, growth, and yield components in both the growing years and when the data were mean.

5.3. Wheat

5.3.1. Residual effect of crops

1. The residues of the previous crop had a significant effect on the growth parameters of wheat, including plant population, height, leaf number, LA, LAI, CGR,

RGR, and shoot dry weight, during both growing years (2020-2021 and 2021-2022), as well as when the data were mean. The plot where mungbean was grown alone before wheat showed the best performance in most of the growth parameters, surpassing the other plots.

2. In both growing years (2020-2021 and 2021-2022), as well as when the data were mean, the plot where mungbean was grown before wheat had the highest values for phenological components such as days to 50 % flowering and 90 % maturity. On the other hand, the plot where sole maize was grown before wheat had the lowest values for the phenological parameters.
3. Wheat's yield and yield attributes were significantly impacted by the residual influence of crops. The sole mungbean was grown on the plot before wheat, and it produced the highest yield and yield components while the lowest was observed in the plot where sole maize was grown before wheat, in both the growing seasons as well as when the data were mean.
4. In 2020-21 and 2021-22 and when both the sets of data were mean, the plot where sole mungbean was grown before wheat showed higher economics in comparison to other treatments. As the benefit-cost ratios were all above 1, this study is expected to be valuable.
5. The plot where sole mungbean was grown before wheat showed the highest uptake of NPK in grain and straw of wheat, while the least uptake was found in the plot where sole maize was grown before wheat during 2020-21 and 2021-22.
6. The residual effects of crops had a significant ($P=0.05$) impact on the pH, EC, and available NPK of the soil in which wheat was cultivated. The plot where sole maize was grown before wheat had the highest values for all soil chemical properties, except for pH, which was highest in the plot where sole mungbean was grown before wheat.

5.3.2. Different levels of fertilizers

1. The growth components of wheat were significantly improved by different levels of fertilizers in both the growing years (2020-2021 and 2021-2022) and when the data were mean. The plot that received 50 % RDF+50 % Nano NPK fertilizers showed the best performance in terms of growth parameters compared to all other treatments.

2. The plot treated with 50% RDF+50 % Nano NPK fertilizers exhibited the highest values for phenological components such as days to 50% flowering and days to 90% maturity while the control plot had the lowest values for both the parameters in both growing years and when the data were average.
3. The yield and yield components of wheat showed a significant response to various levels of fertilizers. The plot treated with 50% RDF + 50 % Nano NPK fertilizers exhibited the highest mean values of yield and yield components, whereas the lowest values were observed in the control plot in both the growing years, as well as when the data were mean.
4. When the data were mean from both growing seasons, the plot treated with 50 % RDF + 50% Nano NPK fertilizers yielded higher economics than all other treatments. However, the second year had better economic outcomes compared to the first year. This study's value lies in the fact that, apart from the control plot, all residual effects of crops and fertilizer application levels resulted in benefit-cost ratio values exceeding 1.
5. The control plot had the lowest NPK absorption during the course of the two growing seasons (2020–21 and 202–22), as well as when the results were mean, compared to the plot treated with 50 % RDF + 50 % Nano NPK fertilizers.
6. There was a substantial interaction between the cropping system and the various fertilizer levels in both the growing years (2020 and 2021) and when the data were mean. The highest average values for most of the growth, yield, and yield components of wheat were recorded on the plot where sole mungbean was grown prior to wheat along with 50 % RDF + 50 % Nano NPK fertilizers.
7. Wheat grain yield, growth, and yield components all exhibited significant ($P=0.05$) positive relationships during both growing seasons as well as when the data were mean.

CONCLUSION

1. to study the advantages of nanofertilizers over conventional fertilizers,

It has been noted that relying solely on nanofertilizers may not yield satisfactory outcomes for crops. Therefore, it is recommended to use them in combination with chemical fertilizers. This approach can increase yields like chemical fertilizers, reduce cultivation costs, and minimize environmental damage. Based on this, it can be concluded that Nano NPK fertilizers have the potential to be a viable alternative to chemical NPK fertilizers in promoting sustainable development. The findings of this study could serve as a valuable reference for future research on the usage of nanofertilizers in agriculture.

2. to study the impact of nitrogen, phosphorus, and potassium nanofertilizers on growth, yield, and yield components of maize + mung bean intercropping,

It was observed that the growth, yield, and yield-related characteristics of maize, mung bean, and wheat crops were notably influenced by the application of Nano NPK fertilizers. Notably, the research highlighted that the most effective fertilizer levels for enhancing the growth and yield-related attributes of these crops were achieved through a combination of 50% recommended dose of fertilizer (RDF) and 50% Nano NPK fertilizers. Specifically, intercropping maize and mung bean with this balanced ratio of 50% RDF and 50% Nano NPK fertilizers emerged as the recommended planting approach, offering optimal results for maize based on the trial outcomes. The study also suggested that the ideal cropping system and fertilizer combination for mung bean involved sole mung bean cultivation in conjunction with 50% RDF and 50% Nano NPK fertilizers. These findings not only provide valuable insights into the synergies between nanofertilizers and conventional fertilizers but also offer practical recommendations for maximizing the growth and yield potential of intercropped maize and mung bean systems. It underscores the importance of tailored fertilizer applications for specific crops and planting arrangements, further emphasizing the potential benefits of integrating nanofertilizers in sustainable agricultural practices.

3. to study the impact of nitrogen, phosphorus, and potassium nanofertilizers on the growth, yield, and yield components of wheat and

It was observed that different fertilizer levels significantly improved the growth components of wheat across multiple growing seasons, and the combination of 50% recommended dose of fertilizer (RDF) and 50 % Nano NPK fertilizers demonstrated superior performance in terms of growth parameters compared to alternative treatments. In terms of yield and yield components, the same treatment regimen proved to be highly effective, consistently yielding the highest mean values. Lastly, the positive relationships observed between wheat grain yield, growth, and yield components throughout the growing seasons underscored the enduring impact of the applied fertilizer treatments. These findings collectively contribute to a nuanced understanding of the intricate interplay between nano fertilizers and wheat cultivation, providing valuable insights for sustainable and optimized agricultural practices.

4. to study the effect of nitrogen, phosphorus, and potassium nanofertilizers on the economics of maize + mung bean and wheat cropping system

1.Maize + Mungbean intercropping:

The utilization of 50% recommended dose of fertilizer (RDF) and 50% Nano NPK fertilizers in the maize + mung bean cropping system demonstrated consistently favorable economic outcomes in both the 2020 and 2021 growth seasons. The economic viability was notably enhanced, particularly in the second year, highlighting a positive trend in the economic benefits associated with the application of nanofertilizers in maize + mungbean intercropping. This observation aligns with the broader understanding that the second year yielded better economic results, emphasizing the potential for sustained financial advantages with the incorporation of nanofertilizers in maize +mungbean production.

2. Wheat:

A similar trend was observed in the wheat cropping, where the plot treated with 50% RDF and 50% Nano NPK fertilizers exhibited superior economic performance. The analysis encompassed gross returns, net benefits, and benefit-cost ratios, consistently outperforming other treatments in both growing seasons and when the data were average. Notably, economic gains were more

favorable in the second year, underlining a trend of improved financial outcomes with sustained application of nanofertilizers in wheat cultivation.

Economic considerations played a central role in assessing the overall success of fertilizer treatments, particularly evident in the maize + mungbean and wheat cropping system. The plot treated with 50% RDF and 50 % Nano NPK fertilizers consistently demonstrated superior economic outcomes when data were mean from both growing seasons. Importantly, this study's value extended beyond individual treatments, highlighting that all fertilizer application levels, except for the control plot, resulted in benefit-cost ratio values exceeding 1. This underscores the economic viability of incorporating nanofertilizers in wheat cultivation, contributing valuable insights for sustainable and economically sound agricultural practices.

The economic findings from the research underscore the potential advantages of employing nitrogen, phosphorus, and potassium nanofertilizers in both maize + mung bean and wheat cropping systems. The positive economic trends observed in these studies provide practical implications for optimizing fertilization strategies to enhance agricultural productivity and financial sustainability.

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APPENDICES

Appendix-A.1: Calculation of fixed cost of cultivation (Rs ha⁻¹) of maize (2020).

S.No.	Particulars	Fixed cost of cultivation (Rs ha ⁻¹)		
		Input	Price (Rs)	Total cost (Rs ha ⁻¹)
1.	Land Preparation			
a.	Field preparation	1 tractor(5hr) ha ⁻¹	800 Rs ha ⁻¹	4,800
2.	Plant protection			
a.	Spraying (1 and 2) cost of Emamectin benzoate (5% SG)	1kg ha ⁻¹	100+2000	3000
3.	Weed management	20 laborers	300 Rs laborer ⁻¹	6000
4.	Harvesting, Threshing, and winnowing	15 laborers	300 Rs laborer ⁻¹	4500
A.	Common cost			18300
B.	Miscellaneous 10% of common cost			1830
Grand Total= 20130				

Appendix-A.2: Calculation of fixed cost of cultivation (Rs ha⁻¹) of maize (2021).

S.No.	Particulars	Fixed cost of cultivation (Rs ha ⁻¹)		
		Input	Price (Rs)	Total cost (Rs ha ⁻¹)
1.	Land Preparation			
a.	Field preparation	1 tractor(5hr) ha ⁻¹	800 Rs ha ⁻¹	4,800
2.	Plant protection			
a.	Spraying (1 and 2) cost of Emamectin benzoate (5% SG)	1kg ha ⁻¹	100+2000	3000
3.	Weed management	20 laborers	300 Rs laborer ⁻¹	6000
4.	Harvesting, Threshing, and winnowing	17 laborers	300 Rs laborer ⁻¹	5400
A.	Common cost			18900
B.	Miscellaneous 10% of common cost			1890
Grand Total= 20790				

Rs=Rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, N=nitrogen, P=phosphorous, K=potassium, SG= soluble granules, SSP=single super phosphate, MOP=muriate of potash.

Appendix-A.3: Variable cost (Rs ha⁻¹) of maize (2020, 2021 and mean data).

S.No.	Particulars	Kg ha ⁻¹	Variable cost (Rs ha ⁻¹)		
			Price (Rs kg ⁻¹)	Cost of application/la- bour (Rs day ⁻¹)	Total cost (Rs ha ⁻¹)
A.	Cropping system				
1.	Sole maize	12	410	6000 20 Labour@300 Rs day ⁻¹	9420
2.	Intercrop maize	6	410	3000 10 Labour@300 Rs day ⁻¹	5460
B.	Different levels of fertilizer				
1.	Control	-	-	-	-
2.	100% RDF			6000 20 Labour@300 Rs day ⁻¹	12184.5
a.	Urea	272.81	7		
b.	SSP	370.65	10		
c.	MOP	49.42	11.5		
3.	100% Nano NPK fertilizers	0.50	950	6000 20 Labour@300 Rs day ⁻¹	6475
4.	50% RDF +50% Nano NPK fertilizers			6000 20 Labour@300 Rs day ⁻¹	9329.75
a.	Urea	136.405	7		
b.	SSP	185.325	10		
c	MOP	24.71	11.5		
d	100% Nano NPK fertilizers	0.25	950		

Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash.

Appendix-A.4: Total cost incurred by treatments (2020).

Treatments	Source cost (ha ⁻¹)	Cost of cultivation (ha ⁻¹)	Interest on the column 3+4 @ 12%per annum for 4 months(ha ⁻¹)	Interest on the column 3+4 @ 10 %per annum for 4 months(ha ⁻¹)	Total cost of cultivation 3+4+5+6 (ha ⁻¹)
2	3	4	5	6	7
M ₁ S ₁	9420.00	20130.00	3546.00	2955.00	36051.00
M ₁ S ₂	21604.50	20130.00	5008.14	4173.45	50916.09
M ₁ S ₃	15895.00	20130.00	4323.00	3602.50	43950.50
M ₁ S ₄	18749.75	20130.00	4665.57	3887.98	47433.30
M ₃ S ₁	5460.00	20130.00	3070.80	2559.00	31219.80
M ₃ S ₂	17644.50	20130.00	4532.94	3777.45	46084.89
M ₃ S ₃	11935.00	20130.00	3847.80	3206.50	39119.30
M ₃ S ₄	14789.75	20130.00	4190.37	3491.98	42602.10
C. SALES PRICE OUTPUT					
Seed: 18.50 Rs kg ⁻¹			Stover: 5Rs kg ⁻¹		

M₁S₁=Sole maize +control, M₁S₂= Sole maize +100% RDF, M₁S₃= Sole maize +100% Nano NPK fertilizers, M₁S₄= Sole maize+50% RDF+ 50% Nano NPK fertilizers, M₂S₁=Intercrop maize +control, M₂S₂= Intercrop maize +100% RDF, M₂S₃= Intercrop maize +100% Nano NPK fertilizers, M₂S₄= Intercrop maize+50% RDF+ 50% Nano NPK fertilizers, Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash.

Appendix-A.5: Total cost incurred by treatments (2021).

Treatments	Source cost (ha ⁻¹)	Cost of cultivation (ha ⁻¹)	Interest on the column 3+4 @ 12%per annum for 4 months(ha ⁻¹)	Interest on the column 3+4 @ 10 %per annum for 4 months(ha ⁻¹)	Total cost of cultivation 3+4+5+6 (ha ⁻¹)
2	3	4	5	6	7
M ₁ S ₁	9420.00	20790.00	3625.20	3021.00	36856.20
M ₁ S ₂	21604.50	20790.00	5087.34	4239.45	51721.29
M ₁ S ₃	15895.00	20790.00	4402.20	3668.50	44755.70
M ₁ S ₄	18749.75	20790.00	4744.77	3953.98	48238.50
M ₃ S ₁	5460.00	20790.00	3150.00	2625.00	32025.00
M ₃ S ₂	17644.50	20790.00	4612.14	3843.45	46890.09
M ₃ S ₃	11935.00	20790.00	3927.00	3272.50	39924.50
M ₃ S ₄	14789.75	20790.00	4269.57	3557.98	43407.30
C. SALES PRICE OUTPUT					
Seed: 18.70 Rs kg ⁻¹			Stover: 5Rs kg ⁻¹		

M₁S₁=Sole maize +control, M₁S₂= Sole maize +100% RDF, M₁S₃= Sole maize +100% Nano NPK fertilizers, M₁S₄= Sole maize+50% RDF+ 50% Nano NPK fertilizers, M₃S₁=Intercrop maize +control, M₃S₂= Intercrop maize +100% RDF, M₃S₃= Intercrop maize +100% Nano NPK fertilizers, M₃S₄= Intercrop maize+50% RDF+ 50% Nano NPK fertilizers, Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash.

Appendix-B.1: Calculation of fixed cost of cultivation (Rs ha⁻¹) of mungbean (2020).

S.No.	Particulars	Fixed cost of cultivation (Rs ha ⁻¹)		
		Input	Price (Rs)	Total cost (Rs ha ⁻¹)
1.	Land Preparation			
a.	Field preparation	1 tractor(5hr) ha ⁻¹	800 Rs ha ⁻¹	4000
2.	Sowing and fertilizer			
a.	Seed sowing and fertilizer application	1 tractor(2hr) ha ⁻¹	800 Rs hrs ⁻¹	1600
3.	Weed management	13 laborers	300 Rs laborer ⁻¹	3900
4.	Harvesting, Threshing, and winnowing	15 laborers	300 Rs laborer ⁻¹	4500
A.	Common cost			14000
B.	Miscellaneous 10% of common cost			1400
Grand Total= 15400				

Appendix-B.2: Calculation of fixed cost of cultivation (Rs ha⁻¹) of mungbean (2021).

S.No.	Particulars	Fixed cost of cultivation (Rs ha ⁻¹)		
		Input	Price (Rs)	Total cost (Rs ha ⁻¹)
1.	Land Preparation			
a.	Field preparation	1 tractor(5hr) ha ⁻¹	800 Rs ha ⁻¹	4000
2.	Sowing and fertilizer			
a.	Seed sowing and fertilizer application	1 tractor(2hr) ha ⁻¹	800 Rs hrs ⁻¹	1600
3.	Weed management	13 laborers	300 Rs laborer ⁻¹	3900
4.	Harvesting, Threshing, and winnowing	17 laborers	300 Rs laborer ⁻¹	5100
A.	Common cost			14600
B.	Miscellaneous 10% of common cost			1460
Grand Total= 16060				

Rs=Rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, N=nitrogen, P=phosphorous, K=potassium, SG= soluble granules, SSP=single super phosphate, MOP=mu-riate of potash, RDF- recommended dose of fertilizers.

Appendix-B.3: Variable cost (Rs ha⁻¹) of mungbean.

Treatments	Kg ha ⁻¹	Rs kg ⁻¹	Variable cost (Rs ha ⁻¹)		
			Price (Rs kg ⁻¹)	Cost of application/labour (Rs day ⁻¹)	Total cost (Rs ha ⁻¹)
A. Cropping system					
1. Sole mungbean		12	100	4500 15 Labour@300 Rs day ⁻¹	4600
2.Intercrop mungbean		6	100	2100 7 Labour@300 Rs day ⁻¹	2200
B. Different levels of fertilizers					
1. Control		-	-	-	-
2.100%RDF				6000 20 Labour@300 Rs day ⁻¹	8775.65
a. Urea	43.5	7	304.5		
b. SSP	247.11	10	2471.1		
3. 100% Nano NPK fertilizers	0.50	950	475	6000 20 Labour@300 Rs day ⁻¹	6475
4. 50% RDF +50% Nano NPK fertilizers				6000 20 Labour@300 Rs day ⁻¹	7629.75
a. 50% Urea	21.75	7	152.25		
b. 50% SSP	124	10	1240		
c. 50% Nano NPK fertilizers	0.25	950	237.5		

Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash, RDF-recommended dose of fertilizers.

Appendix-B.4: Total cost incurred by treatments (2020).

Treatments	Source cost (ha ⁻¹)	Cost of cultivation (ha ⁻¹)	Interest on the column 3+4 @ 12%per annum for 4 months(ha ⁻¹)	Interest on the column 3+4 @ 10 %per annum for 4 months(ha ⁻¹)	Total cost of cultivation 3+4+5+6 (ha ⁻¹)
2	3	4	5	6	7
M ₂ S ₁	4600.00	15400.00	2400.00	2000.00	24400.00
M ₂ S ₂	13375.65	15400.00	3453.08	2877.57	35106.29
M ₂ S ₃	11075.00	15400.00	3177.00	2647.50	32299.50
M ₂ S ₄	12229.75	15400.00	3315.57	2762.98	33708.30
M ₃ S ₁	2200.00	15400.00	2112.00	1760.00	21472.00
M ₃ S ₂	10975.65	15400.00	3165.08	2637.57	32178.29
M ₃ S ₃	8675.00	15400.00	2889.00	2407.50	29371.50
M ₃ S ₄	9829.75	15400.00	3027.57	2522.98	30780.30
C. SALES PRICE OUTPUT					
Seed: 77.55Rs kg ⁻¹			Stover: 2Rs kg ⁻¹		

M₂S₁=Sole mungbean +control, M₂S₂= Sole mungbean +100% RDF, M₂S₃= Sole mungbean +100% Nano NPK fertilizers, M₂S₄= Sole mungbean+50% RDF+ 50% Nano NPK fertilizers, M₃S₁=Intercrop mungbean +control, M₃S₂= Intercrop mungbean +100% RDF, M₃S₃= Intercrop mungbean +100% Nano NPK fertilizers, M₃S₄= Intercrop mungbean +50% RDF+ 50% Nano NPK fertilizers, Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash.

Appendix-B.5: Total cost incurred by treatments (2021).

Treatments	Source cost (ha ⁻¹)	Cost of cultivation (ha ⁻¹)	Interest on the column 3+4 @ 12%per annum for 4 months(ha ⁻¹)	Interest on the column 3+4 @ 10 %per annum for 4 months(ha ⁻¹)	Total cost of cultivation 3+4+5+6 (ha ⁻¹)
2	3	4	5	6	7
M ₂ S ₁	4600.00	16060.00	2479.20	2066.00	25205.20
M ₂ S ₂	13375.65	16060.00	3532.28	2943.57	35911.49
M ₂ S ₃	11075.00	16060.00	3256.20	2713.50	33104.70
M ₂ S ₄	12229.75	16060.00	3394.77	2828.98	34513.50
M ₃ S ₁	2200.00	16060.00	2191.20	1826.00	22277.20
M ₃ S ₂	10975.65	16060.00	3244.28	2703.57	32983.49
M ₃ S ₃	8675.00	16060.00	2968.20	2473.50	30176.70
M ₃ S ₄	9829.75	16060.00	3106.77	2588.98	31585.50
C. SALES PRICE OUTPUT					
Seed: 88.58 Rs kg ⁻¹			Stover: 2Rs kg ⁻¹		

M₂S₁=Sole mungbean +control, M₂S₂= Sole mungbean +100% RDF, M₂S₃= Sole mungbean +100% Nano NPK fertilizers, M₂S₄= Sole mungbean+50% RDF+ 50% Nano NPK fertilizers, M₃S₁=Intercrop mungbean +control, M₃S₂= Intercrop mungbean +100% RDF, M₃S₃= Intercrop mungbean +100% Nano NPK fertilizers, M₃S₄= Intercrop mungbean +50% RDF+ 50% Nano NPK fertilizers, Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash.

Appendix C.1: Calculation of fixed cost of cultivation (Rs ha⁻¹) of wheat (2020-2021).

S.No.	Particulars	Fixed cost of cultivation (Rs ha ⁻¹)		
		Input	Price (Rs)	Total cost (Rs ha ⁻¹)
1.	Land Preparation			
a.	Field preparation	1 tractor(5hr) ha ⁻¹	800 Rs ha ⁻¹	4000
2.	Sowing and fertilizer			
a.	Seed sowing and fertilizer application	1 tractor(2hr) ha ⁻¹	800 Rs hrs ⁻¹	1600
3.	Irrigation	6 laborers	300 Rs laborer ⁻¹	1800
4.	Weed management	20 laborers	300 Rs laborer ⁻¹	6000
5.	Harvesting, Threshing, and winnowing	15 laborers	300 Rs laborer ⁻¹	4500
A.	Common cost			14300
B.	Miscellaneous 10% of common cost			1430
Grand Total= 15730				

Appendix-C.2: Calculation of fixed cost of cultivation (Rs ha⁻¹) of wheat (2021-2022).

S.No.	Particulars	Fixed cost of cultivation (Rs ha ⁻¹)		
		Input	Price (Rs)	Total cost (Rs ha ⁻¹)
1.	Land Preparation			
a.	Field preparation	1 tractor(5hr) ha ⁻¹	800 Rs ha ⁻¹	4000
2.	Sowing and fertilizer			
a.	Seed sowing and fertilizer application	1 tractor(2hr) ha ⁻¹	800 Rs hrs ⁻¹	1600
3.	Irrigation	6 laborers	300 Rs laborer ⁻¹	1800
4.	Weed management	20 laborers	300 Rs laborer ⁻¹	6000
5.	Harvesting, Threshing, and winnowing	18 laborers	300 Rs laborer ⁻¹	5400
A.	Common cost			19400
B.	Miscellaneous 10% of common cost			1940
Grand Total= 16720				

Rs=Rupees, ha⁻¹=per hectare, hr⁻¹=per hour, %=percentage. Rs=rupees, ha⁻¹=per hectare, hr⁻¹=per hour, kg⁻¹=per kilogram, %=percent, SSP=single super phosphate, MOP=muriate of potash, RDF-Recommended dose of fertilizers.

Appendix-C.3: Variable cost (Rs ha⁻¹) of wheat.

Treatments	Kg ha ⁻¹	Rs kg ⁻¹	Variable cost (Rs ha ⁻¹)		
			Price (Rs kg ⁻¹)	Cost of applica- tion/labour (Rs day ⁻¹)	Total cost (Rs ha ⁻¹)
A. Residual effect of crops					
1. Wheat (PBW-550)		80	100	4500 15 Labour@300 Rs day ⁻¹	12500
B. Different levels of fertilizers					
1. Control		-	-	-	
2.100% RDF				6000 20 Labour@300 Rs day ⁻¹	12816
a. Urea	260	7	1820		
b. SSP	375	10	3750		
c. MOP	67	11.5	770.5		
3. 100% Nano NPK fertilizers	0.50	950	475	6000 20 Labour@300 Rs day ⁻¹	6475
4. 50% RDF +50% Nano NPK fertilizers				6000 20 Labour@300 Rs day ⁻¹	9408
a. 50% Urea	130	7	910		
b. 50% SSP	187.5	10	1875		
c. 50%MOP	33.5	11.5	385.25		
d. 50% Nano NPK fertilizers	0.25	950	237.5		

Appendix-C.4: Total cost incurred by treatments (2020-2021).

Treatments	Source cost (ha ⁻¹)	Cost of cultivation (ha ⁻¹)	Interest on the column 3+4 @ 12%per annum for 4 months(ha ⁻¹)	Interest on the column 3+4 @ 10 %per annum for 4 months(ha ⁻¹)	Total cost of cultiva- tion 3+4+5+6 (ha ⁻¹)
2	3	4	5	6	7
M ₁ S ₁	12500.00	15730.00	3387.60	2823.00	34440.60
M ₁ S ₂	25316.00	15730.00	4925.52	4104.60	50076.12
M ₁ S ₃	18975.00	15730.00	4164.60	3470.50	42340.10
M ₁ S ₄	21908.00	15730.00	4516.56	3763.80	45918.36
M ₂ S ₁	12500.00	15730.00	3387.60	2823.00	34440.60
M ₂ S ₂	25316.00	15730.00	4925.52	4104.60	50076.12
M ₂ S ₃	18975.00	15730.00	4164.60	3470.50	42340.10
M ₂ S ₄	21908.00	15730.00	4516.56	3763.80	45918.36
M ₃ S ₁	12500.00	15730.00	3387.60	2823.00	34440.60
M ₃ S ₂	25316.00	15730.00	4925.52	4104.60	50076.12
M ₃ S ₃	18975.00	15730.00	4164.60	3470.50	42340.10
M ₃ S ₄	21908.00	15730.00	4516.56	3763.80	45918.36
C. SALES PRICE OUTPUT					
Seed: 23 Rs kg ⁻¹			Stover: 5Rs kg ⁻¹		

M₁S₁= Residual effect of maize on wheat + control, M₁S₂= Residual effect of maize on wheat +100% RDF, M₁S₃= Residual effect of maize on wheat +100% Nano NPK fertilizers, M₁S₄= Residual effect of maize on wheat+ 50% RDF+ 50% Nano NPK fertilizers, M₂S₁= Residual effect of mungbean on wheat + control, M₂S₂= Residual effect of mungbean on wheat +100% RDF, M₂S₃= Residual effect of mungbean on wheat+100% Nano NPK fertilizers, M₂S₄= Residual effect of mungbean on wheat+50% RDF+ 50% Nano NPK fertilizers, M₃S₁=Residual effect of maize +mungbean on wheat + control, M₃S₂= Residual effect of maize + mungbean on wheat +100% RDF, M₃S₃= Residual effect of maize +mungbean on wheat +100% Nano NPK fertilizers, M₃S₄= Residual effect of maize + mungbean on wheat + 50% RDF+ 50% Nano NPK fertilizers, kg⁻¹=per kilogram, ha⁻¹=per hectare.

Appendix-C.5: Total cost incurred by treatments (2021-2022).

Treatments	Source cost (ha ⁻¹)	Cost of cultivation (ha ⁻¹)	Interest on the column 3+4 @ 12%per annum for 4 months(ha ⁻¹)	Interest on the column 3+4 @ 10 %per annum for 4 months(ha ⁻¹)	Total cost of cultivation 3+4+5+6 (ha ⁻¹)
2	3	4	5	6	7
M ₁ S ₁	12500.00	16720.00	3506.40	2922.00	35648.40
M ₁ S ₂	25316.00	16720.00	5044.32	4203.60	51283.92
M ₁ S ₃	18975.00	16720.00	4283.40	3569.50	43547.90
M ₁ S ₄	21908.00	16720.00	4635.36	3862.80	47126.16
M ₂ S ₁	12500.00	16720.00	3506.40	2922.00	35648.40
M ₂ S ₂	25316.00	16720.00	5044.32	4203.60	51283.92
M ₂ S ₃	18975.00	16720.00	4283.40	3569.50	43547.90
M ₂ S ₄	21908.00	16720.00	4635.36	3862.80	47126.16
M ₃ S ₁	12500.00	16720.00	3506.40	2922.00	35648.40
M ₃ S ₂	25316.00	16720.00	5044.32	4203.60	51283.92
M ₃ S ₃	18975.00	16720.00	4283.40	3569.50	43547.90
M ₃ S ₄	21908.00	16720.00	4635.36	3862.80	47126.16
C. SALES PRICE OUTPUT					
Seed: 23 Rs kg ⁻¹			Stover: 5Rs kg ⁻¹		

M₁S₁= Residual effect of maize on wheat + control, M₁S₂= Residual effect of maize on wheat +100% RDF, M₁S₃= Residual effect of maize on wheat +100% Nano NPK fertilizers, M₁S₄= Residual effect of maize on wheat+ 50% RDF+ 50% Nano NPK fertilizers, M₂S₁= Residual effect of mungbean on wheat + control, M₂S₂= Residual effect of mungbean on wheat +100% RDF, M₂S₃= Residual effect of mungbean on wheat+100% Nano NPK fertilizers, M₂S₄= Residual effect of mungbean on wheat+50% RDF+ 50% Nano NPK fertilizers, M₃S₁=Residual effect of maize +mungbean on wheat + control, M₃S₂= Residual effect of maize + mungbean on wheat +100% RDF, M₃S₃= Residual effect of maize +mungbean on wheat +100% Nano NPK fertilizers, M₃S₄= Residual effect of maize + mungbean on wheat + 50% RDF+ 50% Nano NPK fertilizers, kg⁻¹=per kilogram, ha⁻¹=per hectare.

APPENDICES-D.1: Coefficient of variation (CV) for the effect of cropping system and different levels of fertilizers on the growth and yield parameters of maize +mungbean and wheat cropping system.

1.MAIZE

Table 1.1.: Effect of cropping system and different levels of fertilizers on the plant height (cm) of sole and intercrop maize at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A. Cropping system												
CV (%)	6.41	8.57	5.60	5.50	14.58	10.18	5.16	5.92	10.49	9.38	5.40	5.59
B. Different levels of fertilizers												
CV (%)	13.35	7.60	6.00	6.13	9.90	6.36	5.92	5.00	11.62	6.96	5.98	5.55

Table 1.2.: Effect of cropping system and different levels of fertilizers on the number of leaves of sole and intercrop maize at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A. Cropping system												
CV (%)	11.59	4.80	5.46	4.50	7.00	4.39	4.64	3.98	9.29	4.59	5.05	4.20
B. Different levels of fertilizers												
CV (%)	8.16	7.04	5.67	5.08	6.05	5.20	5.03	6.06	7.10	6.12	5.35	5.57

Table 1.3.: Effect of cropping system and different levels of fertilizers on the leaf area index of sole and intercrop maize at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A. Cropping system												
CV (%)	13.57	5.00	6.28	7.94	7.30	5.26	5.76	5.13	10.44	5.13	6.02	6.54
B. Different levels of fertilizers												
CV (%)	19.70	5.96	6.83	7.60	17.81	5.95	6.08	6.42	18.75	5.96	6.46	7.01

Table 1.4.: Effect of cropping system and different levels of fertilizers on the crop growth rate of sole and intercrop maize at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020			2021			Mean data		
	30-60 DAS	60-90 DAS	90DAS-At harvest	30-60DAS	60-90DAS	90DAS-At harvest	30-60DAS	60-90DAS	90DAS-At harvest
A. Cropping system									
CV (%)	8.14	6.15	13.42	7.80	6.48	16.81	7.97	6.32	15.12
B. Different levels of fertilizers									
CV (%)	5.00	5.90	14.04	5.02	6.01	16.36	5.01	5.95	15.20

Table 1.5.: Effect of cropping system and different levels of fertilizers on the shoot dry weight of sole and intercrop maize at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
A. Cropping system												
CV (%)	5.79	11.02	8.96	7.76	5.72	10.77	8.71	8.46	5.75	10.89	8.84	7.90
B. Different levels of fertilizers												
CV (%)	4.61	5.04	5.11	5.15	5.08	5.88	5.75	5.50	4.85	5.46	5.43	5.36

Table 1.6.: Effect of cropping system and different levels of fertilizers on the sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	Cob length(cm)			Cob diameter(cm)			No. of grains/cob		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	5.59	6.12	5.86	5.27	5.20	5.23	5.41	5.99	5.70
B. Different levels of fertilizers									
CV (%)	5.62	5.89	5.76	5.10	5.22	5.16	5.28	5.30	5.29

Table 1.7.: Effect of cropping system and different levels of fertilizers on the yield parameters of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	Cob weight(g)			No. of grain per row			No. of grain rows per cob		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	7.04	7.35	7.20	7.87	8.00	7.93	5.41	5.99	5.70
B. Different levels of fertilizers									
CV (%)	7.31	7.01	7.16	7.12	7.49	7.30	5.28	5.30	5.29

Table 1.8.: Effect of cropping system and different levels of fertilizers on the yield parameters of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	Test weight(g)			Straw yield (kg/ha)			Grain yield(kg/ha)		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	3.02	3.21	3.11	7.83	7.00	7.36	8.05	7.15	7.59
B. Different levels of fertilizers									
CV (%)	3.17	3.02	3.09	7.63	7.34	7.49	7.59	7.36	7.46

Table 1.9.: Effect of cropping system and different levels of fertilizers on the yield, harvest index and maize equivalent yield of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	Biological yield(kg/ha)			Harvest index (%)			Maize equivalent yield (kg/ha)		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	7.04	7.00	7.02	3.59	3.72	3.66	4.60	5.18	4.88
B. Different levels of fertilizers									
CV (%)	6.74	6.50	6.62	2.98	3.68	3.09	5.19	5.48	5.33

Table 1.10.: Effect of cropping system and different levels of fertilizers on the physicochemical properties of soil during the year (2020 and 2021) and Mean data.

Treatments	Organic carbon (%)			Available nitrogen(kg/ha)			Available phosphorous		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	0.71	0.60	0.65	5.76	6.49	6.12	5.40	5.30	5.34
B. Different levels of fertilizers									
CV (%)	0.89	0.54	0.72	5.00	5.01	5.00	5.55	5.14	5.30

Table 1.11.: Effect of cropping system and different levels of fertilizers on soil physicochemical properties of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	Available potassium(kg/ha)			EC (dS/m)			pH		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	7.24	5.98	5.42	5.92	5.94	5.93	1.74	1.70	1.72
B. Different levels of fertilizers									
CV (%)	5.80	10.41	8.11	9.63	9.71	9.67	1.69	1.67	1.69

Table 1.12.: Effect of cropping system and different levels of fertilizers on the FAW infestation on leaves, ear and kernel of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	FAW infestation on leaves			FAW infestation on Ear			FAW infestation on kernel		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system									
CV (%)	5.20	5.37	5.44	5.99	5.83	5.79	6.92	7.41	7.16
B. Different levels of fertilizers									
CV (%)	5.69	5.53	5.40	5.70	6.39	5.85	5.41	5.02	5.21

2.MUNGBEAN

Table 2.1.: Effect of cropping system and different levels of fertilizers on the plant height (cm) of sole and intercrop mungbean at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A. Cropping system												
CV (%)	5.86	6.59	5.59	6.51	5.67	5.52	5.47	6.48	5.77	5.64	5.37	6.50
B. Different levels of fertilizers												
CV (%)	6.36	8.87	7.52	7.48	6.24	5.19	7.88	7.49	6.30	7.03	7.70	7.48

Table 2.2.: Effect of cropping system and different levels of fertilizers on the number of leaves of sole and intercrop mungbean at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A. Cropping system												
CV (%)	5.54	5.07	11.96	5.97	6.81	5.11	6.11	6.27	5.42	5.09	7.01	6.12
B. Different levels of fertilizers												
CV (%)	8.28	7.43	6.80	9.05	7.39	5.28	8.68	8.65	7.06	6.36	7.74	8.85

Table 2.3.: Effect of cropping system and different levels of fertilizers on the no. of branches/plant of sole and intercrop mungbean at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A. Cropping system												
CV (%)	5.27	5.43	5.22	5.11	5.53	6.99	5.38	6.07	5.40	6.21	5.30	5.59
B. Different levels of fertilizers												
CV (%)	7.24	14.70	5.61	7.68	9.45	13.90	6.87	8.73	8.35	14.30	6.24	8.20

Table 2.4.: Effect of cropping system and different levels of fertilizers on the leaf area (cm²) of sole and intercrop mungbean at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A. Cropping system												
CV (%)	6.33	6.31	8.04	6.30	6.40	5.15	5.87	5.04	6.36	5.73	6.95	5.67
B. Different levels of fertilizers												
CV (%)	5.93	6.62	7.03	7.42	11.09	7.23	10.22	5.11	8.51	6.93	8.63	6.27

Table 2.5.: Effect of cropping system and different levels of fertilizers on the leaf area index of sole and intercrop mungbean at all observation stages during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest	20DAS	40DAS	60DAS	At harvest
A. Cropping system												
CV (%)	12.60	6.56	7.05	4.77	6.17	5.55	5.29	5.32	9.39	6.05	6.17	5.41
B. Different levels of fertilizers												
CV (%)	7.83	5.40	7.15	7.64	12.14	7.43	7.05	7.70	9.98	6.41	7.10	7.47

Table 2.6.: Effect of cropping system and different levels of fertilizers on the yield parameters of sole and intercrop mungbean during the year (2020 and 2021) and Mean data.

Treatments	No. of pods/plant			No. of seed/pod			Pod length(cm)			Test weight(g)		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system												
CV (%)	7.92	7.80	7.86	3.72	3.56	3.64	2.51	3.44	2.98	3.25	3.80	3.52
B. Different levels of fertilizers												
CV (%)	6.99	7.01	7.00	4.06	4.55	4.31	3.28	3.35	3.31	5.06	5.48	5.27

Table 2.7.: Effect of cropping system and different levels of fertilizers on the yield and harvest index of sole and intercrop mungbean during the year (2020 and 2021) and Mean data.

Treatments	Seed yield(kg/ha)			Straw yield(kg/ha)			Biological yield(kg/ha)			Harvest index (%)		
	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data	2020	2021	Mean data
A. Cropping system												
CV (%)	7.96	7.61	7.76	7.43	8.12	7.77	7.38	7.94	7.37	2.00	2.50	2.25
B. Different levels of fertilizers												
CV (%)	8.02	7.58	7.81	7.00	7.51	7.25	6.72	7.21	6.86	3.29	3.96	3.63

3.WHEAT

Table 3.1.: Effect of crop residues and different levels of fertilizers on the plant height(cm) of wheat at all observation stages during the year (2020-21 and 2021-22) and Mean data.

Treatments	2020-21					2021-22					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At harvest
A. Crop residues															
CV (%)	6.63	5.85	5.65	6.99	5.57	6.32	5.19	7.57	7.26	8.28	6.47	9.09	5.52	6.61	7.12
B. Different levels of fertilizers															
CV (%)	6.30	5.10	4.65	5.40	5.62	5.68	5.16	5.70	5.97	6.03	5.99	2.34	5.13	5.17	5.69

Table 3.2.: Effect of crop residues and different levels of fertilizers on the number of leaves of wheat at all observation stages during the year (2020-21 and 2021-22) and Mean data.

Treatments	2020-21					2021-21					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At harvest
A. Crop residues															
CV (%)	8.23	5.08	7.95	7.83	9.15	6.57	5.31	8.65	8.47	8.03	7.40	5.19	8.30	8.15	8.59
B. Different levels of fertilizers															
CV (%)	7.26	5.16	6.76	7.28	8.96	5.12	6.18	7.01	8.37	8.57	6.19	5.67	6.88	7.82	8.76

Table 3.3.: Effect of crop residues and different levels of fertilizers on the leaf area (cm²) of wheat at all observation stages during the year (2020-21 and 2021-22) and Mean data.

Treatments	2020-21					2021-22					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest
A. Cropping residues															
CV (%)	5.79	4.34	5.36	9.10	9.11	7.68	4.57	6.14	11.97	8.50	6.73	4.45	5.75	10.53	8.80
B. Different levels of fertilizers															
CV (%)	4.61	4.71	4.36	8.72	8.73	6.28	5.10	5.01	10.48	11.72	5.44	4.90	6.86	9.60	10.22

Table 3.4.: Effect of crop residues and different levels of fertilizers on the leaf area index of wheat at all observation stages during the year (2020-21 and 2021-22) and Mean data.

Treatments	2020-21					2021-22					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At harvest
A. Crop residues															
CV (%)	8.01	6.76	7.26	9.10	10.01	7.69	6.67	7.08	11.12	9.10	7.85	6.71	7.17	10.11	10.18
B. Different levels of fertilizers															
CV (%)	7.80	6.27	5.60	8.72	9.21	7.69	6.48	5.75	9.21	8.72	7.75	6.37	5.68	8.97	9.10

Table 3.5.: Effect of crop residues and different levels of fertilizers on the yield parameters of wheat during the year (2020-21 and 2021-22) and Mean data.

Treatments	No. of grains/spike			Spike length(cm)			Test weight (g)			No. of effective tillers/m ²		
	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data
A. Crop residues												
CV (%)	8.00	7.45	7.73	8.81	8.23	8.52	3.23	3.49	3.34	8.34	8.29	8.32
B. Different levels of fertilizers												
CV (%)	6.62	7.23	6.96	7.79	7.16	7.48	3.26	3.52	3.35	7.01	7.11	7.06

Table 3.6.: Effect of crop residues and different levels of fertilizers on the yield and harvest index of wheat during the year (2020-21 and 2021-22) and Mean data.

Treatments	Grain yield(kg/ha)			Straw yield(kg/ha)			Biological yield(kg/ha)			Harvest index (%)		
	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data
A. Crop residues												
CV (%)	7.04	7.16	7.10	7.23	7.19	7.21	7.36	6.01	6.16	3.65	2.26	2.95
B. Different levels of fertilizers												
CV (%)	7.10	7.39	7.23	7.09	7.91	7.50	6.90	7.96	7.20	2.94	3.97	3.46

Table 3.7.: Effect of cropping system and different levels of fertilizers on the physicochemical properties of soil during the year (2020-21 and 2021-22) and Mean data.

Treatments	Organic carbon (%)			Available nitrogen(kg/ha)			Available phosphorous)		
	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data
A. Cropping system									
CV (%)	1.02	0.86	0.94	6.02	5.98	6.00	6.47	5.62	6.02
B. Different levels of fertilizers									
CV (%)	0.88	0.81	0.85	5.05	5.40	5.23	5.31	5.34	5.27

Table 3.8.: Effect of cropping system and different levels of fertilizers on soil physicochemical properties during the year (2020-21 and 2021-22) and Mean data.

Treatments	Available potassium(kg/ha)			EC (dS/m)			pH		
	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data	2020-21	2021-22	Mean data
A. Cropping system									
CV (%)	7.48	5.21	6.35	5.92	5.94	5.93	1.73	1.70	1.71
B. Different levels of fertilizers									
CV (%)	5.84	9.61	7.72	9.63	9.71	9.67	1.69	1.67	1.68

APPENDICES-D.2: Coefficient of variance (CV) for the interaction between cropping system, crop residues and different levels of fertilizers on the growth and yield of maize + mungbean and wheat cropping system.

1.MAIZE

Table 1.1.: Interaction between cropping system and different levels of fertilizers on the growth parameters of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
Plant height(cm)												
CV (%)	13.35	7.60	6.00	6.13	9.90	6.36	5.92	5.00	11.62	6.96	5.98	5.55
No. of leaves												
CV (%)	8.16	7.04	5.67	5.08	6.05	5.20	5.03	6.06	7.10	6.12	5.35	5.57
Leaf area index												
CV (%)	19.70	5.96	6.83	7.60	17.81	5.95	6.08	6.42	18.75	5.96	6.46	7.01
Shoot dry weight (g)												
CV (%)	4.61	5.04	5.11	5.15	5.08	5.88	5.75	5.50	4.85	5.46	5.43	5.36

Table 1.2.: Interaction between cropping system and different levels of fertilizers on the crop growth rate of sole and intercrop maize during the year (2020 and 2021) and Mean data.

2020				2021			Mean data		
	30-60 DAS	60-90 DAS	90 DAS- at harvest	30-60 DAS	60-90 DAS	90 DAS- at harvest	30-60 DAS	60-90 DAS	90 DAS- at harvest
Crop growth rate(g/m²/day)									
CV (%)	5.00	5.90	14.04	5.02	6.01	16.36	5.01	5.95	15.20

Table 1.3.: Interaction between cropping system and different levels of fertilizers on the yield and yield parameters of sole and intercrop maize during the year (2020 and 2021) and Mean data.

Cob length(cm)				Cob diameter (cm)				No. of grains/cob			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	5.62	5.89	5.76		5.10	5.22	5.16		5.28	5.30	5.29
Cob weight(g)				No. of grain per row				No. of grain rows per cob			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	7.31	7.01	7.16		7.12	7.49	7.30		5.28	5.30	5.29
Test weight(g)				Straw yield(kg/ha)				Grain yield(kg/ha)			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	3.17	3.02	3.09		7.63	7.34	7.49		7.59	7.36	7.46
Biological Yield(kg/ha)				Harvest index (%)				Maize equivalent yield(kg/ha)			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	6.74	6.50	6.62		2.98	3.68	3.09		5.19	5.48	5.33

Table 1.4.: Interaction between cropping system and different levels of fertilizers on the physicochemical properties of soil during the year (2020 and 2021) and Mean data.

pH				Organic carbon (%)				EC (dS/m)			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	1.69	1.67	1.69		0.89	0.54	0.72		9.63	9.71	9.67
Available nitrogen(kg/ha)				Available phosphorous(kg/ha)				Available potassium(kg/ha)			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	5.00	5.01	5.00		5.55	5.14	5.30		5.80	10.41	8.11

Table 1.5.: Interaction between cropping system and different levels of fertilizers on the FAW infestation in leaves, ear, and kernel of sole and intercrop maize during the year (2020 and 2021) and Mean data.

FAW infestation on leaves				FAW infestation on ear				FAW infestation on kernel			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	5.69	5.53	5.40		5.70	6.39	5.85		5.41	5.02	5.21

2.MUNGBEAN

Table 2.1.: Interaction between cropping system and different levels of fertilizers on the growth parameters of sole and intercrop mungbean during the year (2020 and 2021) and Mean data.

Treatments	2020				2021				Mean data			
	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest	30DAS	60DAS	90DAS	At harvest
Plant height(cm)												
CV (%)	6.36	8.87	7.52	7.48	6.24	5.19	7.88	7.49	6.30	7.03	7.70	7.48
No. of leaves												
CV (%)	8.28	7.43	6.80	9.05	7.39	5.28	8.68	8.65	7.06	6.36	7.74	8.85
No. of branches/plant												
CV (%)	7.24	14.70	5.61	7.68	9.45	13.90	6.87	8.73	8.35	14.30	6.24	8.20
Leaf area(cm ²)												
CV (%)	5.93	6.62	7.03	7.42	11.09	7.23	10.22	5.11	8.51	6.93	8.63	6.27
Leaf area index												
CV (%)	7.83	5.40	7.15	7.64	12.14	7.43	7.05	7.70	9.98	6.41	7.10	7.47

Table 2.2.: Interaction between cropping system and different levels of fertilizers on the yield and yield parameters of sole and intercrop maize during the year (2020 and 2021) and Mean data.

No. of pods/plant				No. of seeds/pod				Pod length(cm)			
CV(%)	2020	2021	Mean data	CV (%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	6.99	7.01	7.00		4.06	4.55	4.31		3.28	3.35	3.31
Test weight(g)				Straw yield(kg/ha)				Seed yield(kg/ha)			
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data
	5.06	5.48	5.27		7.00	7.51	7.25		8.02	7.58	7.81
Biological yield(kg/ha)				Harvest index (%)							
CV(%)	2020	2021	Mean data	CV(%)	2020	2021	Mean data				
	6.72	7.21	6.86		3.29	3.96	3.63				

3.WHEAT

Table 3.1.: Interaction between crop residues and different levels of fertilizers on the growth parameters of wheat during the year (2020-21 and 2021-22) and Mean data.

Treatments	2020-21					2021-22					Mean data				
	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At har-vest	30DAS	60DAS	90DAS	120DAS	At harvest
Plant height(cm)															
CV (%)	6.30	5.10	4.65	5.40	5.62	5.68	5.16	5.70	5.97	6.03	5.99	2.34	5.13	5.17	5.69
No. of leaves															
CV (%)	7.26	5.16	6.76	7.28	8.96	5.12	6.18	7.01	8.37	8.57	6.19	5.67	6.88	7.82	8.76
Leaf area(cm ²)															
CV (%)	4.61	4.71	4.36	8.72	8.73	6.28	5.10	5.01	10.48	11.72	5.44	4.90	6.86	9.60	10.22
Leaf area index															
CV (%)	7.80	6.27	5.60	8.72	9.21	7.69	6.48	5.75	9.21	8.72	7.75	6.37	5.68	8.97	9.10

Table 3.2.: Interaction between crop residues and different levels of fertilizers on the yield and yield parameters of wheat during the year (2020-21 and 2021-22) and Mean data.

No. of grains/spike				Spike length(cm)				Test weight(g)			
CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data
	6.62	7.23	6.96		7.79	7.16	7.48		3.26	3.52	3.35
No. of effective tillers/m ²				Straw yield(kg/ha)				Grain yield(kg/ha)			
CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data
	7.01	7.11	7.06		7.09	7.91	7.50		7.10	7.39	7.23
Biological Yield(kg/ha)				Harvest index (%)							
CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data				
	6.90	7.96	7.20		2.94	3.97	3.46				

Table 3.3.: Interaction between crop residues and different levels of fertilizers on the physicochemical properties of soil during the year (2020-21 and 2021-22) and Mean data.

pH				Organic carbon (%)				EC (dS/m)			
CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data
	1.69	1.67	1.68		0.88	0.81	0.85		9.63	9.71	9.67
Available nitrogen(kg/ha)				Available phosphorous(kg/ha)				Available potassium(kg/ha)			
CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data	CV(%)	2020-21	2021-22	Mean data
	5.05	5.40	5.23		5.31	5.34	5.27		5.84	9.61	7.72

APPENDICES-D.3: Impact of cropping system, crop residues and different levels of fertilizers on the NPK concentrations in both the grain and straw of maize-mungbean and wheat cropping systems.

1.Maize

Table 1.1.: Impact of cropping system and different fertilizer levels on the nitrogen concentration in both sole and intercropped maize straw and grain.

Treatments	2020		2021		Mean data	
	Nitrogen (%)		Nitrogen (%)		Nitrogen (%)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M ₁	0.537	1.409	0.542	1.499	0.540	1.454
M ₃	0.487	1.316	0.522	1.382	0.505	1.349
SEM (±)	0.020	0.065	0.038	0.069	0.029	0.067
CD(P=0.05)	NS	NS	NS	NS	NS	NS
B- Different levels of fertilizer						
S ₁	0.403 ^b	1.159 ^c	0.410 ^c	1.249 ^b	0.406 ^c	1.204 ^b
S ₂	0.447 ^b	1.255 ^b	0.479 ^{bc}	1.355 ^b	0.463 ^{bc}	1.305 ^b
S ₃	0.530 ^b	1.229 ^b	0.574 ^{ab}	1.289 ^b	0.552 ^{ab}	1.259 ^b
S ₄	0.668 ^a	1.806 ^a	0.666 ^a	1.779 ^a	0.667 ^a	1.793 ^a
SEM (±)	0.043	0.072	0.047	0.074	0.044	0.073
CD(P=0.05)	0.132	0.225	0.146	0.228	0.135	0.226

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₁=Maize(sole), M₃=Maize + Mungbean (intercropping), S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

Table 1.2.: Impact of cropping system and different fertilizer levels on the phosphorous concentration in both sole and intercropped maize straw and grain.

Treatments	2020		2021		Mean data	
	Phosphorous (%)		Phosphorous (%)		Phosphorous (%)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M ₁	0.292 ^a	0.473	0.289 ^a	0.504	0.291 ^a	0.489
M ₃	0.233 ^b	0.438	0.246 ^b	0.461	0.240 ^b	0.450
SEM (±)	0.007	0.019	0.006	0.020	0.007	0.019
CD(P=0.05)	0.045	NS	0.038	NS	0.041	NS
B- Different levels of fertilizer						
S ₁	0.179 ^d	0.399 ^b	0.181 ^c	0.414 ^c	0.180 ^c	0.407 ^b
S ₂	0.295 ^b	0.458 ^b	0.300 ^{ab}	0.490 ^b	0.297 ^a	0.474 ^b
S ₃	0.264 ^c	0.416 ^b	0.270 ^b	0.447 ^{bc}	0.267 ^b	0.432 ^b
S ₄	0.312 ^a	0.548 ^a	0.321 ^a	0.579 ^a	0.316 ^a	0.564 ^a
SEM (±)	0.007	0.022	0.006	0.023	0.007	0.022
CD(P=0.05)	0.023	0.068	0.034	0.072	0.028	0.070

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₁=Maize(sole), M₃=Maize + Mungbean (intercropping), S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

Table 1.3.: Impact of cropping system and different fertilizer levels on the potassium concentration in both sole and intercropped maize straw and grain.

Treatments	2020		2021		Mean data	
	Potassium (%)		Potassium (%)		Potassium (%)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M ₁	2.013 ^a	0.398	1.992 ^a	0.421	2.002 ^a	0.410
M ₃	1.534 ^b	0.412	1.611 ^b	0.433	1.573 ^b	0.423
SEM (±)	0.045	0.015	0.039	0.007	0.042	0.019
CD(P=0.05)	0.273	NS	0.240	NS	0.255	NS
B- Different levels of fertilizer						
S ₁	1.492 ^c	0.335 ^b	1.495 ^d	0.352 ^b	1.493 ^c	0.344 ^b
S ₂	1.767 ^b	0.429 ^a	1.867 ^b	0.457 ^a	1.817 ^b	0.443 ^a
S ₃	1.774 ^b	0.401 ^a	1.760 ^c	0.435 ^a	1.767 ^b	0.418 ^a
S ₄	2.060 ^a	0.455 ^a	2.082 ^a	0.464 ^a	2.071 ^a	0.459 ^a
SEM (±)	0.052	0.018	0.054	0.021	0.053	0.019
CD(P=0.05)	0.160	0.054	0.165	0.066	0.162	0.060

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₁=Maize(sole), M₃=Maize + Mungbean (intercropping), S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

2.MUNGBEAN

Table 2.1.: Impact of cropping system and different fertilizer levels on the nitrogen concentration in both sole and intercropped mungbean straw and grain.

Treatments	2020		2021		Mean data	
	Nitrogen (%)		Nitrogen (%)		Nitrogen (%)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M ₂	0.480 ^a	4.177	0.465 ^a	4.176	0.472 ^a	4.173
M ₃	0.265 ^b	3.967	0.275 ^b	3.981	0.270 ^b	3.973
SEM (±)	0.011	0.111	0.011	0.105	0.011	0.107
CD(P=0.05)	0.067	NS	0.065	NS	0.066	NS
B- Different levels of fertilizer						
S ₁	0.254 ^c	3.435 ^c	0.263 ^c	3.447 ^c	0.258 ^c	3.441 ^b
S ₂	0.409 ^b	4.447 ^a	0.395 ^b	4.408 ^a	0.402 ^b	4.427 ^a
S ₃	0.287 ^c	4.332 ^b	0.290 ^c	4.435 ^a	0.288 ^c	4.383 ^a
S ₄	0.540 ^a	4.073 ^{ab}	0.532 ^a	4.023 ^b	0.536 ^a	4.048 ^a
SEM (±)	0.013	0.122	0.014	0.116	0.014	0.110
CD(P=0.05)	0.040	0.375	0.044	0.357	0.042	0.339

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₂=Mungbean(sole), M₃=Maize + Mungbean (intercropping), S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

Table 2.2.: Impact of cropping system and different fertilizer levels on the phosphorous concentration in both sole and intercropped mungbean straw and grain.

Treatments	2020		2021		Mean data	
	Phosphorous (%)		Phosphorous (%)		Phosphorous (%)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M ₂	0.078 ^a	0.533 ^a	0.079 ^a	0.561 ^a	0.078 ^a	0.547 ^a
M ₃	0.035 ^b	0.441 ^b	0.037 ^b	0.463 ^b	0.036 ^b	0.452 ^b
SEM (±)	0.003	0.006	0.004	0.003	0.003	0.004
CD(P=0.05)	0.019	0.035	0.022	0.019	0.020	0.027
B- Different levels of fertilizer						
S ₁	0.027 ^d	0.298 ^c	0.029 ^d	0.315 ^c	0.028 ^d	0.307 ^c
S ₂	0.062 ^b	0.575 ^a	0.063 ^b	0.608 ^a	0.063 ^b	0.592 ^a
S ₃	0.049 ^c	0.460 ^b	0.050 ^c	0.489 ^b	0.050 ^c	0.474 ^b
S ₄	0.087 ^a	0.615 ^a	0.090 ^a	0.636 ^a	0.088 ^a	0.626 ^a
SEM (±)	0.003	0.015	0.003	0.013	0.003	0.014
CD(P=0.05)	0.008	0.047	0.010	0.042	0.009	0.045

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₂=Mungbean(sole), M₃=Maize + Mungbean (intercropping), S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

Table 2.3.: Impact of cropping system and different fertilizer levels on the potassium concentration in both sole and intercropped mungbean straw and grain.

Treatments	2020		2021		Mean data	
	Potassium (%)		Potassium (%)		Potassium (%)	
	Straw	Grain	Straw	Grain	Straw	Grain
A - Cropping System						
M ₂	0.351 ^a	1.200	0.338 ^a	1.180	0.344 ^a	1.189
M ₃	0.194 ^b	1.238	0.200 ^b	1.217	0.197 ^b	1.227
SEM (±)	0.006	0.018	0.006	0.012	0.006	0.015
CD(P=0.05)	0.037	NS	0.034	NS	0.035	NS
B- Different levels of fertilizer						
S ₁	0.192 ^c	0.878 ^c	0.199 ^d	0.869 ^c	0.196 ^c	0.873 ^c
S ₂	0.312 ^a	1.419 ^a	0.303 ^b	1.393 ^a	0.307 ^a	1.405 ^a
S ₃	0.247 ^b	1.214 ^b	0.239 ^c	1.198 ^b	0.243 ^b	1.206 ^b
S ₄	0.339 ^a	1.366 ^a	0.335 ^a	1.334 ^a	0.337 ^a	1.350 ^a
SEM (±)	0.010	0.036	0.008	0.033	0.009	0.032
CD(P=0.05)	0.032	0.109	0.028	0.103	0.030	0.106

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₂=Mungbean(sole), M₃=Maize + Mungbean (intercropping), S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

3.WHEAT

Table 3.1.: Impact of crop residues and different fertilizers levels on the nitrogen concentration in wheat straw and grain.

Treatments	2020-2021		2021-2022		Mean data	
	Nitrogen (%)		Nitrogen (%)		Nitrogen (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
A. Residual effect of crops						
M₁	1.320 ^c	0.537	1.419 ^b	0.567 ^a	1.367 ^b	0.552 ^a
M₂	1.612 ^a	0.497	1.673 ^a	0.499 ^b	1.643 ^a	0.496 ^b
M₃	1.447 ^b	0.482	1.534 ^b	0.502 ^b	1.491 ^b	0.492 ^b
SEM (±)	0.028	0.012	0.044	0.014	0.034	0.012
CD(P=0.05)	0.109	NS	0.175	0.054	0.135	0.046
B. Different levels of fertilizer						
S₁	1.271 ^b	0.495	1.319 ^c	0.516	1.295 ^c	0.506
S₂	1.418 ^b	0.511	1.484 ^b	0.526	1.451 ^b	0.519
S₃	1.353 ^b	0.493	1.422 ^{bc}	0.519	1.388 ^{bc}	0.506
S₄	1.796 ^a	0.522	1.943 ^a	0.529	1.869 ^a	0.526
SEM (±)	0.040	0.010	0.044	0.012	0.038	0.010
CD(P=0.05)	0.119	NS	0.130	NS	0.114	NS

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₁=Residual effect of maize on wheat, M₂= residual effect of mungbean on wheat, M₃=Residual effect of Maize+ Mungbean intercrop on wheat, S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

Table 3.2.: Impact of crop residues and different fertilizers levels on the phosphorous concentration in wheat straw and grain.

Treatments	2020-2021		2021-2022		Mean data	
	Phosphorous (%)		Phosphorous (%)		Phosphorous (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
A. Residual effect of crops						
M ₁	0.136	0.074 ^a	0.137	0.073 ^a	0.136	0.073 ^a
M ₂	0.140	0.064 ^b	0.136	0.060 ^b	0.138	0.062 ^b
M ₃	0.138	0.065 ^b	0.137	0.063 ^b	0.137	0.064 ^b
SEM (±)	0.003	0.002	0.004	0.002	0.003	0.002
CD(P=0.05)	NS	0.007	NS	0.010	NS	0.009
B. Different levels of fertilizer						
S ₁	0.122 ^c	0.054 ^b	0.118 ^c	0.053 ^c	0.120 ^c	0.054 ^c
S ₂	0.142 ^b	0.077 ^a	0.139 ^b	0.073 ^a	0.141 ^b	0.075 ^a
S ₃	0.132 ^{bc}	0.060 ^a	0.129 ^{bc}	0.059 ^b	0.131 ^{bc}	0.060 ^b
S ₄	0.157 ^a	0.079 ^a	0.160 ^a	0.077 ^a	0.158 ^a	0.078 ^a
SEM (±)	0.003	0.001	0.004	0.002	0.003	0.001
CD(P=0.05)	0.010	0.002	0.012	0.005	0.011	0.003

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M1=Residual effect of maize on wheat, M2= residual effect of mungbean on wheat, M3=Residual effect of Maize+ Mungbean intercrop on wheat, S1=Control, S2= 100% RDF, S3=100% Nano NPK fertilizers, S4=50% RDF+ 50% Nano NPK fertilizers.

Table 3.3.: Impact of crop residues and different levels of fertilizers on the potassium concentration in wheat straw and grain.

Treatments	2020-2021		2021-2022		Mean data	
	Potassium (%)		Potassium (%)		Potassium (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
A. Residual effect of crops						
M₁	0.465	1.306 ^a	0.467	1.303 ^a	0.465	1.304 ^a
M₂	0.489	1.131 ^b	0.474	1.082 ^b	0.481	1.102 ^b
M₃	0.468	1.127 ^b	0.464	1.108 ^b	0.466	1.117 ^b
SEM (±)	0.009	0.035	0.014	0.031	0.011	0.031
CD(P=0.05)	NS	0.139	NS	0.120	NS	0.121
B. Different levels of fertilizer						
S₁	0.407 ^c	1.035 ^d	0.394 ^c	0.990 ^c	0.401 ^c	1.007 ^d
S₂	0.461 ^b	1.233 ^b	0.450 ^b	1.214 ^b	0.455 ^b	1.223 ^b
S₃	0.434 ^c	1.171 ^c	0.425 ^{bc}	1.167 ^b	0.430 ^{bc}	1.169 ^c
S₄	0.594 ^a	1.313 ^a	0.603 ^a	1.285 ^a	0.599 ^a	1.299 ^a
SEM (±)	0.013	0.019	0.013	0.021	0.012	0.018
CD(P=0.05)	0.037	0.058	0.040	0.061	0.035	0.053

Means followed by different letters (a, b, c, d) are statically different at 0.05%, S=Significant, NS= Non-significant, SEM (±) = Standard error mean, CD= Critical difference, RDF=recommended dose of fertilizer, M₁=Residual effect of maize on wheat, M₂= residual effect of mungbean on wheat, M₃=Residual effect of Maize+ Mungbean intercrop on wheat, S₁=Control, S₂= 100% RDF, S₃=100% Nano NPK fertilizers, S₄=50% RDF+ 50% Nano NPK fertilizers.

PHOTO GALLERY

1) FIELD WORK

A) Maize and mungbean cropping (2020) *kharif* season



Fig.1: Harrowing of field



Fig.2: Tractor drawn planking



Fig3: Preparation of bunds.



Fig.3: Demarcation of plot



Fig.4: Preparation of bunds



Fig.5: Application of NPK fertilizers



Fig.6: Experimental plot



Fig.7: Sowing of seeds



Fig.8: Germination of crop



Fig.10: Irrigated field



Fig.11: Gap filling



Fig.12: Spraying of nanofertilizers



Fig.13: Irrigated field.



Fig.16: Spraying of nanofertilizers



Fig.17: Intercropping field.



Fig.18: Control plot at 30DAS



Fig 19: 50% RDF +50% Nano NPK treated plot



Fig.20: Intercropping plot at 30DAS.



Fig. 20: Control plot at 30DAS



Fig.21: 100% Nano NPK treated plot at 30DAS.



Fig.22, 23 and 24 : Flowering of mungbean



Fig.25: Control plot



Fig.26: 100% RDF treated plot



Fig.27: 100% Nano NPK fertilizer treated plot



Fig.28: 50% RDF +50% Nano NPK fertilizers treated plot



Fig.29: Control plot



Fig.30: 100% RDF treated plot.



Fig.31: 100% Nano NPK treated plot



Fig.32: 50% RDF+50% Nano NPK treated plot



Fig.33: Silking of maize



Fig.34 and 35: Cob development of maize



Fig.36: Recording of data



Fig.37 and 38: Field at 90DAS



Fig.39



Fig.40



Fig.41



Fig. 42



Fig.43

Fig.39-43: Pod development of mungbean



Fig.44, 45 and 46: Harvesting of maize.



Fig. 47: Drying of stover yield



Fig 48: Recording of stover yield



Fig.49: Drying of maize cobs



Fig.50: Harvesting of mungbean



Fig.51: Drying of mungbean stover



Fig.52:Threshing of munbean



Fig. 53, 54, 55 and 56: Mungbean pods and seeds.

B. Wheat (*rabi* season)



Fig.1: Spacing of Field



Fig.2: Line Sowing



Fig.3: Germination of wheat.



Fig. 4: First Irrigation



Fig.5: Irrigated field



Fig.6: Wheat field at 21 DAS



Fig.7: Foliar spraying of nanofertilizers



Fig.8 and 9: Weeding of wheat field



Fig.10: Field at 30DAS



Fig.11: Tillering stage



Fig.12 and 13: Panicle initiation stage



Fig 14 and 15: Field at 90DAS



Fig 16: Field at 120DAS



Field 17: Recording of reading at 120DAS.



Fig.18, 19 and 20: Harvesting of wheat.



Fig 21: Drying of wheat harvest



Fig 22: Wheat straw



Fig.23: Measuring of wheat biological yield



Fig.24, 25 and 26: Threshing of wheat

C)Maize and Mungbean (2021) *kharif* season



Fig. 1: Preparation of field for demarcation of plots



Fig..2: Levelling and bund preparation



Fig. 3: Experimental field



Fig. 4: Sowing of seeds.

A. Maize 2021(*kharif*)



Fig.5: Pre-treated maize seeds



Fig. 6: Germination of crop



Fig. 7: Spraying of nanofertilizers.



Fig.8: Control plot at 30DAS



Fig.9: 100% RDF treated plot at 30DAS.



Fig.10: 100% Nano NPK treated plot at 30DAS.



Fig.11: 50% RDF+50% Nano NPK treated plot at 60DAS.



Fig.12: Foliar spraying of nanofertilizers



Fig.13: Tasseling in maize.



Fig.14: Control plot tasseling



Fig.15: 100 % RDF treated plot



Fig.16:100% Nano NPK treated plot



Fig.17: 50% RDF +50% Nano NPK treated plot



Fig.18: Silking of maize



Fig.19 and 20: Pod development



Fig.21, 22 and 23: Plot at 95 DAS



Fig. 24



Fig.25



Fig.26



Fig.27



Fig.28



Fig.29

Fig.24-29: Harvesting of maize crop



Fig.30 and Fig.31: Drying of maize stover.



Fig.32: Measuring of biological yield using weighing balance



Fig.33: Recording of harvest data.



Fig. 34



Fig. 35



Fig.36



Fig.37

Fig.34, 35, 36 and 37: Recording of harvest data

B) Mungbean 2021(*kharif*)



Fig.1: Mungbean at 15DAS (control plot)



Fig.2: Mungbean at 15 DAS (treated plot)



Fig.3: Intercrop mungbean at 15DAS



Fig.4: Recording of data at 20 DAS (control intercrop plot)



Fig.5: Mungbean at 20DAS



Fig. 6 and 7: Data collection and field scouting



Fig.8: Weeding of the field



Fig.9, 10 and 11: Flowering of mungbean



Fig.12: 30DAS interop field (control)



Fig.13: 100% RDF treated plot (maize +mungbean)



Fig.14: 100% Nano NPK treated plot (maize +mungbean)



Fig.15 : 50% RDF +50% Nano NPK treated plot



Fig.16



Fig. 17



Fig.18



Fig.19



Fig.20



Fig.21

Fig.16-21: Pod development of mungbean



Fig.22: View of field



Fig.23: Drying of mungbean stover



Fig.24 and 25: Weighing of mungbean stover



Fig.26: Mungbean seeds

C)Wheat *rabi* (2021-2022)



Fig.1: Field preparation

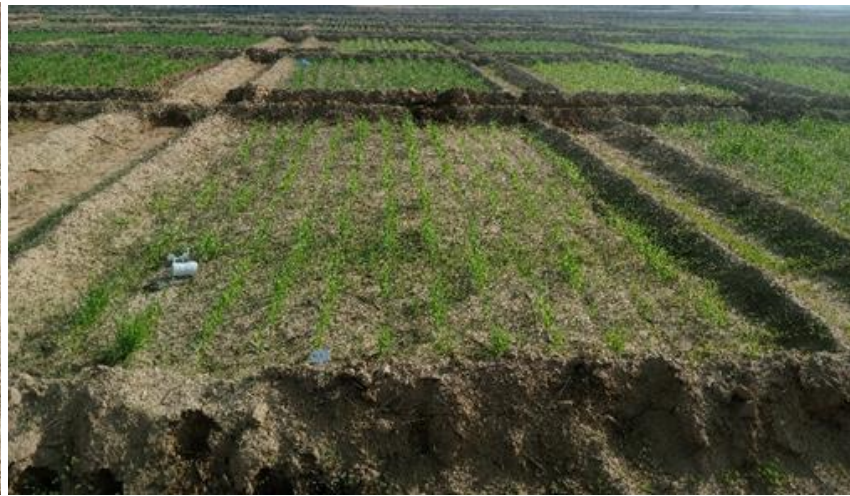


Fig.2: Germination of wheat



Fig.3: Foliar application of nanofertilizers



Fig.4: Irrigated field



Fig.5: Field at 60DAS (tillering stage)



Fig.6: Data collection at 60DAS



Fig.7: Panicle initiation stage



Fig.8 :Data collection



Fig.9 and 10: Field at 90 DAS

Fig.10: Field at 95 DAS



Fig.11 and Fig.12: Plot at 120 DAS



Fig.13, 14 and 15: Harvesting of wheat.



Fig 16, 17 and 18: Collection and drying of wheat harvest.



Fig.19: Drying of wheat harvest



Fig.20 and 22: Recording of biological yield of wheat using weighing balance.



Fig.23 and 24: Threshing of wheat harvest .



Fig 25:Wheat grain after threshing.

D) Effect of Nanofertilizers on fall armyworm (FAW) infestation



Fig 1and 2: Extensive foliage damage

Fig.3: Whorl damage with excreta



Fig.4: Eggs of fall armyworm



Fig.5 and 6: Larvae of fall armyworm



Fig.7: Scraping of leaves



Fig.8 and 9 Extensive foliage and whorl damage



Fig.10: Kernel damage



Fig. 11: Emamectin Benzoate (5% SC)



Fig.12: Surfactant



Fig.13 and Fig. 14: Interaction with local farmer

2)LABORATORY WORK

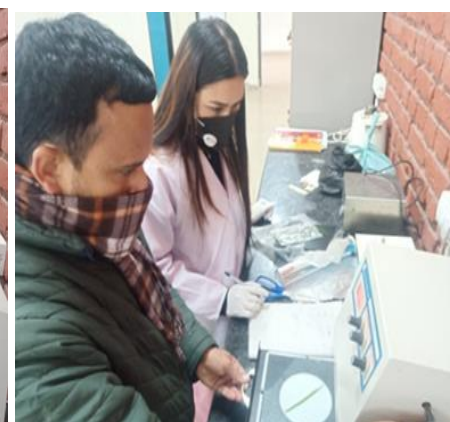


Fig.1-4: Estimation of leaf area using leaf area meter.



Fig.5: Measuring of shoot dry weight.



Fig.6 and 7: Digestion of grain and straw sample for estimation of total nitrogen



Fig.8:Distillation



Fig. 9:Titration



Fig.10:Titrated and non titrated sample



Fig.11 and 12: Digestion of seed and straw sample in hot plate.

Fig.13 and 14: Filtration of digested samples.

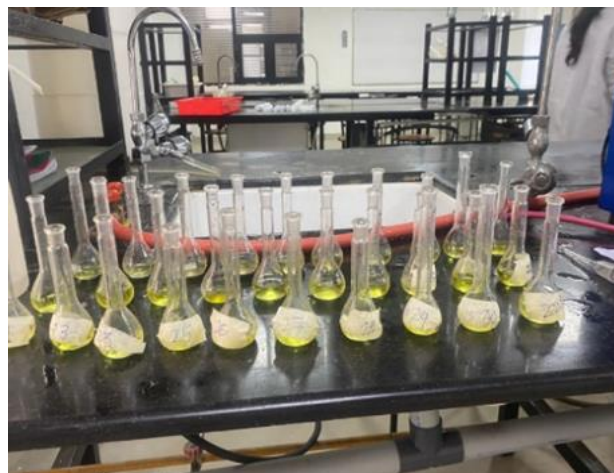


Fig.14, 15 and 16: Estimation of total phosphorous using spectrophotometer.

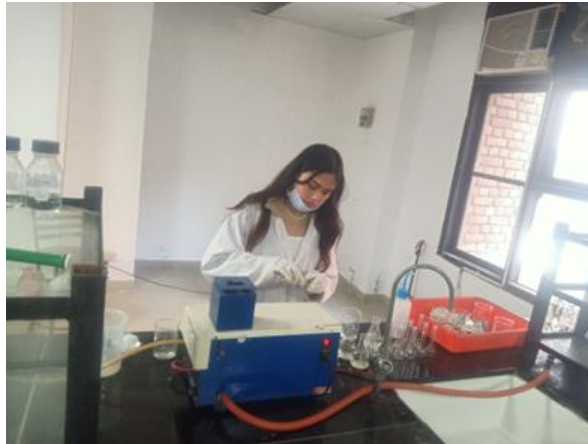


Fig 17, 18 and 19: Estimation of total potassium using flame photometer.



Fig.20: Soil samples.



Fig 21: Drying of soil samples.



Fig 22, 23 and 24: Drying and sieving of soil sample.



Fig.25 and 26: Estimation of soil EC using EC meter.



Fig. 27 and 28: Estimation of soil pH using PH meter.

Fig.29: Organic carbon testing in soil samples.



Fig.30: Titrated result of organic carbon estimation.



Fig.31: Mechanical shaking of soil.



Fig.32: Filtration of soil after mechanical shaking.



Fig.33, 34 and 35: Preparation and analysis of soil sample for estimation of available potassium using Flame photometer.



Fig.36, 37 and 38: Preparation and analysis of soil sample for estimation of available phosphorous using Spectrophotometer.

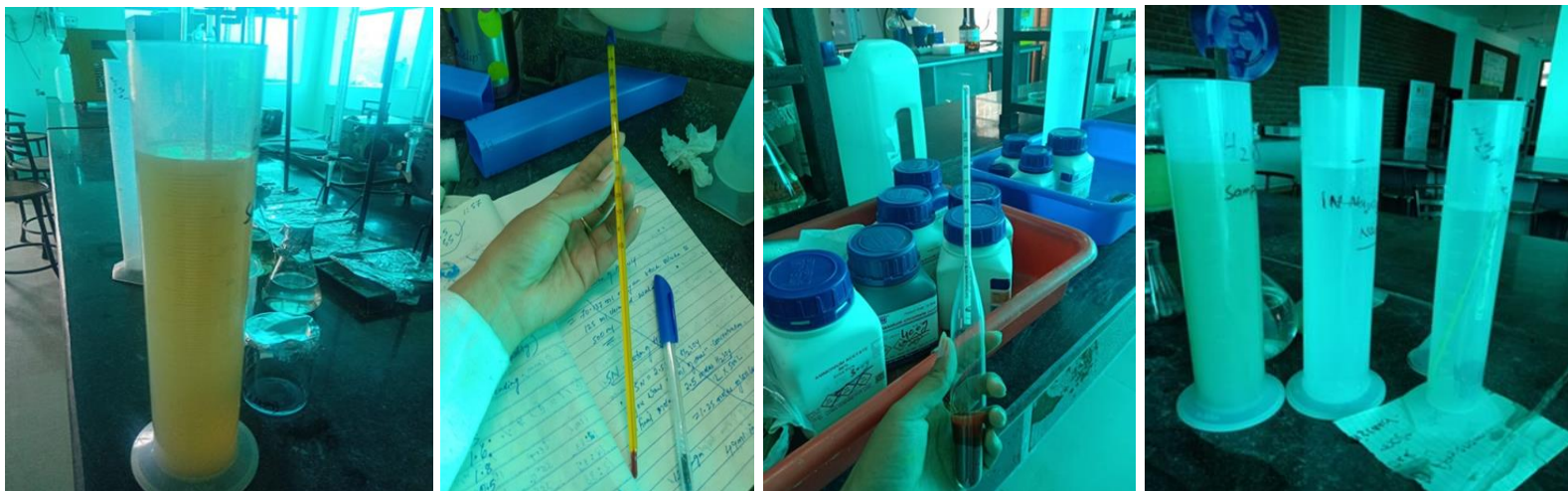


Fig.39, 40, 41 and 41: Analysis of soil sample for estimation of soil texture by using hydrometer.



Fig.42: Distillation and titration of soil sample for estimation of available nitrogen.

LISTS OF PUBLICATIONS

Book

- Identification of agronomic and horticultural weeds

Research Paper

- Effect of cadmium induced stress on morphological growth and yield of rice (*Oryza sativa* L.)
- Phytotoxic effect of cadmium induced stress on LAI, CGR, and Yield of Rice plant (*Oryza sativa* L.)
- Effect of Nano-NPK and chemical Fertilizers on the growth, yield attributes and yield of sole and intercrop maize in Punjab.
- Performance of mungbean as influenced by different levels of fertilizers and cropping systems in the Semi-arid region of India.
- Influence of different sources of fertilizers and weed control treatments on growth, phenology, and yield of baby corn (*Zea mays* L.) in the Semi-arid region of India.
- Ameliorative effects of waste decomposer and effective microorganisms on composting of paddy straw.

Review paper

- Impact of nanofertilizers on growth and yield parameters of rice crop; A Review

LISTS OF CONFERENCES

- Participation and Oral presentation in the International Web conference on " PERSPECTIVE ON AGRICULTURE AND APPLIED SCIENCES" in Covid-19 scenario (PAAS-2020).
- Participation and poster presentation in international web conference on Global Research Initiatives for Sustainable Agriculture and Allied Sciences (GRISAAS-2021) Punjab.
- Participation in International conference on "SMART AND SUSTAINABLE AGRICULTURE FOR FOOD SECURITY" (SSAFS-2022), Punjab
- Participation in International webinar on "ROLE OF NANOTECHNOLOGY IN CURRENT SCENARIO" 2021 Andhra Pradesh.
- Participation and Oral presentation in 3rd International conference on global initiatives in Agricultural, Forestry and applied sciences (GIAFAS-2021), Uttarakhand.
- Participation in "INTERNATIONAL CONFERENCE ON INNOVATION AND INTELLECTUAL PROPERTY RIGHTS" 2022.
- Participation and Poster Presentation in the 4th International Conference on Global Efforts in Agriculture, Forestry, Environment and Food security, 2022.
- Participation in 5th International conference on Advance in Agriculture International Conference on Advance in Agriculture Technology and Allied Sciences (ICAATAS-2022), Odisha.
- Participation and oral presentation in the international conference on "Recent trends in smart and sustainable agriculture for food security" 2022.

LISTS OF WORKSHOPS

- Participate in 15 days training cum-certificate Programme on trending Novel Technologies in Agriculture, Animal Husbandry, Fisheries science and their allied system-2023.
- Participation in 15 days International online training cum workshop 2021 organized by Agro Environmental Education and Farmer's welfare society, Punjab.