RESPONSE OF MAIZE TO INTEGRATED NUTRIENT MANAGEMENT AND ITS RESIDUAL EFFECT ON THE SUCCEEDING CHICKPEA IN MAIZE-CHICKPEA CROPPING SYSTEM IN CENTRAL PLAIN ZONE OF PUNJAB

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Agronomy

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Declaration

I hereby declare that the thesis entitled **"Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in maize-chickpea cropping system in central plain zone of Punjab"** submitted for **DOCTOR OF PHILOSOPHY IN AGRICULTURE (AGRONOMY)** to the School of Agriculture, Lovely Professional University is entirely original work and all ideas and references are duly acknowledged. The research work has not been formed the basis for the award of any other degree.

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CERTIFICATE I

This is to certify that the thesis entitled, **"Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in maize-chickpea cropping system in central plain zone of Punjab"** submitted in fulfillment of the requirement for the degree of **DOCTOR OF PHILOSOPHY (Ph.D.)** in the discipline of **AGRICULTURE (Agronomy)** embodies the results of a piece of bonafide research carried out by **Dipak Prakash Gite** under my guidance and supervision. To the best of my knowledge, the present work is the result of original investigation and study. No part of this thesis has ever been submitted for any other degree, diploma or equivalent course.

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CERTIFICATE II

This is to certify that the thesis **"Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in maize-chickpea cropping system in central plain zone of Punjab"** submitted by **Dipak Prakash Gite (Registration No. 12214016)** to the Lovely Professional University, Phagwara in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (Ph.D.)** in the discipline of **AGRICULTURE (AGRONOMY)** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an external examiner.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND SYMBOLS USED

Abbreviated Form	**Full Form**
%	Percentage
/	PER
@	At the rate
^0C	Degree Celsius
B:C	Benefit Cost ratio
C.D.	Critical difference
cfu	Colony forming units
cm	Centimeter (s)
DAS	DAS
DMP	Dry Matter Production
d Sm^{-1}	Deci siemen per meter
EC	Electrical conductivity
et al.	et alia (others/and other co-workers)
etc.	et cetera
Fig.	Figure
FYM	Farm yard manure
g	Gram
GMR	Gross monetary return
ha	Hectare
ha^{-1}	per hectare

HI	Harvest Index
INM	Integrated nutrient management
kg	Kilogram
LAI	Leaf area index
Max.	Maximum
Min.	Minimum
NS	Non significant
NMR	Net Monetary Return
NOL	Number of Leaves
pH	Measure of acidity or alkalinity
OC	Organic Carbon
OM	Organic Matter
q	Quintal
t	Tonne

LIST OF APPENDIX

ABSTRACT

The research entitled "Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in a maize-chickpea cropping system in the central plain zone of Punjab" was executed over the *kharif* and *rabi* 2023-24 and 2024-25 at the Agronomy Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab (India). The experimental plot soil was sandy loam in texture. The experiment was conducted in spilt plot design and replicated thrice. The main plot comprised four nutrient management strategies: N_0 (control), N_1 (50% RDF), N_2 (75% RDF), and N_3 (100% RDF). The sub-plots included three levels of farmyard manure (FYM): F_0 (Control), F_1 (5 t ha^{-1}), and F_2 (10 t ha^{-1}), applied during the *kharif* maize season. This arrangement resulted in a total of twelve treatment combinations.

To inspect the residual influence of INM, chickpea was cultivated for all treatments. Fertilizer applications for the maize crop were carried out as per the designated treatment combinations. Observations on morphometric traits of maize were noted at appropriate growth phases, while data on yield attributes, yield, nutrient uptake, and post-harvest soil characteristics were collected after harvest. In the case of chickpea, observations on yield attributes, productivity, nutrient absorption, and soil status after harvest, to assess the carry-over effects of INM practices. An economic analysis of the maize–chickpea cropping system was also performed to determine the cost-effectiveness of the treatments.

The findings of the experimentation indicated that applying 100% RDF to maize significantly improved various morphometric traits, yield components, yield, nutrient percentage and its uptake, along with improvements in grain quality traits such as protein content, moisture content, ash content, and crude protein yield. Post-harvest soil analysis further revealed reduction in soil pH and increased levels of EC, OC, and the availability of primary nutrients (nitrogen, phosphorus, and potassium) compared to lower RDF levels (Control, 50%, and 75% RDF). However, the microbial population under 100% RDF was found to be comparable to that under 75% RDF, suggesting similar biological activity in the soil under both treatments.

Incorporation of FYM at 10 t ha^{-1} considerably improved the morphometry, yield traits, yield, nutrient concentration and uptake in maize. It also enhanced grain protein, moisture, ash percent, and crude protein yield. Post-harvest soil analysis

indicated a marked increase in EC, OC, availability of macronutrients (N, P, K), and microbial population in contrast with other treatments in both study seasons. However, incorporation of FYM at 10 t ha^{-1} led to a marked reduction in soil pH and bulk density.

The integrated application of 100% RDF and 10 t ha^{-1} FYM significantly enhanced maize performance, reflected in improved growth traits, yield components, total yield, nutrient percentage, and its uptake, as well as protein percent and crude protein yield. This treatment also positively influenced soil fertility status, showing increased levels of available N, P, K, and microbial population after harvesting of maize. It was observed to be superior during the first year across most parameters and remained statistically at par with 100% RDF + 5 t ha^{-1} FYM and 75% RDF + 10 t ha^{-1} FYM in the second year across various maize parameters.

The study demonstrated that applying 100% RDF to maize considerably enhanced the yield components, yield, and nutrient concentration and its uptake of the subsequent chickpea. Furthermore, post-harvest soil analysis indicated elevated levels of organic carbon and available macronutrients compared to treatments receiving lower fertilizer doses (Control, 50% RDF, and 75% RDF). The microbial population recorded under this treatment was found to be at par with that observed under the residual influence of 75% RDF, indicating similar contributions to soil biological health.

Incorporation of 10 t ha^{-1} FYM to prior maize notably enhanced yield components, overall productivity, nutrient concentration and its uptake of the succeeding chickpea. Post-harvest soil analysis revealed substantial improvements in EC, OC, available nitrogen, phosphorus, and potassium over other FYM levels during both years of the study. Moreover, FYM at this rate notably reduced soil pH and bulk density.

The interaction between the carryover impact of 100% RDF and 10 t ha^{-1} FYM notably enhanced the yield traits, yield, nutrient intake, and soil available N, P, and K in chickpea. This combination showed similarity to 100% RDF + 5 t ha^{-1} FYM and 75% RDF + 10 t ha^{-1} FYM for most chickpea parameters across both years.

The economic evaluation of the maize–chickpea cropping system demonstrated that applying of 100% recommended dose of fertilizers (RDF) consistently generated the highest gross returns (₹2,49,971 and ₹2,77,518 ha^{-1}), net returns (₹1,41,550 and ₹1,65,225 ha^{-1}), and B:C ratio (2.31 and 2.47) across both years, significantly outperforming other RDF treatments. Among the FYM levels, incorporation of 10 t ha^{-1} FYM registered highest gross returns (₹2,20,750 and ₹2,40,864 ha^{-1}) and net returns (₹1,05,451 and ₹1,21,856 ha^{-1}), with notable improvement over lower FYM doses. The highest B:C ratio in the first year was observed under the control treatment (2.02), whereas in the second year, the 5 t ha^{-1} FYM achieved the highest B:C ratio (2.04).

A meaningful association between RDF and FYM was seen in terms of economic returns. The treatment combination of 100% RDF+ 10 t ha^{-1} FYM resulted in highest gross returns (₹2,63,020 and ₹2,91,559 ha^{-1}) across both years, showing a marked advantage over other combinations during the first cropping cycle. However, in second cropping cycle, showed statistical similarity to that of 100% RDF with 5 t ha^{-1} FYM (₹2,85,414 ha^{-1}). The highest net returns (₹1,45,777 and ₹1,72,721 ha^{-1}) registered under 100% RDF + 5 t ha^{-1} FYM, which remained statistically comparable to 100% RDF + 10 t ha^{-1} FYM (₹1,44,198 and ₹1,68,865 ha^{-1}) in both study years.

Based on the experimental findings, the incorporation of 100% RDF combined with 5 t ha^{-1} FYM (N_3F_1) to maize, followed by 50% RDF to succeeding chickpea, was identified as the most economically viable and agronomically effective strategy. This treatment not only boosted crop productivity but also played a key role in the long-term enhancement of soil fertility in the maize–chickpea rotation.

CHAPTER I

INTRODUCTION

Agricultural land is a limited resource, making it essential to increase area based grain output, time, and input to satisfy the needs of an expanding population. The need for highly intensive cropping systems is well acknowledged to address these challenges. However, the production gains achieved during the Post-Green Revolution era often came at the expense of soil health. Achieving sustainable high-level production has only been possible through proper management of factors essential for maintaining soil fertility. Outcomes from continuous fertilizer application studies suggest that the absence of farmyard manure can result in declining soil productivity, likely due to nutrient deficiencies (Srinivasarao *et al.,* 2008). Intensive land use, combined with consistent use of maximum quantities of synthetic inputs and organic amendments, significantly impacts soil quality and performance of crop. Considering the declining soil health and crop production, greater emphasis is being placed on the Integrated Nutrient Management (INM) approach, which is key to sustaining soil health and ensuring the durability of agricultural systems. This system focuses on the balanced use of organic, synthetic, and biological nutrients to boost overall soil health, improve how efficiently nutrients are used, and support long-term agricultural productivity. Developing intensive cropping systems that are not only productive and economically viable but also environmentally sustainable and stable over time is of paramount importance in the current scenario.

Sustainable agricultural production emphasizes utilizing natural resources in a manner that increases output while preserving the resource base for future generations. Despite past advancements in crop production, issues such as improper fertilizer use, the separation of crop and animal production systems, and inefficient resource management have resulted in low resource efficiency and environmental degradation. To sustainably enhance crop yields and satisfy the needs of a growing population, there is a strong need to adopt integrated nutrient management (INM) practices. Nutrient availability is crucial for achieving optimal crop production. However, due to global energy crisis and rising costs of chemical fertilizers, greater focus must be placed on supplementing these fertilizers with more affordable nutrient sources like organics and biofertilizers (Kataraki *et al*., 2004a). Organic nutrient sources applied to a preceding crop often provide significant benefits to succeeding crops. Nonetheless, relying solely on organic inputs is rarely sufficient to meet the nutrient demands of modern agricultural practices. Therefore, an optimal blend of organic and synthetic nutrient inputs is critical for maximizing agricultural output and sustainability.

Maize (*Zea mays* L.) is believed to have originated in Mexico before spreading to Europe during trade exchanges and subsequently to other parts of the world, where it became a key staple food. Introduced to Europe in the early sixteenth century, maize gradually expanded to other regions during the European conquest. It is topmost widely growing crop globally, thriving in regions between the equator and 50° latitude in both hemispheres and at elevations up to 3000 meters above sea level (Shekhar & Singh, 2021). The domestication of maize dates back to approximately 7000 BC (Joyce, 2020). It is recognized by varying names, including Zea, Silk maize, Makka, and Barajovar (Kumar & Jhariya, 2013). It is also known as the "miracle crop" or "queen of cereals," maize is noted for exceptional grain output compared to other cereals (Malhotra, 2017). As a C4 plant, maize exhibits superior energy efficiency, effectively converting solar energy into biomass (Kannan *et al*., 2013).

Maize acts as a major staple food for about 900 million low-income people, encompassing 120 to 140 million smallholder farming households and nearly one-third of the world's malnourished children (Murdia *et al*., 2016). By 2050, the growing need for corn in developing countries is projected to double. This highlights the necessity for intensified efforts to enhance maize production, particularly in response to weather-related threats such as water scarcity, soil salinity, and extreme temperatures (Lenka *et al*., 2019). However, various factors contribute to low maize yields in developing nations, including the use of low-quality seeds, limited availability of hybrid varieties, suboptimal planting densities, financial constraints faced by farmers, unpredictable weather conditions, and poor agronomic management throughout the crop's growth cycle.

Maize is increasingly recognized as a commercially significant food grain crop due to its rising demand in the poultry sector, where it is replacing sorghum and pearl millet. As a highly fertilizer-responsive crop that is predominantly cultivated under irrigated conditions, maize requires substantial nutrient inputs, particularly nitrogen. However, its inclusion in rotation with leguminous crops can effectively maintain soil nitrogen (N) and phosphorus (P) levels, even when fertilizer application is reduced to 75% of the recommended dose (Begum *et al*., 2007). The continuous monocropping of cereals has exerted significant pressure on soil fertility, leading to declining soil health, depletion of groundwater resources, frequent pest and disease outbreaks, and other environmental challenges (Singh and Deshmukh, 2008). Integrating legumes within cereal-based cropping systems is a key strategy in Integrated Nutrient Management (INM) and is regarded as a long-term investment in resource conservation technologies. Legumes contribute substantial nitrogen to the subsequent non-leguminous crop grown in rotation, thereby reducing the dependency on external nitrogen inputs (Kebede, 2021). Despite their lower yield potential, particularly under low-input conditions, legumes benefit from the residual impact of fertilizers given to prior cereal crops. This enhances the output and longevity of crop rotation. Incorporating pulses like chickpea into a cereal–legume cropping system enhances rotational productivity and boosts nutrient use efficiency (NUE) by lowering the fertilizer needs of the following cereal crop.

Chickpea (*Cicer arietinum* L.), commonly referred to as Gram or Bengal Gram, is a highly significant leguminous crop cultivated worldwide. It serves as a vital source of protein, carbohydrates, vitamins, and essential minerals, particularly benefiting populations in developing regions (Singh *et al*., 2022). Chickpea is utilized for both human consumption and animal feed. It can be consumed in whole form, either fried or boiled with salt, but is predominantly used as split pulses, which are cooked before consumption. The by-products, including husks and broken dal particles, are valuable as livestock feed, while chickpea straw serves as a high-quality fodder. Additionally, chickpea flour (besan) is widely used in the preparation of various confectionery products. From a nutritional perspective, it comprises approximately 21.1% protein, 61.5% carbohydrates, and 4.5% fat, along with significant amounts of calcium, iron, and niacin (Tripathi *et al*.,2020).

Currently, fertilizer application mainly considers the specific nutrient needs of each crop, often disregarding the carryover impact of organic manures and fertilizers given to prior crop. Moreover, application of synthetic fertilizers, even in uniform proportions, fails to support long-term soil fertility and productivity within successive cropping practices. The performance of a succeeding crop within a rotation is significantly impacted by prior crop and the associated nutrient addition. Consequently, recent research has shifted focus from individual crop nutrition to an integrated cropping system approach. Overall productivity of a cropping system is largely determined by the efficient utilization of residual and cumulative nutrients. Although considerable research has been carried out on the effects of inorganic fertilizers and organic manures on maize and chickpea when grown as individual crops, there is insufficient information available on how integrated nutrient management strategies affect the maize-chickpea cropping system.

However, in light of the aforementioned points, the primary aim of this research is to investigate the "Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in a maize-chickpea cropping system in the central plain zone of Punjab," based on the following objectives;

1. To study the effect of integrated nutrient management levels on growth, yield attributes, yield and quality of maize.
2. To study the residual effect of integrated nutrient management on yield attributes and yield of succeeding chickpea crop.
3. To evaluate the effect of integrated nutrient management on nutrient uptake and soil health in maize-chickpea cropping system.
4. To work out the economics of different treatments.

CHAPTER II

REVIEW OF LITERATURE

Current experimentation was undertaken to investigate “Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in maize-chickpea cropping system in central plain zone of Punjab”. An effort has been made to summarize relevant research conducted in India and other countries, which is discussed under these specific titles.

2.1 Effect of integrated nutrient management on morphological traits of maize
2.2 Effect of integrated nutrient management on yield traits and yield of maize
2.3 Effect of integrated nutrient management on quality traits of maize
2.4 Effect of integrated nutrient management on uptake of macronutrients by maize
2.5 Effect of integrated nutrient management on soil characteristics after maize harvest
2.6 Residual effect of integrated nutrient management on yield traits and yield of chickpea
2.7 Residual effect of integrated nutrient management on nutrient uptake by chickpea
2.8 Residual effect of integrated nutrient management on soil characteristics after chickpea harvest
2.9 Effect of integrated nutrient management on economics of maize-chickpea rotation

2.1 Effect of integrated nutrient management on morphological traits of maize

Vadivel *et al.* (2001) experimented on impact of combined N management strategies on morphology and output of maize during *rabi* 1995-96 at TNAU, Coimbatore. They observed that incorporation of FYM under organic treatments registered maximum height, leaf area index, and dry matter production. Among synthetic treatments, higher level of N with recommended P and K (RDF) recorded highest plant height, leaf area index, and dry matter production.

Wagh (2002) experimented on impact of spacing and INM on the morphometric parameters and grain output performance of corn at the College of Agriculture, Pune. They found that the maize showed tallest height, maximum leaf count, leaf area, and dry matter production with 100% RDF coupled with 5 t FYM/ha with biofertilizers compared to different treatments.

Kumar *et al.* (2005) experimented on growth parameters, production and economic returns of maize in maize-wheat rotation as affected by INM during 2001-2002 and 2002-03 at IARI, New Delhi. They observed that the 100% RDF +10 t FYM/ha noted highest height and maximum leaf area index in maize.

Rajeshwari *et al.* (2007) Performed a experiment on impact of INM on morphology and maize yield at UAS, Dharwad during 2003-04. The results showed that applying 100% recommended nitrogen, phosphorous and potassium dose (RDF) through inorganic fertilizers significantly increased height, number of leaves, leaf area, leaf area index, and dry matter production. These values was higher compared to treatments using only organic sources and were comparable to combined applications of inorganic fertilizers (75% or 50% RDN + phosphorous and potassium) with organic sources like farmyard manure (FYM), distillery yeast sludge, or press mud.

Joshi *et al.* (2013) investigated impact of INM on maize morphology, grain output, and economic returns during the *kharif* 2010 at the instructional farm, COA, Udaipur (Rajasthan). Their results showed that 150% of the RDF resulted in tallest plant, leaf area index, dry matter accumulation, and chlorophyll concentration in maize. However, these values were statistically comparable to 100% RDF with 10 t of farmyard manure.

Sharma *et al.* (2016) investigate during the summer 2011-12 at the PAU, Ludhiana, to assess the impact of N and FYM levels on summer maize. They showed that the 120 kg N + recommended dose of phosphorus and potassium led to greatest improvements in plant height, leaf area index, and dry matter production. Among FYM treatments, the highest values were recorded with 25 t ha^{-1} FYM, followed by 12.5 t ha^{-1}.

Jadav *et al.* (2017) examined the effects of integrated nutrient management on maize morphology and yield during *rabi* season of 2016 at Sardar krushinagar Dantiwada Agricultural University. The results showed that 15 t FYM ha^{-1} developed tallest plants, the highest leaf count, stem girth, and leaf area, followed by 10 tonnes FYM in main plot. In subplot, the best results with respect to leaf count, stem girth and leaf area were observed with 100% RDF in combination with biofertilizers.

Mozafari *et al.* (2018) experimented during 2017 at Kandahar, Afghanistan to check the effect of moisture conservation and INM on morphology and maize productivity. They found that the 50% RDF+ 10 t FYM increased height of plant, area of leaf and dry matter accumulation of maize but it was found at par with 100 % RDF.

Khan and Jan (2018) An investigation was carried out in 2011 and 2012 at Peshawar, to check the impact of soil amendments and scheduled irrigation regimes on corn. The FYM at 10 t/ha led to the greatest leaf area and maximum height.

Roopashree *et al.* (2019) experimented on influence of INM on baby corn morphology and grain output during *kharif* 2008-09 at Shettahalli, Mandya District, Karnataka, India. Outcomes obtained that the 100% RDF+ 10 t FYM registered tallest height, area of leaf and dry matter production and this outcomes similar to 100% RDF.

Singh *et al*. (2019) studied in spring season of 2014 to check the impact of INM on maize morphology, yield, and economic returns. Findings showed that the tallest plants, maximum area of leaf, and highest dry matter accumulation recorded in 15 tonnes FYM, which was statistically comparable to 10 tonnes FYM treatment. Among the nutrient levels, 100% RDF noted highest values for plant height, leaf area and dry matter accumulation.

Lakum *et al.* (2020) studied 2015-17 to check the impact of both organic manures and synthetic inputs on maize performance, including grain output, nutrient profile, and seed quality within a maize–chickpea rotation. Findings showed that the maximum chlorophyll content was registered under the 100% recommended chemical fertilizers. Among organic inputs, farmyard manure at 10 tonnes recorded the highest chlorophyll levels.

Iqbal *et al.* (2020) conducted a study at Study Farm of Agronomy, SKUAST, Kashmir, Wadura, during *kharif* season of 2017. The research evaluated the impact of varying organic and synthetic inputs on the morphology and productivity of popcorn. Findings of the investigation showed that the 100% recommended fertilizer dose resulted in the tallest plant, maximum leaf area index, and dry matter accumulation.

Karki *et al.* (2020) experimented on effect of different N doses on production of spring maize during 2018 at Ishma rural municipality, Chaurashi, Gulmi. They found that 120 :60:40 kg NPK (RDF) recorded highest plant height and leaf numbers.

Prabhavathi *et al.* (2021) conducted an two year experiment during 2019-20 and 2020-2021 at S.V. Agriculture Collage, Tirupati to find impact of INM on corn morphology and morphological parameters in corn-groundnut rotation. The experimental results showed that the 10 t FYM registered tallest plant and DMA.

Manjunatha *et al.* (2022) studied during *kharif* 2018-19 at the Agronomy Section research farm, NDRI, Karnal (HR), to assess the impact of different jeevamrutha formulations alongside different nutrient scales on fodder maize. The findings revealed that applying 100% RDF registered the maximum height, leaf numbers, and girth of stem.

Kuldeep *et al.* (2022) studied on impact of FYM and split doses of N on maize morphological characters and production during *rabi* 2021-22 at Anand Agriculture University, Anand (Gujarat). They observed that the height of the plant and leaf count was found maximum in 10 t FYM. Among the split application of nitrogen the 100% N (50% at basal+50 % in 3 equal split) with recommended P and K found maximum height of the plant and leaf count.

Naveena and Geetha (2022) experimented on impact of treated wastewater irrigation with variable fertilizer inputs on maize morphology and yield during summer 2021 at GKVK, Bengaluru. They found that the combination of 100% recommended fertilizer dose with 10 tonnes ha^{-1} FYM recorded maximum height, leaf area, chlorophyll content and stem girth.

Rangaswamy *et al.* (2023) conducted an experiment on maize yield as impacted by Zn-enriched FYM, zinc solubilizer and synthetic inputs during *rabi* 2021-22 at ANGRAU, Mahanandi (AP). They found that the 10 t FYM enriched with Zn recorded maximum dry matter production.

Naveen *et al.* (2023) conducted an investigation at the time of *rabi* 2022 at the Maize Research Centre, PJTSAU, Rajendranagar, Hyderabad, Telangana, to study the effects of cultivation techniques, crop residues incorporation, and varying synthetic inputs on morphology and maize yield. The study disclosed that applying the full recommended dose of inorganic fertilizers (100% RDF) resulted in the greatest height, leaf area, dry matter accumulation, and chlorophyll index.

2.2 Effect of integrated nutrient management on yield traits and yield of maize

Vadivel *et al.* (2001) influence of combined nitrogen strategies on the morphology and productivity of rainfed maize during the *rabi* seasons of 1995–96 and 1996–97 at TNAU, Coimbatore. Their findings indicated that FYM under organic nutrient management significantly improved cob length and weight, seed index , grain yield, and straw yield. In contrast, among the inorganic fertilizer treatments, the use of a higher nitrogen level combined with phosphorus and potassium yielded best performance.

Wagh (2002) conducted an experiment on impact of crop geometry and INM on sweet corn morphology and yield at the College of Agriculture, Pune. They reported that the maximum cobs and its length, weight, number of grains and seed index (g) found under the 100 % RDF + 5 t tonnes FYM + biofertilizer.

Kataraki *et al.* (2004) showed that standard dose of synthetic inputs (100% RDF) significantly achieved greater values of number of seed rows cob^{-1} (16.17), seeds per row (31.59), cob length (16.54 cm), and seed index (27.31 g) compared to treatments receiving 50 and 75% RDF.

Kumar *et al.* (2005) studied the impact of INM on maize morphometric characters, grain output, and economic performance in a maize–wheat system over two consecutive years (2001-2002 and 2002-2003) at the IARI, New Delhi. The outcomes demonstrated that the fertilizer given at the standard recommended level (100%) coupled with 10 tonnes farm yard manure led to the highest values for cobs count and its length, grains count, Seed index , and grains yield.

Mehta *et al.* (2005) evaluated the impact of sulphur, phosphorus, and FYM on yield traits and maize production during 1999–2000. Their findings indicated that applying 10 t ha^{-1} FYM significantly improved yield parameters such as cobs count, rows count, cob weight, shelling percentage, seed index and both grain and stover yields.

Singh and Nepalia (2009) experimented on impact of INM on QPM (Maize) production during *kharif* 2004-05 at COA, Udaipur. They showed that the 125%RDF registered maximum cobs/plant, cob length and seed index and this outcomes similar to 100% RDF. Among manure sources, vermicompost 5 t recorded highest cobs/plant, cob length and seed index and it was similar to 10 tonnes FYM.

Tetarwal *et al.* (2011) evaluated the effects of INM on the maize yield, economic viability, uptake, and fertility of soil during the *kharif* 2008-09 at the ARS, Jhalawar (RJ). Their outcomes showed that applying 150% recommended fertilizer dose enhanced plant height, dry matter production, cobs/plant, number of grains, seed index, grains and total biomass. However, these experimental results statistically similar to those obtained with 100% RDF together with10 tonnes FYM.

Balai *et al.* (2011) examined the role of INM on maize productivity and quality under a system of continuous cropping and fertilization at the Instructional Farm, COA, Udaipur, Rajasthan during *kharif* 2008 season. Their findings indicated that the treatment involving 100% RDF coupled with 10 t FYM per hectare resulted in the highest grain and stover yields, cob weight and length, 100- grain weight, seed index, and shelling percentage.

Joshi *et al.* (2013) undertook study in the *kharif* 2010 at COA, Udaipur, to examine the influence of INM on maize (*Zea mays*) in terms of growth, yield, and economic returns. They reported that the combination of complete RDF application (100%RDF) with 10 tonnes FYM contributed to the highest values of seed index, cob weight, grains number, cobs number, along with grain and stover yields.

Shinde *et al.* (2014) assessed impact of irrigation management and INM on maize morphology, yield and quality during 2004-05 at Parbhani. The findings indicated that the 100% RDF+ 10 tonnes ha^{-1} FYM noted maximum cobs/plant, seed index, grain and stover yield which was at par with 100 % RDF+ 5 t FYM.

Pandey and Awasthi (2014) carried out a field investigation during the 2010-11 season at the experimental farm, NDUAT, Kumarganj, Faizabad, to check the impact of INM on maize productivity and soil characteristics. The study revealed that peak grain yield was achieved with the combined application of 100% preferred fertilizers dose and 10 tonnes FYM. In terms of biological yield, the 100% RDF along with zinc recorded the maximum value, which was comparable to the treatment involving 100% RDF with 10 t/ha FYM.

Jan *et al.* (2014) experimented on impact of soil amendments on corn yield attributes and yield under different irrigation schedule during summer 2011-12 at New Developmental Farm, University of Agriculture, Peshawar, Pakistan. They observed that the incorporation of 10 tons ha^{-1} FYM produced maximum ears, grains, shelling percentage, grain yield and harvest index as compared with other soil amendments.

Yadav *et al.* (2015) experimented on impact of INM on corn productivity during *kharif* 2014 at COA, Udaipur. They observed that the 100% RDF + 4 t ha^{-1} of vermicompost recorded maximum kernel, stover and biological yield of maize but it showed similarity with complete fertilizer application (100% RDF) with 10 tons of FYM per hectare and the highest harvest index was found under 100% RDF.

Khan *et al.* (2017) studied on a sustainable approach toward maize production: effectiveness of FYM and urea N during 2004 at Research field of Agriculture, University of Agriculture, Peshawar, Pakistan. They found that incorporating 10 tons of FYM recorded maximum number of cobs and grains cob^{-1} under varying FYM levels.

Khan and Jan (2018) carried out a study during 2011 and 2012 at Peshawar, to examine impact of soil conditioning and irrigation schedules on corn. Their findings showed that applying 10 tonnes of FYM noted maximum biological yield.

Mozafari *et al.* (2018) carried out a study in 2017 at Kandahar, Afghanistan, to analyze the outcome of moisture management strategies and INM on maize morphology and productivity. The findings indicated that applying 50% of the recommended fertilizer dose with 10 tonnes FYM notably enhanced number of grain rows, grains number, seed index, grain and straw yield. However, these results were statistically similar to those observed with 100% RDF.

Verma *et al.* (2018) experimented on role of INM on maize morphology, yield traits and yield under maize-wheat sequence cropping during 2015-16 at CSKHPKV, Palampur. They showed 100 % RDF noted maximum corn length, cobs number, grains count, seed index, grains and stover output.

Roopashree *et al.* (2019) performed experiment on influence of integration of nutrients on morphometrc traits and yield of baby corn in *kharif* 2008-09. Findings revealed that applying 100% RDF+ 10 tonnes of FYM noted highest growth dimensions (length and girth), cob yield per plant, individual cob weight, baby corn yield, and fodder yield. These results were statistically comparable to the 100% RDF alone.

Singh *et al*. (2019) evaluated influence of integration of nutrient strategies on maize external features, yield, and economics at Gobind Ballabh Pant University of

Agriculture during the spring 2014. Their results indicated that applying 10 t/ha FYM led to the most favourable outcomes in terms of cob length and weight, grain rows count, grains per row, total grains per cob. Similarly, nutrient application at 100% RDF also noted higher values for these yield attributes.

Lakum *et al*. (2020) carried a two-year experimentation at AAU, Gujrat to check the impact of both organic and synthetic sources on performance of corn within a maize–chickpea rotation during the 2015-17 cropping seasons. They reported that seed and straw yields highest under 100% RDF. Among the organic sources, FYM at 10 tonnes ha^{-1} achieved the best results, with grains and stover yield. Combined use of 100% RDF with 10 tonnes FYM yielded the greatest amount of grain and stover.

Sharma *et al.* (2020) investigated from 2014 to 2017 at Regional Research Station, PAU, Ballowal Saunkhri, SBS Nagar (PB), India. The study assessed the effects of INM in maize-wheat rotation on yield, nutrient uptake and soil characteristics. They showed the highest corn length, seed index and maize grains and straw yield registered under 100 % RDF+10 t FYM and it showed similarity with 100% RDF.

Iqbal *et al.* (2020) performed a field trial during *kharif* 2017. The purpose was to check the influence of various organic and synthetic inputs on popcorn morphology and production. Their findings revealed that the use of 100% RDF registered highest values of grain rows, grains per row, total grains count, seed index, grains output, stover output, overall biomass, and grain-to-biomass ratio (harvest index).

Karki *et al.* (2020) experimented on effect of different N doses on production of spring maize during 2018 at Ishma rural municipality, Chaurashi, Gulmi. They found that the applying full dose of 120:60:40 kg NPK/ha recorded maximum values of cob length, kernels count per row, kernel rows, total grains, shelling (%), seed index and production output.

Rangaswamy *et al.* (2023) experimented on maize yield as impacted by Zn-enriched FYM, zinc solubilizer and synthetic inputs during *rabi* 2021-22 at ANGRAU, Mahanandi (AP). They found that applying 10 t FYM enriched with Zn recorded maximum kernel yield and stover yield.

2.3 Effect of integrated nutrient management on quality traits of maize

Shinde *et al.* (2014) studied on impact of watering and INM strategies on maize morphology, yield and quality during *rabi* 2004-05 at Parbhani. The experimental results found that 100% RDF+ 10 t farm yard manure registered greatest protein percentage and protein production and this treatment comparable to 100 % RDF+ 5 tonnes FYM.

Sharma *et al.* (2016) experimented on role of FYM and nitrogen levels on summer maize during 2011-12 at research farm, PAU, Ludhiana and showed 120 kg nitrogen with suggested phosphorus and potassium dose produced highest ash content in maize. In terms of FYM, highest values was observed under 25 t FYM followed by 12.5 t FYM.

Lakum *et al.* (2020) carried a study at AAU, Anand, during the *kharif* and *rabi* seasons of 2015-17 to study the impact of manures and synthetic inputs on maize yield, nutrient concentration, and quality of seed in a maize-chickpea rotation. Their findings revealed that applying 100 % synthetic dose resulted in the highest seed protein content (10.43%). Among the organic treatments, the FYM at 10 t/ha led to the greatest seed protein content (10.65%).

Desai *et al.* (2022) assessed the balanced nutrient management approach practices on corn in corn-clusterbean rotation during the years 2019-20 and 2020-21. The results revealed that 75% RDF +25% N from vermicompost + NPK consortium recorded greatest protein percent and protein production but it showed similarity with 100% RDF and other treatments.

Kuldeep *et al.* (2022) studied on influence of FYM and N scheduling in splits on maize morphology and production during *rabi* 2021-22 at Anand Agriculture University, Anand (Gujarat). They found that the plant crude protein content and protein yield was found maximum under 10 t FYM. Among the split application of nitrogen, 100% N (50% at basal+50 % in 3 equal split) with recommended P and K found highest content of crude protein and crude protein yield.

Naveen *et al.* (2023) studied during the *rabi* 2022–23 at ARI, Rajendranagar, under PJTSAU, Hyderabad, Telangana. Research focused on influence of tillage practices, residue incorporation practices, and varying nutrient scales on energy efficiency, microbial activity, dehydrogenase enzyme levels, weed characteristics, and quality traits in maize. Results revealed that applying 100% of the recommended inorganic fertilizer dose (RDF) led to the maximum value of protein concentration and protein yield in maize.

2.4 Effect of integrated nutrient management on uptake of macronutrients by maize

Wagh (2002) conducted an experiment on impact of varying planting spacing and balanced nutrient application strategies on sweetcorn morphology and productivity at the COA, Pune. They showed the highest intake of primary macronutrients was found with the RDF (100 %) in conjunction with FYM (5 tonnes) + biofertilizer**.**

Mehta *et al.* (2005) investigated during 1999-2000 at the Instructional Farm, COA, Udaipur, to revealed the role of sulphur, phosphorus and FYM on maize performance under southern Rajasthan conditions. Results demonstrated that applying of FYM (10 tonnes) noted highest intake of nitrogen and phosphorus macronutrient by grains and stover, with total nutrient intake also being maximized under this treatment.

Karki *et al.* (2005) conducted a investigation on impact of INM on maize morphology, yield, content and uptake at IARI, New Delhi during 2003. They showed that the use 100 % recommended fertilizer dose registered highest primary macronutrient content and intake in grains and straw.

Masood *et al.* (2014) studied a pot investigation to assess the short-term influence of FYM on maize morphology and soil attributes. The study demonstrated that intake of primary macronutrients by maize increase progressively with increasing FYM levels, reaching the highest values in 10 t/ha relative to the untreated control.

Khan and Jan (2018) investigated the effect of soil conditioning and varying irrigation scheduling on maize during the 2011 and 2012 seasons. Their results indicated that of 10 tonnes FYM resulted in greatest N concentration under both grain and stover.

Sharma *et al.* (2020) undertook a field study at the Regional Research Station, Ballowal Saunkhri, PAU from 2014 to 2017 to evaluate integration of nutrient strategies in a rainfed maize-wheat rotation. Findings showed that the combination of 100% recommended fertilizers with 10 tonnes FYM led to the topmost intake of nitrogen, phosphorus, and potassium by maize grains. A comparable trend was seen for nutrient intake by straw, with 100% RDF + 10 t/ha FYM treatment outperforming other combinations.

Lakum *et al.* (2020) studied at AAU, Anand to examined impact of organics and chemical inputs on production, chemical concentration, and seed quality of maize in a corn-bengal gram rotation at the time of *kharif* and *rabi* 2015 to 2017. The results indicated that the greatest intake of primary macronutrients by grains and stover, was obtained under 100% RDF. Also in organic matter treatments, 10 tonnes FYM noted the highest intake of primary macronutrients by seed, and by straw. In terms of interaction effect, the 100 % RDF and 10 t FYM combination recorded highest primary macronutrients concentration and intake by seed and straw.

Manjunatha *et al.* (2022) experimented at NDRI, Karnal (HR) at the time of *kharif* 2018-19 to studied the impact various jeevamrutha compositions under varying nutrient levels in maize. Experimental results revealed that highest primary macronutrients intake obtained with 100 % RDF.

Yadav and Singh (2022) studied on influence of organic and chemical nutrient inputs on primary nutrient concentration and intake by maize during *kharif* 2019-20 at Farmers field, Tulsipur, Ghazipur (UP). The findings indicated that incorporating 100% of the recommended fertilizer dose together with 10 t ha^{-1} vermicompost noted the highest percent and intake of primary macronutrients. However, these values statistically similar to those observed under 100% RDF combined with 10 tonnes of FYM.

Desai *et al.* (2022) experimented on influence of INM practices on quality traits, post-harvest soil fertility, nutrient concentration and their intake by maize in maize-clusterbean cropping sequence" in 2019-20 and 2020-21. Experimental results indicated that 75% RDF +25% N from vermicompost + NPK consortium recorded highest N content and intake of primary macronutrients by grains and straw but it showed similarity with 100% RDF and other treatments.

Kuldeep *et al.* (2022) studied on impact of FYM and stepwise nitrogen supplementation on maize morphology and yield during *rabi* 2021-22 at Anand Agriculture University, Anand (Gujarat). They observed that percent and intake of primary macronutrients was found maximum under 10 t FYM. Among the split application of nitrogen the 100% N (50% at basal+50 % in 3 equal split) with recommended phosphorus and potassium found maximum values of concentration and intake.

2.5 Effect of integrated nutrient management on soil characteristics after maize harvest

Kumar *et al.* (2002) investigated the influence of different fertility scales on hybrid maize (*Zea mays*) during *kharif* 1998-2000 at Oilseeds Research Station Farm, Kangra (HP). They found that the 100% RDF in conjunction with 10 t of FYM notably maximized nitrogen, phosphorus and potassium in the soil.

Tetarwal *et al.* (2011) experimented on influence of INM strategies on production, profitability, intake of nutrients and properties of soil in maize during *kharif* 2008-09 at ARS, Aklera, Jhalawar (RJ). They observed that highest organic carbon (%), available nitrogen and phosphorus of soil were obtained in 100% RDF in conjunction with 10 t FYM.

Dubey *et al.* (2012) studied on impact of continuous use of chemical fertilizer during 2010 at Madhya Pradesh. They observed that applying 100% NPK fertilizers notably enhanced crop yield and increased the organic carbon, available nitrogen, phosphorus and potassium compared to the initial levels.

Masood *et al.* (2014) studied a pot culture investigation to check the short-term influence of farmyard manure on maize morphology and soil characteristics. Their results demonstrated that applying FYM at rates up to 10 tonnes per hectare significantly decreases bulk density, pH, increases porosity and organic matter in maize.

Pandey and Awasthi (2014) conducted an experiment on impact of INM on soil characteristics of maize during 2010-11 at Experimental field, NDUAT, Kumarganj, Faizabad. Findings showed that RDF (100%) recorded highest soil electrical conductivity and bulk density.

Parewa *et al.* (2014) experimented on effect of chemical inputs, FYM and bioinoculants on soil characteristics during 2009-10 and 2010-11 at BHU, Varanasi. The results obtained that the applied 100% NPK (RDF) recorded lowest pH of soil, highest electrical conductivity (dsm^{-1}), organic carbon (%), available nitrogen, phosphorus, potassium status, bacterial and fungal count. Among FYM levels, 10 t ha^{-1} FYM recorded lowest bulk density, pH, highest electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium status, bacterial count and fungal count. The combination of 100% NPK (RDF) in conjunction with 10 tonnes FYM recorded maximum available phosphorus, bacterial and fungal count.

Meshram *et al.* (2016) experimented at the time of 2011-12 and 2012-13 to check the prolonged impact of manuring and chemical inputs on humus fractions, microbial and enzymatic activities in a vertisol at VNMKV, Parbhani. They observed that the highest values of soil organic carbon, soil bacteria, actinomycetes was obtained under 100% RDF+ 10 t FYM application and highest fungal count was found under 10 mg/ha (10 t/ha) FYM application. The soil organic carbon and actinomycetes was showed similarity with 10 mg/ha FYM (10 t/ha) application.

Sangeeta *et al.* (2019) experimented at College Farm, Raichur during *kharif* season of 2016 and 2017 on soil microbial count and dehydrogenase activity of direct seeded rice as impacted by INM. They observed that significantly highest bacteria, fungi and actinomycetes count was found under 100% recommended fertilizer dose coupled with 10 t FYM and it showed similarity with 100% recommended fertilizer dose (NPK).

Sharma *et al.* (2020) studied investigation at Regional Research Station, Ballowal Saunkhri, district SBS Nagar, India during 2014-17 on Impact of INM under corn-wheat sequence on production, uptake and soil parameters. They revealed that the highest organic carbon, available phosphorus, potassium, fungal, actinomycetes and bacterial count was found under 100 % RDF combined with 10 t FYM but organic carbon, available phosphorus and potassium showed similarity with 100 % RDF.

Mian *et al.* (2021) experimented during 2019 to examine the impact of P and Zn applied alone and with FYM on maize yield. They found that the incorporation of 10 t FYM alone recorded lowest soil pH, highest organic matter, soil nitrogen, phosphorus and potassium.

Manimaran *et al.* (2022) studied at TNAU, Coimbatore on prolonged impact of fertilization and intensive cropping on maize productivity and soil nutrient availability. They found that the 100 % RDF along with 10 tonnes FYM increased soil electrical conductivity, organic carbon, nitrogen, phosphorus and potassium.

Singh *et al.* (2022) investigated at Instructional Farm, COA, Udaipur during 2016-17 and 2017-18 on soil quality indicators and microbial biomass of soil impacted by prolonged use of organic and chemical inputs under wheat-maize rotation in typic haplustepts. The results found that highest EC was observed under 150 % recommended fertilizer dose but it showed similarity with 100 % recommended fertilizer dose and other treatments.

Kuldeep *et al.* (2022) studied impact of FYM and stepwise nitrogen supplementation on corn morphology and yield during *rabi* 2021-22 at Anand Agriculture University, Anand (Gujarat). They observed that the lowest pH, highest organic carbon (%), available phosphorus and potassium was found in 10 t FYM. Among the split application of nitrogen the 100% N (50% at basal+50 % in 3 equal split) with recommended phosphorus and potassium found maximum available phosphorus.

John *et al.* (2023) present investigation was carried out at RARS, Pattambi, Kerala during 2020-2021 on continuous use of organics and synthetic fertilizers under rice-rice rotation since 1997. They found that the highest bacteria, fungi and actinomycetes count noted in 100% RDF (NPK) + 5 t FYM.

Rangaswamy *et al.* (2023) experimented on influence of FYM combined with varying zinc treatments on maize during 2021-22 at College Farm of Agriculture, Mahanandi, ANGRAU (AP). They observed that the incorporation of 10 t farm yard manure with $ZnSO_4$ recorded lowest soil pH, highest available nitrogen, phosphorus, potassium and 10 t FYM enriched with 5 kg ZnSB recorded highest organic carbon.

Fageria *et al.* (2023) studied on influence of NPK levels with FYM on soil health properties at maize field at SHUATS, Prayagraj during *Zaid* 2022. They found that the application of 100% NPK (RDF) registered lowest pH, highest electrical conductivity (%), organic carbon, available nitrogen, phosphorus and potassium. Across the FYM levels, the 10 t FYM recorded lowest bulk density, pH, highest electrical conductivity, organic carbon, and availability of primary macronutrients.

Naveen *et al.* (2023) A trial was conducted at the *rabi* 2022-23 at the Maize Research Centre, PJTSAU, Rajendranagar, Hyderabad (TS). to evaluate the impact of different tillage methods, crop residue handling practices, and nutrient regimes on energy efficiency, microbial populations, quality traits, and soil characteristics in corn. The outcomes showed that applying 100% RDF led to the highest populations of bacteria, fungi, and actinomycetes, along with elevated values of electrical conductivity, organic carbon, and primary macronutrients

2.6 Residual effect of integrated nutrient management on yield traits and yield of chickpea

Gable *et al.* (2008) experimented on influence of INM on chickpea morphology and yield under maize-chickpea rotation during *kharif* and *rabi* 2005-06 at Dr. PDKV, Akola. They found that the residual effect 100%RDF recorded maximum straw yield and biological yield.

Srinivasarao *et al.* (2010) investigated immediate and carryover impact of integrated sulphur management within a corn-gram rotation during the 2000-2004 *kharif* and *rabi* seasons at the IIPR, Kanpur (UP). Their findings indicated that the incorporation of 4 t/ha FYM as a residual treatment led to the maximum harvest index in chickpea.

Gudadhe *et al.,* (2011) carried a investigation during 2006–07 and 2007–08 at the Agronomy Research Farm, MPKV, Rahuri, in Ahmednagar district (MS), to assess various organic and synthetic nutrient levels affect the morphometric parameters, yield traits, productivity, financial performance, and nutrient utilization in a hybrid cotton-gram rotation under Western Maharashtra conditions. The findings revealed that the residual influence of 100% recommended fertilizer dose together with 10 t FYM/ha notably enhanced pods count and its weight, seed index, seed and haulm output of chickpea.

Rajkumara *et al.* (2012) experimented during 2004-05 to 2009-10 at Water Management Research Centre, Belvatagi on nonstop application of organics to delivery of nitrogen and phosphorus on corn and gram under irrigation. They found that the residual effect of 100% RDF application increases the chickpea seed yield.

Rathore *et al.* (2014) experimented on integration of soil fertility management in rice-french bean system during 2005-2008. They found that the residual effect of 10 t FYM recorded maximum pods numbers plant^{-1} and biomass yield of French bean.

Elamin *et al.* (2015) studied during 2012 and 2013 at ARI Main Farm, Rajendranagar, to found the residual impact of *kharif* sorghum on morphometric characters and yield parameters of *rabi* chickpea rotation. They observed that the residual effect of 100 % RDF increases the pods count, seed index, seed and haulm yield and harvest index of chickpea.

Chhipa *et al.* (2017) experimented on residual influence of INM on clusterbean morphology, yield and quality at Collage of Agriculture, Bikaner. They found that the residual effect of 100 % RDF recorded maximum pod weight and yield of clusterbean. In terms of residual organic manures effect, the residual effect of 21 t ha^{-1} FYM recorded maximum pod weight followed by 14 t ha^{-1} FYM.

Bhuva and Detroja (2018) at Jamnagar, Gujarat from 2010 to 2014 to enhance the productivity and sustainability of a pearl millet-chickpea rotation using organic nutrient sources and the results found that the residual application of 7.5 FYM recorded maximum pods count, seed index, seed and stalk yield.

Jat and Praharaj (2018) experimented on the effects of Zn and Mo in combination with manure in a soybean-gram rotation during the 2016-17 and 2017-18 seasons at the IIPR, Regional Station, Bhopal. Experimental results indicated that residual impact of 5 t FYM resulted in the highest seed index and harvest index for chickpea.

Paikra *et al.* (2019) experimented at IGKV, Raipur to evaluate the influence of various nutrient management strategies for sustainable soil health under soybean: Chickpea rotation during 2017-18 and 2018-19. They reported that the use of 100 % fertilizer input to preceding crop resulted in maximum seed and straw yield of succeeding chickpea across both years.

Lakum *et al.* (2020) investigated at the time of 2015-16 and 2016-17 to identify the carryover impact of manures and fertilizers on chickpea under maize-chickpea rotation at AAU, Anand. The findings revealed that the residual impact of 100% RDF improved grain and haulm yield in chickpea, showed statistical similarity to 75% RDF. Among organic treatments, the residual impact of FYM (10 t/ha) notably enhanced seed index, grain, and haulm yield compared to control, while remaining at par with castor cake and vermicompost. Based on the experimental findings, the carryover effect of 100 % recommended fertilizer dose combined with FYM 10 tonnes notably improved seed and haulm yield of chickpea in the corn-gram rotation.

Sonboir *et al.* (2020) carried out a study during the *kharif* and *rabi* seasons at the IGKV, Raipur. The experiment aimed to assess different crop establishment techniques and nutrient management strategies influenced the productivity of *kharif* rice and their subsequent carryover effects on a following chickpea crop. Experimental results indicated that the residual impact of 100% RDF coupled with 5 tonne of farmyard manure (FYM) led to the highest pods count, as well as superior seed and straw yields in chickpea. However, these values were statistically similar to residual 100% RDF.

Kumawat *et al.* (2020) studied an experiment on influence of phosphorous and bio-inoculants and their carryover impact on following gram during 2016 to 17 and 2017 to 18. They found that 100% recommended dose of nitrogen and potassium with 60 kg phosphorus + NPK consortia noted maximum number of pods plant, seed yield, straw yield, biological yield.

Hasan (2020) conducted an experiment on influence of residual effect of organic amendments and varying doses of fertilizer on the green gram yield during 2018. They observed that the incorporation of 5 t vermicompost+100 %RDF registered maximum biological yield followed by 10 t FYM+ 100 % RDF.

2.7 Residual effect of integrated nutrient management on nutrient uptake by chickpea

Nawle *et al.* (2009) studied at 2006-2007 cropping season to evaluate INM on a *kharif* sorghum-chickpea rotation. The showed that the residual application of a nutrient regime comprising 25% nitrogen supplied through farmyard manure, 25% via vermicompost, and 50% from chemical fertilizers (RDF) led to highest intake of primary macronutrient by the chickpea. However, this treatment was statistically comparable with residual 100% RDF.

Gudadhe *et al.* (2011) studied at 2006-07 and 2007-08 at Agronomy Farm, MPKV, Rahuri (MS) to assess the impact of varying scales of organic and synthetic fertilization on the morphology, yield attributes, overall yield, economics, and nutrient intake in a cotton-gram rotation. They revealed that the carryover effect of RDF + 10 t FYM notably enhanced the intake of nitrogen, phosphorus, and potassium.

Sohu *et al.* (2015) check the carryover impact of INM on morphology and chickpea production under rice-chickpea cropping system at Quaid-e-Awam Agriculture Research Institute (QAARI) Larkana, Sindh Pakistan during 2012. They found that the residual effect of recommended fertilizer dose recorded highest primary macronutrient content.

Hiremath *et al.* (2016) carried investigation during 2012–13 and 2013–14 at farmer field in Nargund taluaka, Gadag district, Karnataka, to evaluate the impact of balanced fertilization on production, financial returns, and nutrient absorption in a hybrid corn-gram rotation. Their findings indicated that the residual effect of RDF combined with zinc registered in the highest intake of primary macronutrients by gram.

Jat and Praharaj (2018) experimented on impact of Zn and Mo with manure in soybean-chickpea rotation during 2016-17 and 2017-18 at research farm, IIPR, Regional Station, Bhopal (MP). They found that the residual effect of 5 t FYM recorded maximum nitrogen, phosphorus, and potassium content of chickpea.

Arunkumar and Thippeshappa (2020) conducted an experiment on residual impact of biochar levels and FYM on morphology, yield and nutrient intake by green gram crop during *kharif* 2018. The results found that residual effect of 10 t FYM with coconut shell biochar recorded highest accumulation and primary micronutrients uptake.

Kumawat *et al.* (2020) carried experimentation at ZARS, Jhabua during the 2016-17 and 2017-18 to evaluate the carryover impact of phosphorus and bioinoculants on chickpea. Their results showed that applying the full recommended doses of nitrogen and potassium, along with 60 kg phosphorus and an NPK biofertilizer consortium, led to the maximum intake of primary macronutrients by both seeds and haulm.

Mandanbhai (2022) carried out an investigation on influence of organics, phosphorus and sulphur on summer peanut and their leftover impact on following moong during 2020 and 2021. The findings showed that the impact of residual 5 t FYM recorded maximum content of primary macronutrients in grain and stover.

2.8 Residual effect of integrated nutrient management on soil characteristics after chickpea harvest

Rathore *et al.* (2014) investigated on synergized soil fertility strategy in rice-french bean during 2005-2008. They found that the carryover effect of 100% recommended fertilizer dose recorded maximum organic carbon, available nitrogen, phosphorus, and potassium.

Ojha *et al.* (2014) experimented on residual impact of farm yard manure on soil characteristics in spring season at Chitwan, Nepal. The findings revealed that the residual effect of 10.5 t FYM recorded lowest pH, bulk density, highest electrical conductivity and organic carbon after harvesting of greengram.

Nagar *et al.* (2016) carried field study to check the effect of organic manures along with phosphocompost on pigeonpea based cropping system at Dr PDKV, Akola (MS) during *Kharif* 2013-14. They observed that the residual effect of 12.5 t FYM with phosphocompost recorded lowest bulk density, pH, highest organic carbon, available nitrogen, phosphorus, potassium, count of fungi, bacteria and actinomycetes.

Sinha (2017) conducted an experiment during 2012-13 at Ambikapur, Chhattisgarh to find the impact of sowing times and INM strategy on production, profitability and health of soil on baby corn-horse gram cropping sequence. They observed that the residual effect of 125 % RDF +10 tonnes FYM noted maximum availability of nitrogen, phosphorus, and potassium which showed similarity with residual 100 % RDF in conjunction with10 t FYM after completion of cropping sequence.

Bhuva and Detroja (2018) conducted an experiment at Jamnagar (GJ) during 2010-11 to 2013-14 on pearl millet-gram rotation with organic source of nutrient supply and the results found that the residual effect of 7.5 FYM recorded lowest bulk density, lowest soil pH and recorded maximum organic carbon and available nitrogen, phosphorus, and potassium.

Lakum *et al.* (2020) studied during 2015–16 and 2016–17 to evaluate the carryover impact of organics and synthetic fertilizers on gram in corn-gram sequence cropping at AAU, Anand. Outcomes showed that residual impact of VC 2.5 t/ha led to maximum soil nitrogen availability (291.5 kg/ha), showed comparability to effects of 10 t/ha FYM (287.6 kg/ha) and castor cake (274.5 kg/ha). Additionally, highest level of available K noted in residual effect of 10 t/ha FYM. Regarding the inorganic inputs, the residual impact of 100% recommended fertilizer dose significantly enhanced the soil nitrogen, phosphorus, and potassium.

Prajakta *et al.* (2021) experimented on residual effects of biochar on soil parameters of chickpea sown after maize in a vertisol during *rabi* 2020-21 at Dr. PDKV. Akola. The results found that the residual effect of 125% recommended dose of nitrogen with recommended phosphorus and potassium + biochar 5 t noted highest available N, P and K but showing similarity to carryover impact of 100% N with recommended P and K.

Mandanbhai (2022) experimented on influence of organics, phosphorus and sulphur on peanut and their residual effect on subsequent green gram during 2020 and 2021. They revealed that effect of residual 5 t FYM recorded maximum organic carbon in soil.

Borah *et al.* (2023) started the study in 1980-1994 at AAU, Gujrat on impact of prolonged manuring and fertilization on pearl millet-mustard-cowpea rotation and found that the leftover impact of 10 t FYM given to *kharif* pearl millet recorded maximum actinomycetes, bacterial and fungal count after harvest of cowpea. In terms of residual RDF levels, 100 % RDF recorded maximum actinomyces, bacteria count after harvest of cowpea and the residual 150 % RDF recorded maximum fungal count followed by residual 100 % RDF.

Thakur *et al.* (2023) experimented on impact of INM strategy on production, soil fertility balance and profitability of rice-gram rotation during 2016-17 and 2017-18 at JNKVV, Jabalpur and found that the lowest soil pH was observed under 100 %RDF (NPK), highest soil N, P and K was noted in 75% NPK + FYM + BF which showed similarity with 100 % RDF (NPK).

Prabhavathi *et al.* (2024) experimented on influence of INM on maize-groundnut rotation during *kharif* and *rabi* season of 2019-20. They found that the effect of residual 100 % RDF recorded highest bulk density during both the year of experimentation. Among sub plot treatments, the effect of residual 10 t FYM recorded lowest bulk density.

Chauhan *et al.* (2024) experimented on residual influence of manuring and humic acid on various characteristics of soil of succeeding chickpea during *kharif* 2022-23 at sardarkrushinagar. The outcomes showed that residual effect of 10 t FYM recorded lowest bulk density, highest electrical conductivity, organic carbon, available nitrogen, phosphorus, and potassium.

2.9 Effect of integrated nutrient management on economics of maize-chickpea rotation

Kumar *et al.* (2005) investigated at IARI, New Delhi during 2001-02 and 2002-03 cropping seasons to study the influence of nutrient strategies on performance and profitability of a maize–wheat rotation. The results highlighted that combining 100% RDF with 10 tonnes FYM notably improved the net monetary returns from the rotation.

Nawle *et al.* (2009) investigated the influence of Nutrient application strategy on a kharif forage sorghum-gram rotation at the time of 2006-07. The findings demonstrated that the residual application of nutrient specifically 25% nitrogen through FYM, 25% nitrogen via vermicompost, and 50% RDF noted highest gross return and net return along with a favourable benefit-cost ratio. This treatment performed comparably to the application of full recommended dose of fertilizers in terms of profitability.

Chauhan (2010) studied the impact of INM on sweetcorn morphology, yield and economics during *kharif* 2004-05. They observed that the 10 t FYM recorded maximum cost of cultivation, gross return and net return. Among the nitrogen and phosphorous levels, the 120: 50 kg nitrogen and potassium recorded highest cost of cultivation, gross return and net return and B:C ratio.

Gudadhe *et al.* (2011) studied during the 2006–07 and 2007–08 seasons at the Agronomy Research Farm, MPKV, Rahuri, located in Ahmednagar (MS), to check the impact of INM on hybrid cotton-gram rotation and they revealed that the leftover impact of RDF coupled with 10t FYM registered maximum cost of cultivation, gross return and net return and B:C ratio of cotton and chickpea rotation.

Rajkumara *et al.* (2012) experimented during 2004-05 to 2009-10 at Water Management Research Centre, Belvatagi on consistent use of organic inputs for nitrogen and phosphorus supplementation in corn and gram cultivation under irrigation. They found that the highest gross return and net return and B:C ratio of corn-chickpea rotation found under 100% RDF applied to preceding maize but the gross returns showed similarity with 100% RDF + 10 t FYM.

Ravi *et al.* (2012) experimented during 2010 to check the influence of nutrient application strategy on morphology and productivity of maize (QPM) and they found that the RDF and 10 t FYM ha^{-1} noted highest gross returns and net returns and B:C ratio of maize.

Rathore *et al.* (2014) carried an investigation on holistic soil fertility approach in rice-french bean system during 2005-2008. They observed that the incorporation of

10 tonnes FYM recorded maximum cost of cultivation of rice-french bean cropping system.

Senthilvalavan and Ravichandran (2016) conducted an experiment during *rabi* 2008-09 and 2009-10 at Annamalai University to study the carryover impact of cultivation methods and different nutrient application strategy introduced to preceding rice on the yield, NPK intake and economics of blackgram grown in rice-fallow blackgram rotation. They noted that the residual impact of RDF+ 12.5 t FYM ha^{-1} recorded maximum net returns and B:C ratio after harvesting of blackgram.

Bana *et al.* (2016) experimented during 2010-12 at IARI, New Delhi. They found that the 10 t FYM recorded maximum net returns and B:C ratio of pearl millet-clusterbean rotation.

Jinjala *et al.* (2016) experimented during *rabi* 2011-12 at NAU, Navsari to check the role of INM on baby corn. They showed maximum gross returns and net returns and B:C ratio found with the 100 % RDF in maize.

Hiremath *et al.* (2016) experimented on optimized nutrient application on yield, profitability, and nutrient assimilation in a hybrid con-gram rotation during 2012-13 and 2013-14. They found that the effect of RDF+Zn applied to maize recorded maximum gross returns and net returns and B:C ratio by maize- chickpea sequence.

Bhuva and detroja (2018) conducted an experiment at Jamnagar, Gujarat during 2010-11 to 2013-14 to improve the productivity and sustainability of pearl millet:chickpea rotation with organic source of nutrient supply and the results found that the incorporation of 7.5 t FYM to pearl millet recorded maximum gross returns and net returns and B:C ratio of pearl millet, gram and system sequence.

Jat and Praharaj (2018) experimented on influence of Zn and Mo with manure in soybean-gram system during 2016-17 and 2017-18 at research farm, IIPR, Regional Station, Bhopal, India. They found that residual effect of 5 t FYM recorded maximum net returns and B:C ratio of soybean-chickpea rotation. In terms of micronutrient and RDF levels the application of 100% RDF with ammonium molybdate at 1 g kg^{-1} seed priming+ 0.5% foliar application of ZnSO4 recorded maximum net returns and B:C ratio.

Singh *et al.* (2019) studied on impact of INM on maize morphology, yield and economics at Gobind Ballabh Pant university of agriculture during spring 2014. They found that the highest gross return observed under 15 t FYM and it showed similarity with 10 t FYM and highest net returns and B:C ratio was found in 10 t FYM. In terms of nutrient levels 100 % RDF recorded maximum gross returns and B:C ratio. The net returns was found maximum in 125% RDF but it similar to 100 % RDF.

Iqbal *et al.* (2020) experimented on impact of different organic and chemical inputs on popcorn growth, yield and yield attributes at SKUAST, Kashmir, Wadura during *kharif* 2017. They found that the 100% RDF noted highest gross returns and B:C ratio.

Sonboir *et al.* (2020) studied over three consecutive cropping seasons to check the varying crop establishment techniques and nutrient input strategies on the performance rice and the subsequent effects on gram The findings indicated that the residual influence of applying 100% fertilizer dose in conjunction with 5 t/ha of FYM yielded the highest net returns and benefit: cost ratio, which remained statistically comparable to residual 100% RDF alone.

Dubey *et al.* (2022) experimented during 2017-18 and 2018-19 at JNKVV Jabalpur on production and financial evaluation of maize under maize-based cropping system. They found that 100 % RDF given to maize recorded maximum cost of cultivation, gross returns and net returns and B:C ratio of rotation.

Rangaswamy *et al.* (2023) experimented on maize yield as impacted by Zn-enriched FYM, zinc solubilizer and synthetic inputs during *rabi* 2021-22 at Agricultural College Farm, ANGRAU, Mahanandi (AP). They found that the 10 t FYM enriched with Zn recorded highest cost of cultivation, gross return and net return. The highest B:C ratio was found maximum in 10 t FYM enriched with Zn +foliar application of 0.2% $ZnSO_4$ showed similarity with 10 FYM + Zn.

CHAPTER III

MATERIAL AND METHODS

This chapter presents a concise summary of the materials utilized and strategies implemented during the ongoing research entitled “Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in maize-chickpea cropping system in central plain zone of Punjab” are categorized under relevant headings.

3.1 Research location

The field investigation was performed at Agronomy Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab (India), during *kharif* and *rabi* season of 2023–24 and 2024-25. The study area is situated at an elevation of 252 meters above mean sea level, located at 31°22'31.81" N latitude and 75°23'03.02" E longitude, as identified via google maps.

3.2 Soil properties of the research location

The field used for the experiment was located at Agronomy Research Farm, Lovely Professional University, Phagwara, Punjab, and consists of alluvial soil with a sandy loam texture. This type of soil is commonly found in the Indo-Gangetic plains. The terrain of the field was relatively flat and uniform. Prior to starting the experiment in 2023, samples of soil were taken from varying locations across the plot at 30 cm depth. These samples were combined and analyzed for various soil properties.

Results of the soil characteristic (Table 1) showed that soil in the study plot had a slightly alkaline pH, low electrical conductivity, low organic carbon levels, and was deficient in available nitrogen. The phosphorus levels were medium, while the available potassium content was high.

3.3 Crop sequence history

The crop sequence history of the research site provided in Table 2.

Table 1. Initial soil status of research location based on composite soil sample

Sr. No	Properties	Result	Procedures applied and reference	Normal range
A)	**Physical Composition**			
1.	Bulk density (g cm^{-3})	1.35	Core Sampler	1.30 -1.55
2.	Particle density (g cm^{-3})	2.62	Pycnometer	2.55-2.70
3.	Porosity (%)	48.47	-	-
B)	**Chemical composition**			
1.	Soil pH	7.70	Glass Electrode pH Meter (Jackson, 1973)	6.5-7.5
2.	Electrical conductivity (dSm^{-1})	0.15	Conductivity meter (Jackson, 1973)	0.8-1.6
3.	Soil organic carbon (%)	0.42	Wet oxidation Method (Piper, 1966)	0.50-0.75
4.	Available nitrogen (kg ha^{-1})	175.62	Alkaline permanganate method (Subbiah and Asija, 1956)	280-560
5.	Available phosphorus (kg ha^{-1})	19.26	Olsen's method (Olsen *et al.*,1954)	11-22
6.	Available potassium (kg ha^{-1})	360.08	Flame Photometer (Jackson, 1973)	110-280
C)	**Microbial composition**			
1.	Bacteria (cfu × 10^6 g^{-1} soil)	18	Serial dilution plate technique (Dhingra and Sinclair 1995)	-
2.	Fungi (cfu × 10^4 g^{-1} soil)	7	Serial dilution plate technique (Dhingra and Sinclair 1995)	-
3.	Actinomycetes (cfu × 10^5 g^{-1} soil)	11	Serial dilution plate technique (Dhingra and Sinclair 1995)	-

Table 2. Crop sequence history of research site

Year	Rainy crop	Winter crop
2020-21	Maize	Wheat
2021-22	Green gram	Mustard
2022-23	Fallow	Oat
2023-24	Current study (Maize)	Current study (Chickpea)
2024-25	Current study (Maize)	Current study (Chickpea)

3.4 Meteorological conditions

The research plot situated in a subtropical region, characterized by hot summers and cool winters, with considerable variations in maximum and minimum temperatures observed across both seasons. In the summer months, the maximum temperature exceeds 47°C, while during winters, the lowest temperature often falls below 5°C, with frequent occurrences of frost. the region experiences an annual rainfall ranging from 500-750 mm, with most occurring during monsoon (July to September). Scanty rainfall is recorded in the winter months (December to February). The weather data recorded at LPU, Phagwara during the experimental period for both years are presented in Tables 3 and 4 and illustrated in Figures 1 and 2.

Table 3. Weekly weather information collected during the experimental period (2023–24).

SMW	Max temp (°C)	Min temp (°C)	Morn RH (%)	Even RH(%)	Wind speed (km/hr)	Rain (mm)	Sunshine hours
19	41.30	23.40	45.25	34.00	7.75	0.00	10.25
20	42.86	25.37	65.29	40.00	9.00	1.09	9.33
21	36.97	22.19	79.43	35.57	10.29	2.03	2.91
22	31.92	20.49	85.57	48.43	5.86	5.63	7.27
23	37.57	22.14	79.43	34.57	5.29	3.26	11.34
24	36.29	23.71	84.43	45.86	3.57	5.89	9.56
25	37.86	27.57	80.86	51.57	2.57	2.31	5.86
26	35.71	27.00	82.71	56.14	2.57	0.31	4.71
27	33.57	25.29	86.71	65.57	3.00	21.89	4.57
28	33.57	25.86	88.43	66.14	7.00	1.60	2.50
29	34.57	27.43	86.43	70.00	5.71	7.09	2.01
30	33.57	27.00	90.86	72.71	4.29	8.57	3.27
31	35.43	27.59	90.86	68.71	5.57	8.66	5.91
32	34.29	26.86	90.29	73.00	4.29	0.83	4.21
33	34.71	27.29	90.57	72.14	5.57	0.26	5.79
34	34.71	26.86	92.00	70.00	4.43	0.00	5.01
35	33.57	26.48	91.71	64.29	5.16	1.57	8.91
36	34.92	24.71	92.00	60.86	5.20	0.00	10.27
37	34.24	25.99	91.00	70.00	4.28	0.57	3.01
38	31.65	23.93	92.00	71.08	3.96	2.27	3.07
39	33.76	21.21	93.00	60.23	4.37	0.34	9.30
40	33.79	17.79	92.51	48.48	5.76	0.00	9.83
41	32.33	18.70	91.89	53.21	4.47	0.94	8.39
42	28.19	15.46	92.01	52.20	4.94	0.29	8.44
43	30.27	13.71	92.59	47.06	5.40	0.00	7.96
44	30.27	14.14	93.42	46.67	3.39	0.09	6.99
45	26.90	12.94	92.10	53.96	5.50	0.00	4.53
46	27.11	10.03	93.83	49.90	5.04	0.00	8.79
47	26.19	9.89	93.10	46.93	4.78	0.00	5.94
48	23.52	11.17	91.56	59.72	4.53	0.94	3.61
49	23.55	7.97	94.62	52.46	4.63	0.00	7.83
50	22.02	4.46	93.95	50.21	3.75	0.00	7.30
51	21.23	4.33	94.26	55.66	4.22	0.00	6.87
52	18.00	7.45	94.26	70.63	2.68	0.00	2.55
1	12.40	6.59	95.00	85.86	3.08	0.00	5.74
2	11.76	6.43	94.29	78.29	2.92	0.00	7.43
3	13.14	5.57	94.57	78.86	3.19	0.00	7.04
4	14.14	5.57	93.57	75.00	4.91	0.00	3.49
5	17.71	9.00	93.43	72.86	5.06	1.26	5.84
6	20.23	3.48	93.48	54.37	5.33	0.00	9.38

Table 4. Weekly weather information collected during the experimental period (2024–25).

SMW	Max temp (°C)	Min temp (°C)	Morn RH (%)	Even RH (%)	Wind speed (km/hr)	Rain (mm) (mm)	Sunshine hours
18	39.40	19.17	80.11	21.70	10.08	0.00	9.00
19	37.89	22.18	71.54	30.42	9.34	0.00	7.89
20	41.50	22.20	73.08	23.73	8.45	0.00	10.86
21	42.06	25.41	71.58	30.51	12.04	0.00	11.41
22	43.61	24.80	69.07	21.52	8.64	0.00	10.00
23	39.81	23.25	75.90	28.60	8.85	1.33	6.28
24	43.36	25.66	71.07	26.66	12.45	0.00	6.48
25	22.11	8.24	90.04	52.39	9.88	0.14	9.23
26	35.32	26.69	89.69	65.47	7.70	0.56	8.47
27	34.08	26.51	88.89	69.00	9.98	0.54	3.53
28	36.42	27.08	90.22	62.56	5.40	0.00	4.90
29	37.13	27.98	87.99	65.18	5.14	0.20	5.33
30	35.47	27.79	90.26	73.07	4.47	0.00	5.77
31	35.53	28.32	92.84	76.44	5.71	1.78	5.36
32	33.79	26.64	91.20	74.22	6.79	3.36	5.62
33	32.53	27.12	93.83	72.48	5.25	4.57	5.44
34	35.10	26.11	94.82	73.06	3.96	3.13	6.03
35	33.27	25.25	94.39	73.68	5.66	0.47	5.78
36	34.13	26.22	95.08	73.72	3.39	1.63	6.98
37	34.64	24.97	93.79	68.21	4.06	0.34	7.43
38	34.81	24.60	94.38	61.58	2.52	0.00	7.57
39	33.62	24.25	94.06	68.49	3.50	0.20	6.54
40	35.48	21.56	94.04	60.61	3.60	1.43	9.62
41	33.43	17.91	93.32	50.41	4.37	0.00	9.23
42	34.11	17.80	93.43	47.57	2.83	0.00	9.36
43	32.77	16.42	93.65	52.55	4.47	0.00	9.10
44	32.61	15.27	93.14	47.22	3.29	0.00	8.84
45	29.24	15.73	94.20	68.12	2.21	0.00	8.43
46	24.55	15.41	95.96	68.51	2.48	0.00	8.33
47	26.93	9.09	93.85	44.45	3.14	0.00	7.63
48	26.48	7.68	93.11	44.32	3.14	0.00	7.89
49	16.34	7.22	92.55	68.51	4.06	0.00	8.31
50	20.73	2.73	91.07	47.07	5.15	0.00	8.44
51	20.35	5.71	92.58	45.83	3.25	0.00	3.76
52	17.16	8.25	93.82	66.95	4.43	0.25	1.99
1	15.26	8.70	94.00	80.57	3.43	0.14	1.99
2	17.10	7.77	95.71	65.14	2.96	0.83	5.04
3	19.29	8.31	92.29	54.85	4.09	0.00	4.31
4	21.66	6.14	92.57	41.57	9.04	0.00	9.24
5	20.90	9.68	94.19	69.60	3.82	0.00	5.97

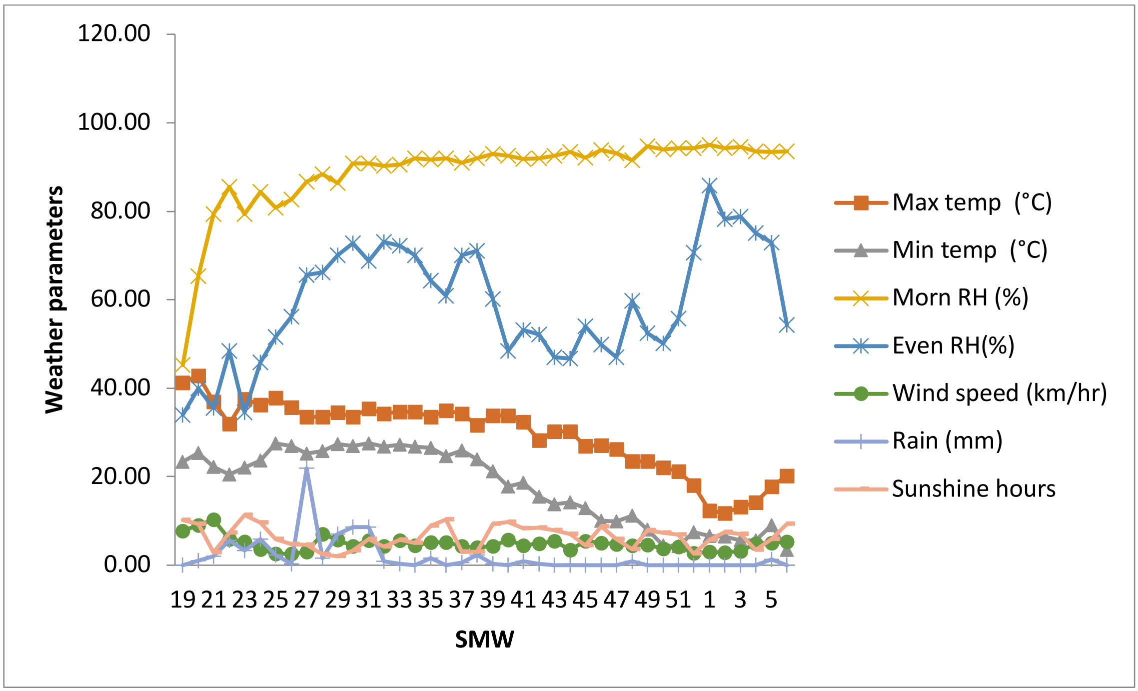


Fig. 1. Weakly weather information during maize–chickpea cropping sequence (2023-24)

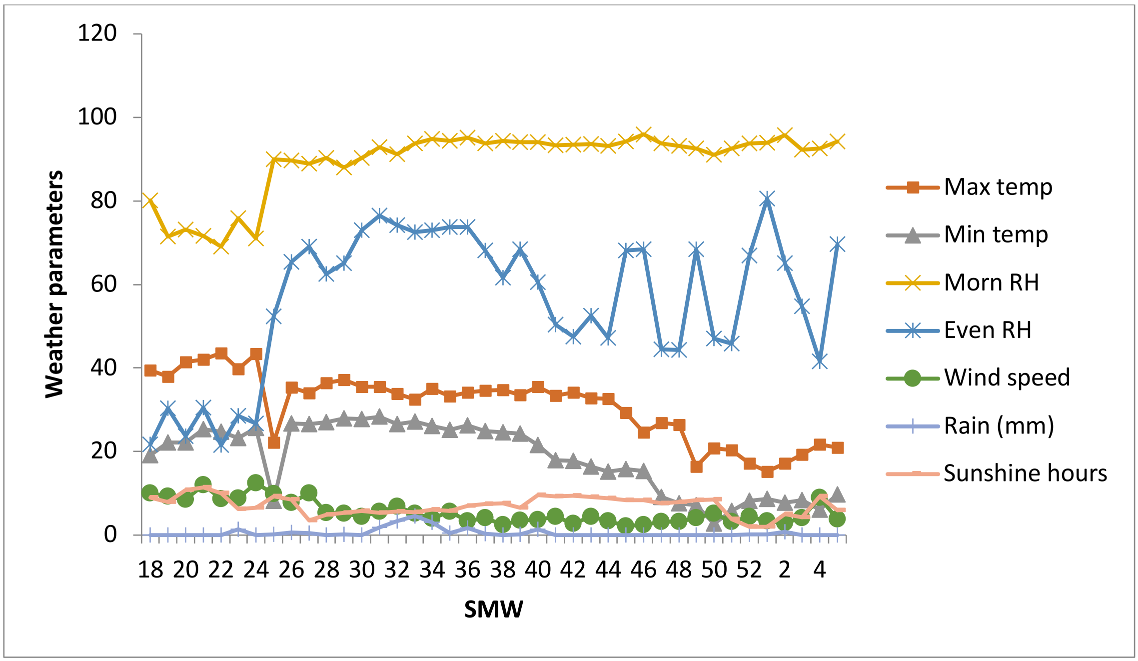


Fig. 2. Weakly weather information during maize–chickpea cropping sequence (2024-25)

3.5 Investigation details

3.5.1 Research and treatment planning

Present investigation was conducted in a split-plot design with three replications. The main plots consisted of four nutrient management levels, while the sub-plots included three levels of farmyard manure (FYM) given to *kharif* maize. To check the carryover impact of INM, a succeeding chickpea was grown with 50% RDF (recommended dose of fertilizers) to all plots. The investigation was conducted on fixed site and consistent random allocation followed across two consecutive years.

3.5.2 Description of treatments

A) Main Plot Treatments: Nutrient management levels

N_0 – Control

N_1 - 50 % RDF

N_2 - 75 % RDF

N_3- 100 % RDF

B) Sub plot treatment: FYM levels

F_0 - Control

F_1 - 5 t ha^{-1} FYM

F_2 - 10 t ha^{-1} FYM

3.5.2.1 Treatment combinations:

$N_0 F_0$	(0 % RDF + 0 t ha^{-1} FYM)
$N_0 F_1$	(0 % RDF + 5 t ha^{-1} FYM)
$N_0 F_2$	(0 % RDF + 10 t ha^{-1} FYM)
$N_1 F_0$	(50 % RDF + 0 t ha^{-1} FYM)
$N_1 F_1$	(50 % RDF + 5 t ha^{-1} FYM)
$N_1 F_2$	(50 % RDF + 10 t ha^{-1} FYM)
$N_2 F_0$	(75 % RDF + 0 t ha^{-1} FYM)
$N_2 F_1$	(75 % RDF + 5 t ha^{-1} FYM)
$N_2 F_2$	(75 % RDF + 10 t ha^{-1} FYM)
$N_3 F_0$	(100 % RDF + 0 t ha^{-1} FYM)
$N_3 F_1$	(100 % RDF + 5 t ha^{-1} FYM)
$N_3 F_2$	(100 % RDF + 10 t ha^{-1} FYM)

3.5.3 Details of layout

The field layout and its details are outlined in Table 5 and represented in Figure 3.

Table 5. Details of field layout

Layout design	Split Plot Design
Combinations	12
Replications	3
Total plots	36
Gross plot size	4.8 m x 3 m (14.4 m^2)
Net plot size (Maize)	3.6 m x 2.6 m
Width of bunds	0.5 m
Width of channel	1.0 m
Length of the field	42.5 m
Width of the field	19.4 m

3.5.4 Crop details:

Maize (*Zea mays* L)

1	Variety	:	PMH-11
2	Seed rate	:	25 kg ha^{-1}
3	Spacing	:	60 cm × 20 cm
4	Recommended dose of fertilizer	:	120 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1}
5	Plant population	:	83,333 plants ha^{-1}

Chickpea (*Cicer arietinum*)

1	Variety	:	GNG-469
2	Seed rate	:	60 kg ha^{-1}
4	Spacing	:	30 cm × 10 cm
5	Recommended dose of fertilizer	:	20 kg N, 50 kg P_2O_5, and 0 kg K_2O ha^{-1}

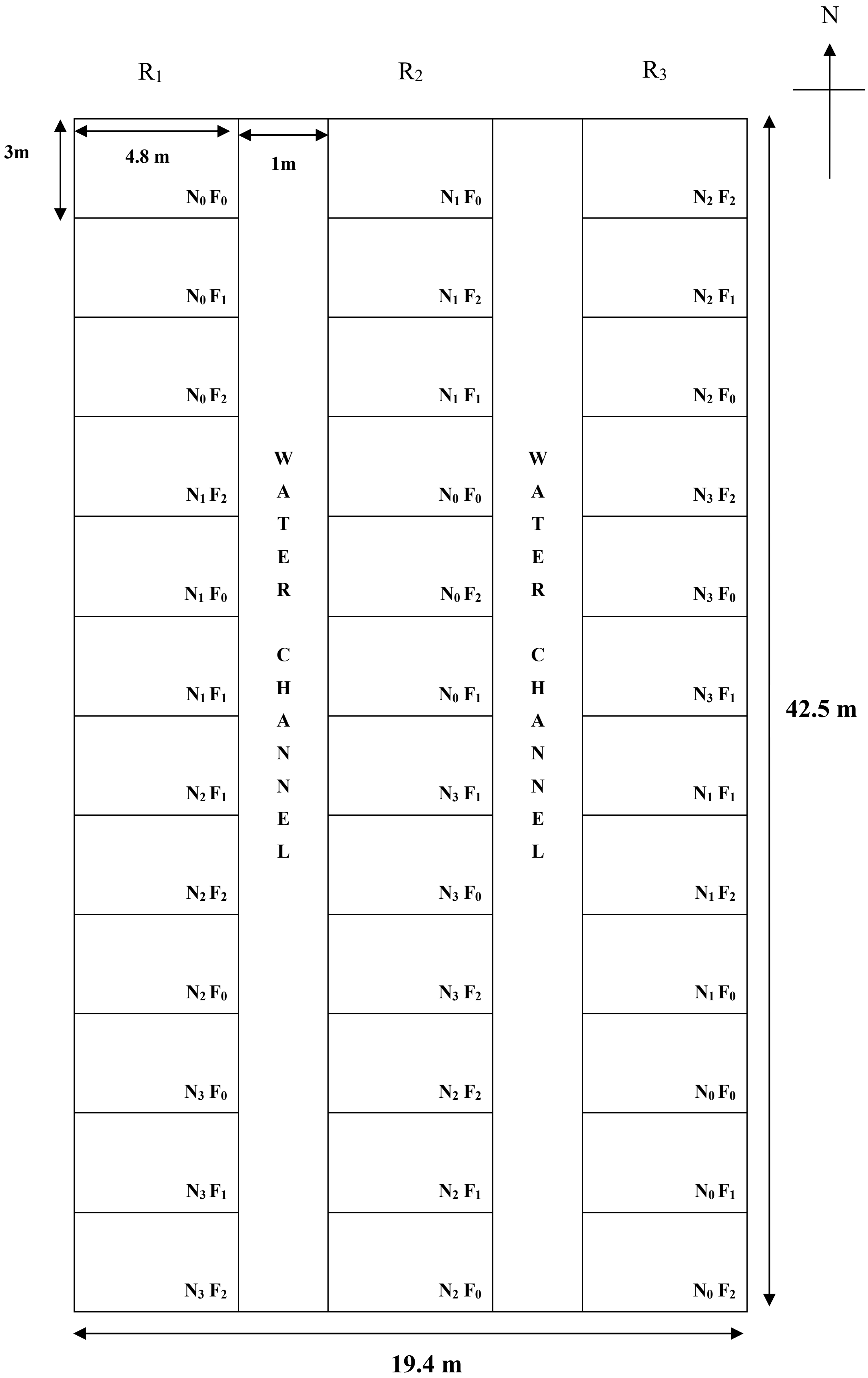


Fig. 3. Experimental field layout

3.6 Details of crop management practices

The crop management practices performed in the experimental field during both seasons over two years are listed in Table 6.

Table 6. Crop management practices performed in the field during 2023–24 and 2024–25.

Sr. No.	Cultural practices	2023–24		2024–25	
		Freq.	Date of operation	Freq.	Date of operation
A	***Kharif* maize crop**				
1	Ploughing	1	10/5/2023	1	6/5/2024
2	Harrowing	2	11/5/2023 15/5/2023	2	7/5/2024 10/5/24
3	Land levelling	1	16/5/2023	1	11/5/24
4	Layout of experiment	1	16/5/2023	1	11/5/24
5	FYM application	1	17/5/2023	1	13/5/24
6	Fertilizer application	1	1/6/2023	1	28/5/2024
7	Sowing	1	1/6/2023	1	28/5/2024
8	Herbicide application	-	-	1	30/5/2024
9	Gap filling	1	11/6/2023	1	7/6/2024
10	Thinning	1	16/6/2023	1	12/6/2024
11	Weeding	3	26/6/2023 24/7/2023 21/8/2023	3	28/6/2024 30/7/2024 24/8/2024
12	Protective irrigation	3	1/6/2023 12/7/2023 23/8/2023	3	28/5/2024 8/7/2024 14/8/2024
13	Top dressing	2	30/6/2023 2/8/2023	2	24/6/2024 27/7/2024
14	Plant protection	3	2/7/2023 15/7/2023 12/8/2023	3	1/7/2024 16/7/2024 20/8/2024
14	Harvesting	1	14/9/2023	1	9/9/2024
15	Threshing	1	25/9/2023	1	19/9/2024
B	***Rabi* chickpea crop**				
1	Ploughing (Manually)	1	20/9/2023	1	14/9/2024
2	Land levelling	1	20/9/2023	1	14/9/2024
3	Layout of experiment	1	21/9/2023	1	17/9/2024
4	Fertilizer application	1	22/9/2023	1	18/9/2024
5	Sowing	1	22/9/2023	1	18/9/2024

6	Plant Gap filling	1	2/10/2023	1	28/9/2024
7	Removal of excessive seedling	1	7/10/2023	1	12/9/2024
8	Weeding	3	17/10/2023 13/11/2023 21/12/2023	3	17/10/2024 19/11/24 23/12/2024
9	Irrigation	3	22/9/23 25/10/2023 1/12/2023	3	18/9/2024 21/10/2024 26/11/2024
10	Harvesting	1	10/2/2024	1	3/2/2025
11	Threshing	1	17/2/2024	1	10/2/2025

3.6.1 Field preparation

The investigation site prepared using tractor-pulled plough, then tractor-drawn harrow was used for harrowing in the month of May during both the first and second years. Fine tilth was obtained through repeated cross harrowing in both years. Leftover residues of prior crop were manually gathered and disposed. Ridges were prepared for sowing of seeds.

After harvest of *kharif* maize, minimum soil disturbance was ensured during field preparation for r*abi* chickpea. Each plot for chickpea sowing was individually prepared through manual ploughing by labor to ensure precise plot-specific soil preparation. Subsequently each plot was individually leveled and flat beds were prepared. The experiment was arranged based on the layout plan shown in Fig. 3 for both years.

3.6.2 FYM incorporation

FYM was given to maize according to treatment combinations. Nutrient concentration of FYM was analyzed prior to application in both years. FYM was applied 15 days prior to seeding to allow adequate decomposition and ensure uniform distribution and nutrient availability throughout the root zone. The primary macronutrient status of FYM utilized in study presented in Table 7.

Plate No. 1. Field and Layout preparation of maize

Plate No. 2. Field preparation, seed and seed treatment of chickpea

Table 7. Nutrient composition of FYM utilized during the study

Particulars	Nutrients	Content %	
		2023-24	2023-24
FYM	N	0.45	0.49
	P	0.22	0.24
	K	0.50	0.56

3.6.3 Fertilizer Application

During the *kharif* season, fertilizers for maize were applied according to the treatment combinations at sowing. The RDF for maize was 120 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1}. Based on treatment specifications, 50%, 75%, and 100% RDF were calculated and applied to the corresponding plots. At sowing, half nitrogen dose, coupled with entire dose of P_2O_5, and K_2O, was given as basal dose, while the 50% of nitrogen was split and given at the knee-high and tasseling stages. The nutrients were given by urea, SSP, and MOP.

During *rabi* season, the carryover effect of Integrated Nutrient Management (INM) was evaluated by cultivating a succeeding chickpea crop in all plots with the addition of 50% RDF to assess the carryover impact of nutrients from the previous treatments of preceding maize. All nutrients given as a basal application during sowing. Sources of nutrients for chickpea were urea and single super phosphate (SSP).

3.6.4 Seed priming and seeding

Certified seeds used for each crop under study. Maize seeds are treated with Azotobacter @ 500g in 500 ml of water for 25 kg of seeds and chickpea seeds are treated with liquid PSB @ 300 ml for 60 kg seeds and then dried in shade before sowing. Maize (var. PMH-11) was sown by the dibbling method, with rows spaced at 60 cm and plants at 20 cm intervals. The seed rate for maize was 25 kg ha^{-1}. During the r*abi* season, chickpea (var. GNG-469) was sown by dibbling with a seed rate of 60 kg ha^{-1}, maintaining a row spacing of 30 cm and 10 cm plant spacing.

Plate No. 3. Maize and Chickpea sowing

3.6.5 Inter cultivation operations

3.6.5.1 Gap filling and removing excess seedlings

Gap filling was performed 10 days after sowing, where necessary, in the *kharif* maize and r*abi* chickpea during two year of experimentation. Removing excess seedlings carried 15 DAS for both maize and chickpea in both experimental years, ensuring that one plant was retained per hill.

3.6.5.2 Irrigation management

The primary water supply was given immediately after seeding to promote uniform germination across both experimental years. Additional irrigation was provided as needed to sustain crop growth. Detailed information on the irrigation schedules to the crops during both years is presented in Table 6.

3.6.5.3 Weed control practices

Atrazine applied before crop emergence @ 0.75 kg per hectare within 2 DAS in maize. Thereafter, weed control maintained through three manual weeding operations for both maize and chickpea during both experimental years to ensure that crops remained free from weed competition throughout the growing period.

3.6.5.4 Plant Protection

Spraying of Spinosad 6 ml per 15 liters of water was carried out thrice for the control of maize stem borer.

3.6.6.5 Harvesting and Threshing

The maize was harvested upon reaching physiological maturity, indicated by a golden-yellow coloration of the plants, using a sickle. Individual plots were harvested from their respective net plot sections. Plants cut close to the base, bundled, and labeled for proper identification. The collected bundles were sun-dried on a clean surface for 4 to 5 days to lower the moisture content. after adequate drying, the cobs were detached from the plants. Subsequently, cobs were cleaned and passed through a corn sheller for grain separation.

The chickpea was harvested when crop attained physiological maturity. initially, the border rows were removed, then plants were then gathered from the defined net plot section. Collected material exposed to sunlight for 5 to 7 days to ensure adequate moisture reduction. Threshing was carried out separately for each treatment by manually striking the dried plants with wooden sticks to release the grains.

Plate No. 4. Weed control of maize and chickpea

3.7 Biometric observations of *kharif* Maize

To gather quantitative data, five plants were randomly chosen from each net plot to observe specific stages of maturity. The chosen plants were properly labeled, and data on growth and yield contributing traits were collected. The total biological yield, grain yield, and straw yield were measured from the net plot area.

3.7.1 Plant count at establishment and harvest

Plant count at establishment and harvest determined by calculating total plants in each net plot at 15 DAS and at harvesting, respectively.

3.7.2 Plant height (cm)

Height of plant was noted at varying developmental phases. Prior to tasseling, measurement taken from base of the plant to tip of the last fully expanded leaf. After tasseling, the height was measured from base to the uppermost visible ligule. Results recorded in cm.

3.7.3 Number of leaves plant^{-1}

The total leaf count was recorded from five randomly chosen plants in each plot and averaged to represent the mean leaves per plant.

3.7.4 Stem girth (cm)

Stem girth (cm) was measured at three positions on the plant just above the prop roots, at the mid-point of the plant's height, and at the base of the uppermost leaf. The measurements were recorded by Vernier caliper, and the average stem girth was computed.

3.7.5 Leaf area plant^{-1} (cm^2)

According to the study schedule for dry matter analysis, the plants were uprooted, and their leaf detached then the area of leaf was measured using a leaf area meter.

3.7.6 Leaf Area Index plant^{-1} (LAI)

The LAI computed by dividing the plant's total leaf area by the ground area it occupies. The calculation was performed according to provided formula:

LAI = Total Leaf Area (cm^2) / Ground Area (cm^2).

Table 8. Biometric observations recorded during the 2023–24 and 2024–25

Sr. No	Particulars	Freq.	DAS/ Harvest
Maize crop			
A	**Plant stand**		
1	Initial plant stand	1	10 DAS
2	Final plant stand	1	At harvest
B	**Growth parameters**		
1	Plant height (cm)	3	30, 60, and 90 DAS
2	Number of leaves plant^{-1}	3	30, 60, and 90 DAS
3	Stem girth (cm)	3	30, 60, and 90 DAS
4	Leaf area plant^{-1} (cm^2)	3	30, 60, and 90 DAS
5	Leaf Area Index plant^{-1} (LAI)	3	30, 60, and 90 DAS
6	Dry matter accumulation (g plant^{-1})	3	30, 60, and 90 DAS
7	Chlorophyll index (SPAD)	3	30, 60, and 90 DAS
C	**Yield attributes and yield**		
1	Number of cobs plant^{-1}	1	At Harvest
2	Weight of cobs plant^{-1} (g plant^{-1})	1	At Harvest
3	Length of cob (cm)	1	At Harvest
4	Number of grain rows cob^{-1}	1	At Harvest
5	Number of grains row^{-1}	1	At Harvest
6	Number of grains cob^{-1}	1	At Harvest
7	Seed index (g)	1	At Harvest
8	Grain yield (q ha^{-1})	1	At Harvest
9	Stover yield (q ha^{-1})	1	At Harvest
10	Biological Yield (q ha^{-1})	1	At Harvest
11	Harvest index (%)	1	At Harvest
D	**Qualitative observations**		
1	Protein content in grains (%)	1	After harvest
2	Crude Protein yield (kg ha^{-1})	1	After harvest
3	Ash content in grains (%)	1	After harvest

Chickpea Crop			
A	**Yield parameters**		
1	Number of pods plant^{-1}	1	At Harvest
2	Weight of pods plant^{-1} (g)	1	At Harvest
3	Seed index (g)	1	At Harvest
4	Seed yield (q ha^{-1})	1	At Harvest
5	Haulm yield (q ha^{-1})	1	At Harvest
6	Biological Yield (q ha^{-1})	1	At Harvest
7	Harvest index (%)	1	At Harvest
Plant analysis (Content and uptake of nutrients)			
A	N, P, and K content (%) and uptake (kg ha^{-1})	1	After harvest
Soil analysis			
A	**Physical properties**		
1	Bulk density (g cm^{-3})	2	Before sowing and after harvest
2	Particle density (g cm^{-3})	2	Before sowing and after harvest
3	Porosity (%)	2	Before sowing and after harvest
B	**Chemical properties**		
1	pH	2	Before sowing and after harvest
2	Electrical conductivity (dSm^{-1})	2	Before sowing and after harvest
3	Organic carbon (%)	2	Before sowing and after harvest
4	Available N, P and K (kg ha^{-1})	2	Before sowing and after harvest
C	**Microbial Properties**		
1	Bacteria (cfu × 10^6 g^{-1} soil)	2	Before sowing and after harvest
2	Fungi (cfu × 10^4 g^{-1} soil)	2	Before sowing and after harvest
3	Actinomycetes (cfu × 10^5 g^{-1} soil)	2	Before sowing and after harvest
Economics			
A	Cost of cultivation (₹ ha^{-1})	1	After harvesting
B	Gross returns (₹ ha^{-1})	1	After harvesting
C	Net returns (₹ ha^{-1})	1	After harvesting
D	Benefit : cost ratio	1	After harvesting

3.7.7 Dry matter accumulation (g plant^{-1})

Five plants were removed from the designated destructive sampling area at varying developmental phases. The samples were first dried under sunlight, then placed in an oven at 60°C until a stable weight was achieved. The samples were weighed after drying, and the weight in grams per plant was averaged and recorded.

3.7.8 Chlorophyll index (SPAD)

Chlorophyll index was measured using a SPAD meter. Readings taken from uppermost fully opened leaves of five randomly chosen, labeled plants in each plot at varying developmental phases. Three readings were recorded per leaf at different positions (base, middle, and tip), avoiding the midrib, and the average SPAD value was calculated for each leaf.

3.7.9 Number of cobs plant^{-1}

The cob count produced by the five tagged plants noted separately of each plant, and the average cob count per plant was calculated.

3.7.10 Weight of cobs plant^{-1} (g plant^{-1})

The husk was removed from the cobs of five observational plants, and the cobs were weighed. The average cob weight per plant was then calculated.

3.7.11 Length of cob (cm)

The cob length from the sampled five plants in each plot, after removing the husk, was measured from peduncle to tip of the cob. Average length was recorded in centimeters.

3.7.12 Number of grain rows cob^{-1}

The average grain rows per cob were calculated by summing the rows from cobs of five randomly chosen plants.

3.7.13 Number of grains row^{-1}

Average grain numbers row^{-1} calculated by summing the total grains from the cobs of five randomly chosen plants and dividing the count by the total number of rows.

3.7.14 Number of grains cob^{-1}

Each cob from sampled plants was dehisced separately, and the number of grains per cob was counted.

3.7.15 Seed index (g)

A random sample of 100 grains from each treatment was counted, weighed, and recorded in grams.

3.7.16 Grain Yield (q ha^{-1})

Cobs from all plants within the net plot were removed and expose in sunlight. After drying, the cobs were dehusked and shelled using a maize sheller. The grains were further dried, weighed, and the grain yield in each net plot was noted. Yield was then converted to quintals per hectare.

3.7.17 Stover Yield (q ha^{-1})

The stover yield in the net plot was noted after drying in sun. It was then converted to quintals per hectare.

3.7.18 Biological Yield (q ha^{-1})

The total dry biomass, including stover and cobs from each net plot, was noted as the biological yield. It was transformed into quintals per hectare.

3.7.19 Harvest Index (%)

HI was determined according to the formula outlined by Donald (1962).

$$\text{HI (\%)} = \frac{\text{Edible portion yield (q ha}^{-1}\text{)}}{\text{Total plant biomass (q ha}^{-1}\text{)}} \text{ X } 100$$

3.7.20 Protein content in grains (%) and crude protein yield (kg ha^{-1})

The N percentage of seed samples was determined using the Micro-Kjeldahl method. To estimate the crude protein content, the nitrogen value was multiplied by 6.25. Protein yield per hectare was figured out by multiplying the crude protein percentage with seed yield (kg ha^{-1}) for each treatment

$$\text{Crude protein yield (kg ha}^{-1}\text{)} = \frac{\text{Protein percent in grains (\%) X Grain yield (kg ha}^{-1}\text{)}}{100}$$

3.7.21 Ash content in grains (%)

The empty crucible was weighed (W_1), and 5 g of the sample was placed into the crucible. The initial weight of the crucible with the sample was recorded as W_2. The sample was then incinerated in a muffle furnace at 550°C for 8 hours until only ash remained. After incineration, the sample was cooled in a desiccator and reweighed (W_3). The percentage of ash content was calculated using the following formula:

$$\text{Ash content (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

3.8 Biometric observations of *rabi* Chickpea

3.8.1 Number of pods plant^{-1}

Pod numbers was determined by direct count on five representative plants at harvest.

3.8.2 Weight of pods plant^{-1} (g)

The pods from five sampled plants were dried in sunlight for one week, then dried pod weight was recorded. The mean pod weight per plant was then calculated.

3.8.3 Seed index (g)

Randomized samples collected from each net plot produce. From each sample, 100 seeds were randomly selected, and their weight was measured in gm.

3.8.4 Seed yield (q ha^{-1})

Seed yield was determined by manually threshing all pods collected from each net plot. The weight of the recovered grains was recorded and subsequently converted to quintals per hectare.

3.8.5 Haulm yield (q ha^{-1})

Haulm yield was calculated by subtracting the seed output from the total biological output of each net plot. Resulting value expressed in quintals per hectare.

3.8.6 Biological Yield (q ha^{-1})

Biological yield was obtained by sun-drying the complete crop produce, including pods, from each net plot for 8-10 days until stable weight was achieved. The final dried weight was noted as the biological yield and converted to quintals per hectare.

3.8.7 Harvest index (%)

HI was determined according to the formula outlined by Donald (1962).

$$\text{HI (\%)} = \frac{\text{Edible portion yield (q ha}^{-1}\text{)}}{\text{Overall plant biomass (q ha}^{-1}\text{)}} \times 100$$

3.9 Plant analysis (Content and uptake of nutrients)

The N concentration in grains/seeds and plant samples was determined using the modified Micro-Kjeldahl method after digesting powdered samples with sulfuric acid (H_2SO_4) and salicylic acid or catalyst mixture (Piper, 1966). Phosphorus and potassium concentration analyzed from triacid extracts obtained by digesting plant material with a triacid mixture (9:4:1 ratio of nitric acid [HNO_3], sulfuric acid [H_2SO_4], and perchloric acid [$HClO_4$]) as suggested by Piper (1966). P concentration quantified by the Vanadomolybdo phosphoric yellow color method using a spectrophotometer (Jackson, 1967). K content was measured with a Flame Photometer (Piper, 1966).

The N, P, and K concentration were documented as percentages. Nutrient uptake was calculated and denoted in kg ha^{-1} applying the formula outlined below:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) X Grain/Seed or Stover/Haulm yield}}{100}$$

3.10 Soil analysis

Combined samples of soil (0-30 cm depth) were collected from random locations of testing field before initiating the trial and after both crop harvest from every single plot. The samples were air-dried in the shade, powered and passed through a 2 mm sieve, and examined for different soil properties.

3.10.1 Bulk density (g cm^{-3})

Obtain an undisturbed soil sample using a core sampler of known volume. Oven-dry the sample at 105°C for 24 hours then measure the weight of the dried soil sample. Formula for calculating bulk density:

$$\textbf{Bulk density (g cm}^{-3}\textbf{)} = \frac{\text{Dry soil weight (g)}}{\text{Core volume (cm}^3\text{)}}$$

3.10.2 Particle density (g cm^{-3})

Weigh 10 g of oven-dried soil and transfer it into a pycnometer. Add distilled water to fill the pycnometer halfway and gently shake to remove air bubbles. Fill the pycnometer to the top with water, record the total weight, and determine the volume of water displaced. Compute particle density using the formula.

$$\text{Particle Density (g/cm}^3\text{)} = \frac{\text{Volume of water displaced (cm}^3\text{)}}{\text{Dry soil weight (g)}}$$

3.10.3 Porosity (%)

The percentage of soil porosity can be computed using the equation:

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle Density}}\right) \times 100$$

3.10.4 Soil pH

pH of soil was measured using a pH meter after equilibrating the soil in a water suspension at a 1:2.5 soil-to-water ratio for 60 minutes (Jackson, 1973).

3.10.5 Electrical conductivity (dSm^{-1})

Electrical conductivity was measured in a filtrate obtained by shaking 20 g soil with 50 ml distilled water for 30 minutes and filtering through Whatman No. 1. The conductivity meter was calibrated with 0.01 M KCl (1.412 dS m^{-1} at 25°C) and filtrate was analyzed (Richards, 1954).

3.10.6 Organic carbon (%)

Organic carbon was assessed by the Walkley and Black method (Piper, 1966). 2 gm sample of soil were oxidized with a mixture of 10 ml potassium dichromate and 20 ml concentrated sulfuric acid. Add 200 ml distilled water, 10 ml orthophosphoric acid, and 4 drops of diphenylamine indicator (solution turns violet), the unreacted dichromate was titrated with ferrous ammonium sulfate solution until the color turned bright green at the endpoint.

3.10.7 Available nitrogen (kg ha^{-1})

A 20 g sample of dried soil was transferred to a distillation flask in a micro-Kjeldahl distillation assembly. To this, 100 ml of 0.32% $KMNO_4$ and 100 ml of 2.5% NaOH were added. Distillation unit was sealed, and distillation was started. Ammonia liberated during heating was absorbed in 25 ml of boric acid with a mixed indicator, turning the solution from pink-red to green. About 100 ml of distillate was collected and titrated with 0.02 N H_2SO_4 until the original pink-red color reappeared. A blank without soil was similarly processed for correction (Subbiah and Asija, 1956).

3.10.8 Available phosphorus (kg ha^{-1})

A 2.5 g soil sample was combined with 50 ml of 0.5 M $NaHCO_3$ and a small amount of Darco-G-60 in a 100 ml conical flask. Mixture shake for half hour and then filtered through filter paper (Whatman no 1). From the filtrate, 5 ml was transferred into a 20 ml volumetric flask. Then, 0.5 ml of 5 N H_2SO_4 was added, and the mixture was shaken until CO_2 evolution ceased. Afterward, 4 ml of ascorbic acid was added, and the volume was made up to 25 ml with distilled water. A blank was prepared in the same way. The intensity of the blue color was measured at 760 nm using a Spectrophotometer (Olsen et al., 1954).

3.10.9 Available potassium (kg ha^{-1})

Take 5 g of dried soil in a 150 ml conical flask and add 25 ml of neutral ammonium acetate solution. Shake the mixture for 5 minutes on a mechanical shaker and filter it using Whatman No. 1 filter paper. Collect the filtrate in a beaker. Dilute 5 ml of the extract with distilled water and measure the potassium content using a flame photometer (Jackson, 1973).

3.10.10 Microbial Properties

The soil microbial count was assessed using the serial dilution plate technique as described by Dhingra and Sinclair (1995). In this method, 1 g of soil sample was aseptically taken in a 10 ml sterile tube containing 9 ml of distilled water and thoroughly shaken. From this suspension, 1 ml was transferred to another 10 ml tube containing 9 ml of distilled water, and the process was repeated to achieve serial dilutions of 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}, and 10^{-9}. After obtaining the desired dilution, 1 ml of the diluted suspension was poured onto Petri dishes containing specific media to promote the growth of targeted microorganisms. The soil moisture content maintained between 20-30% (w/w) was found to be optimal for the assessment of microbial properties, as it supports adequate microbial activity and ensures accurate enumeration under aerobic conditions. This moisture range is considered suitable for maintaining a favorable environment for microbial survival, proliferation, and detection during laboratory analysis.

A) Media for bacterial isolation (Nutrient Agar - NA): Peptone (5 g), Beef extract (3 g)**,** Agar (20 g), Distilled water (1000 ml).

B) Media for fungal isolation (Potato Dextrose Agar - PDA): Peptone (200 g), Dextrose (20 g)**,** Agar (20 g)**,** Distilled water (1000 ml).

C) Media for actinomycete isolation (Ken Knight Agar): Dextrose (1 g), KH_2PO_4 (1 g), $NaNO_3$ (0.1 g), KCl (0.1 g)**,** $MgSO_4$ (1 g)**,** Agar (15 g)**,** Distilled water: (1000 ml).

3.11 Economics

3.11.1 Cost of cultivation (₹ ha^{-1})

The COC for the cropping system in present investigation was determined by summing up all expenses incurred. This included the cost of inputs, expenses for mechanical operations, and labour charges. The cost of cultivation was calculated and recorded for each treatment separately.

3.11.2 Gross returns (₹ ha^{-1})

The grain/seed and stover/haulm yields (kg ha^{-1}) of maize and chickpea were converted into monetary values (Rs) based on prevailing market prices. Treatment-wise gross monetary returns per hectare were then computed accordingly.

3.11.3 Net returns (₹ ha^{-1})

Net monetary returns were determined by deducting cultivation cost from gross monetary returns.

3.11.4 Benefit : cost ratio

The Benefit-Cost (B:C) ratio is a measure of profitability, computed by dividing the gross returns by cost of cultivation for a given treatment or cropping system. It indicates the economic efficiency of the investment.

$$\text{B:C ratio} = \frac{\text{Total income from crop (GR) (₹ ha}^{-1}\text{)}}{\text{Overall input cost (COC) (₹ ha}^{-1}\text{)}}$$

3.12 Statistical Analysis

Statistical analysis was performed using the methods for split-plot design outlined by Gomez and Gomez (1984). Total variance (σ^2) and degrees of freedom (n-1) were partitioned among various sources. The treatment variance was compared with the error variance to compute the F-value, which was used to test significance at the 5% level. Treatment effects were summarized in tables showing mean values for varying parameters along with the corresponding standard error (SE (m) ±) and critical difference (CD at 5% level).

3.13 Pooled Analysis

The simple analysis of variance may unsuitable under varying seasonal conditions due to possible differences in error variances between seasons and treatment × seasons interaction may be significant. Therefore, a pooled analysis was performed for the preceding *kharif* maize and succeeding *rabi* chickpea over two years, following the method outlined by Panse and Sukhatme (1978). Bartlett's test was used to assess the homogeneity of error variance. The interaction between season and treatment was tested against the joint error variance estimate to determine the existence of any significant season × treatment interaction.

Table 9. Analysis of Variance (ANOVA) Structure for the Split-Plot Design Followed During 2023-24 and 2024-25

Source of Variation	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Sum of Squares (MSS)	F-value
Replications (R)	r -1 = 3 - 1 = 2	SSR	MSR = SSR/2	MSR / MSe(main)
Main Plot Treatments (A)	a - 1 = 4 - 1 = 3	SSA	MSA = SSA/3	MSA / MSe(main)
Error (Main Plot)	(r - 1)(a - 1) = 2 × 3 = 6	SSE (main)	MSe (main)	-
Sub-Plot Treatments (B)	b - 1 = 3 - 1 = 2	SSB	MSB = SSB/2	MSB / MSe(sub)
A × B Interaction	(a - 1)(b - 1) = 3 × 2 = 6	SSA×B	MSA×B = SSA×B/6	MSA×B / MSe(sub)
Error (Sub-Plot)	a(r -1)(b - 1) = 4 (2)×2 = 16	SSE (sub)	MSe (sub)	-
Total	Rab - 1 = (3×4×3) – 1 = 35	SST	-	-

CHAPTER IV

RESULTS AND DISCUSSION

This chapter summarizes the experimental results of a field study conducted to evaluate “Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in a maize-chickpea cropping system in the central plain zone of Punjab.” The study was conducted at Agronomy Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab (India), during *Kharif* and *Rabi* seasons of 2023-24 and 2024-25. The chapter includes data on the effects of varying rates of recommended dose of fertilizers and FYM on maize morphology, yield components, productivity, quality, nutrient uptake, and soil properties, along with their residual impact on chickpea. Experimental results are analysed using statistical parameters and discussed with logical interpretations, incorporating relevant theories and previous research findings wherever applicable.

4.1 Impact of integrated nutrient management on *kharif* maize

4.1.1 Plant stand ha^{-1}

4.1.1.1 Initial plant stand

Plant count at establishment of maize noted under varying treatments is shown in Table 10. Results revealed that the plant count at establishment remained unaffected by the application of RDF, FYM levels, or their interaction over the two years of investigation.

Initial plant stand primarily depends on the amount of stored food reserves present in the seed and how efficiently these reserves are converted into energy for germination and early growth. Along with this, the soil’s physical condition also significantly influences seedling establishment.

4.1.1.2 Final plant stand

The plant count at harvest of maize recorded under different treatments is depicted in Table 10. The findings revealed that neither the RDF levels, FYM applications, nor their interaction had a significant effect on the final plant population in either year of the study.

The final plant stand is affected by the soil's physicochemical characteristics, along with the biological environment, all of which contribute to improved plant growth and help sustain an optimal plant population. The plant count at harvest was relatively stable, suggesting that the changes observed in varying parameters across both seasons were due to the effects of the treatments rather than differences in plant population.

Table 10: Effect of integrated nutrient management on plant stand at establishment and harvest of maize during 2023-24 and 2024-25

Treatments	Plant stand ha^{-1}			
	Initial plant stand		Final plant stand	
	2023-24	2024-25	2023-24	2024-25
Nutrient management levels				
N_0 : Control	73259.26 (87.91)	73406.89 (88.09)	66814.81 (80.18)	70962.33 (85.16)
N_1 : 50 % RDF	73703.70 (88.45)	75177.11 (90.21)	67777.78 (81.33)	72333.27 (86.80)
N_2 : 75 % RDF	74074.07 (88.89)	76364.47 (91.64)	68370.37 (82.04)	73076.02 (87.69)
N_3 : 100 % RDF	74962.96 (89.95)	77600.78 (93.12)	68592.59 (82.30)	74201.89 (89.04)
SEm ±	580.12	895.54	1738.38	1274.27
CD 5%	NS	NS	NS	NS
FYM levels				
F_0 : Control	73555.56 (88.23)	74652.75 (89.58)	67444.44 (80.93)	71277.95 (85.53)
F_1 : 5 t ha^{-1} FYM	73833.33 (88.58)	75487.52 (90.59)	67888.89 (81.46)	72646.52 (87.18)
F_2 : 10 t ha^{-1} FYM	74611.11 (89.53)	76771.67 (92.13)	68333.33 (82.00)	74005.67 (88.81)
SEm ±	305.98	629.17	554.16	722.74
CD 5%	NS	NS	NS	NS
Interaction N*F				
SEm ±	611.95	1258.35	1108.33	1445.47
CD 5%	NS	NS	NS	NS

(Values in parentheses represent the original percentages of plant population)

4.1.2 Morphological traits

4.1.2.1 Plant height (cm)

The height of plant recorded under varying treatments and their combinations at varying developmental phases is shown in Table 11, 11 (a) and figure No. 4.

Effect of RDF levels

Application of RDF notably impacted the height of the plant at all morphological phases except 30 DAS across both years. The height of plant increases with increase in RDF levels. The maximum plant height (133.85, 139.07 cm at 60 DAS and 149.35, 155.17 cm at 90 DAS) was noted with 100% RDF (N_3), which was found statistically better over control (N_0), 50% (N_1), and 75% RDF (N_2) across both years. The minimum height at both 60 DAS and 90 DAS was registered in the control (N_0).

The height of plants serves as an indicator of their growth response to the given RDF levels. Results indicates that maize height gradually increased as the crop matured, reaching its maximum at 90 DAS. This growth was driven by the enhanced availability of primary macronutrients from fertilizers, which boosted NUE and accelerated cell division and expansion. (Wailare *et al.,* 2017; Singh *et al.,* 2017; Raman and Suganya 2018; Prasad *et al.,* 2024). Similar outcomes noted by Vadivel *et al.,* (2001), Rajeshwari *et al.,* (2007), Sharma *et al.,* (2016), Jadav *et al.,* (2017), Mozafari *et al.,* (2018), Roopashree *et al.,* (2019), Singh *et al.,* (2019), Iqbal *et al.,* (2020), Karki *et al.,* (2020), Manjunatha *et al.,* (2022), Kuldeep *et al.,* (2022), Naveen *et al.,* (2023).

Effect of FYM levels

The application of FYM notably impacts height at all developmental phases, except at 30 DAS, across both study years. The height increased in response to increasing FYM levels. The maximum plant height (125.15, 128.16 cm at 60 DAS and 140.98, 143,49 cm at 90 DAS) was noted in incorporation of 10 t ha^{-1} FYM (F_2), showed notably better response than control (F_0), and 5 t ha^{-1} FYM (F_1) in first and second season. The control treatment (N0) recorded the shortest height at both 60 DAS and 90 DAS.

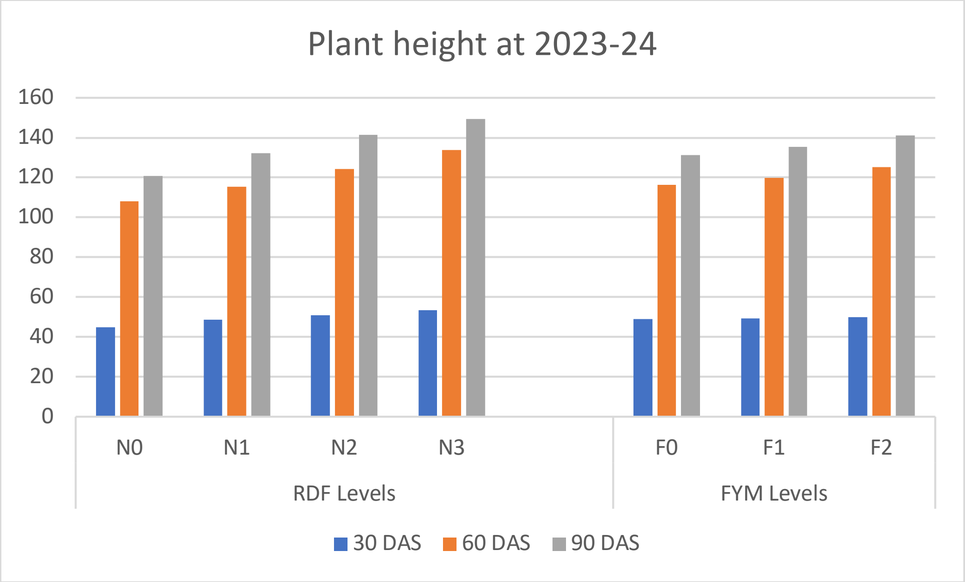
Organic manures increase the organic matter content of soil, including humic compounds that aid in nutrient retention and stimulate root development. These benefits contribute to more vigorous plant growth, resulting in taller maize plants (Verma *et al.,* 2018). This results are corroborate with Sharma *et al.,* (2016), Jadav *et al.,* (2017), Khan and Jan (2018), Singh *et al.,* (2019), Prabhavati *et al.,* (2021), Kuldeep *et al.,* (2022).

Interaction effect

The combined impact of RDF and FYM rates showed no marked effect at 30 DAS, and found significant at 60 and 90 DAS in across both study years. Greater height at 60 DAS (139.60 and 142.11 cm) and at 90 DAS (152.88 and 156.21 cm) recorded under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study years. In the first year, N_3F_2 was considerably better to over varying treatment combinations. However, in second year, N_3F_2 was at par with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) at 60 DAS but at 90 DAS, it showed similarity with N_3F_1, N_3F_0 and N_2F_2. A similar trend of results observed by Wagh (2002), Kumar *et al.,* (2005), Joshi *et al.,* (2013), Roopashree *et al.,* (2019), Naveena and Geetha (2022).

Table 11: Effect of integrated nutrient management on maize height (cm) at varying morphological phases during 2023-24 and 2024-25

Treatments	**Plant height (cm)**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	44.93	43.39	108.12	103.74	120.78	113.50
N_1 : 50 % RDF	48.60	49.71	115.38	116.48	132.13	134.04
N_2 : 75 % RDF	50.87	52.64	124.42	128.70	141.42	146.93
N_3 : 100 % RDF	53.29	56.17	133.85	139.07	149.35	155.17
SEm ±	0.28	0.84	0.80	1.15	1.12	1.01
CD 5%	NS	NS	2.76	3.99	3.87	3.50
FYM levels						
F_0 : Control	49.00	48.75	116.24	115.82	131.28	130.59
F_1 : 5 t ha^{-1} FYM	49.42	50.57	119.94	122.02	135.50	138.16
F_2 : 10 t ha^{-1} FYM	49.85	52.13	125.15	128.16	140.98	143.49
SEm ±	0.34	0.49	0.52	0.76	0.38	0.93
CD 5%	NS	NS	1.54	2.27	1.14	2.79
Interaction N*F						
SEm ±	0.69	0.99	1.03	1.51	0.76	1.86
CD 5%	NS	NS	3.09	4.53	2.27	5.57



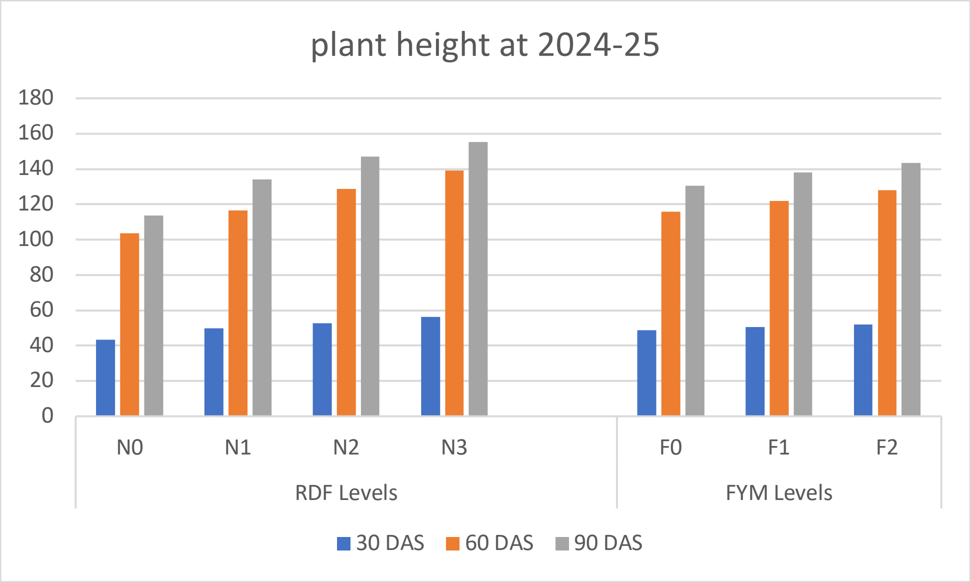


Fig. 4. Maize height (cm) at varying morphological phases as impacted by various treatments

Table 11 (a): Interaction between RDF and FYM levels on maize height at 60 and 90 DAS in 2023-24 and 2024-25

Plant height (60 DAS) (2023-24)					Plant height (60 DAS) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	106.70	108.52	109.15	108.12	**N_0**	99.79	104.12	107.32	103.74
N_1	111.31	113.96	120.87	115.38	**N_1**	109.96	115.62	123.87	116.48
N_2	118.59	123.70	130.98	124.42	**N_2**	118.66	128.09	139.35	128.70
N_3	128.37	133.59	139.60	133.85	**N_3**	134.86	140.23	142.11	139.07
Mean	116.24	119.94	125.15		**Mean**	115.82	122.02	128.16	
SEm±	1.03				**SEm±**	1.51			
CD 5%	3.09				**CD 5%**	4.53			
Plant height (90 DAS) (2023-24)					**Plant height (90 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	115.30	121.59	125.44	120.78	**N_0**	103.55	115.83	121.11	113.50
N_1	127.18	130.65	138.56	132.13	**N_1**	126.58	133.99	141.56	134.04
N_2	137.20	140.01	147.04	141.42	**N_2**	138.68	147.05	155.07	146.93
N_3	145.44	149.74	152.88	149.35	**N_3**	153.55	155.76	156.21	155.17
Mean	131.28	135.50	140.98		**Mean**	130.59	138.16	143.49	
SEm±	0.76				**SEm±**	1.86			
CD 5%	2.27				**CD 5%**	5.57			

4.1.2.2 Number of leaves plant^{-1}

The leaf count under varying treatments and their combinations at varying morphological stages are depicted in Table 12 and 12 (a).

Effect of RDF levels

RDF application markedly affected the leaf count at all morphological phases except 30 DAS during first and second year. An increase in leaf count was observed with higher RDF levels. The maximum leaf count plant^{-1} (11.36, 11.73 at 60 DAS and 9.78, 10.81 at 90 DAS) was noted with 100% RDF (N_3) across the two years of research. At 60 DAS, N_3 was statistically superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2) in first and second year. However, at 90 DAS, N_3 showed similarity with 75% RDF (N_2) in first year but significantly superior to the control (F_0), 50% (F_1) and 75% RDF (F_2) during next year. Minimum leaf count noted in the control (N_0).

Leaves play a crucial role in photosynthesis, light interception, water and nutrient utilization, as well as overall crop growth and yield. The periodic leaf count exhibited a steady increase until physiological maturity but declined at the harvest stage due to senescence. Maize plants exhibited accelerated growth due to a sufficient nutrient supply, particularly nitrogen. This enhanced growth led to the development of more nodes and internodes, ultimately increasing the number of leaves (Gharge *et al.,* 2020; Naveen *et al.,* 2023). A similar outcomes was noted in studies by Rajeshwari *et al.,* (2007), Karki *et al.,* (2020), Manjunatha *et al.,* (2022), Kuldeep *et al.,* (2022).

Effect of FYM levels

Leaf count was notably impacted by FYM application at all morphometric phases, except at 30 DAS, during the two-year investigation. Maximum leaf count plant^{-1} (10.35, 10.56 at 60 DAS and 8.96, 9.55 at 90 DAS) noted with the 10 t ha^{-1} FYM (F_2), showing considerable superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two study seasons. Minimum number of leaves was registered in control (N_0).

Greater leaf numbers and larger leaf size, can be attributed to the improved nutrient balance facilitated by FYM application at the active crop's active growth period. The assured availability of vital nitrogen likely promoted cell division and enlargement, resulting in improved vegetative growth (Wanniang and Singh 2017). Similar results reported by Jadav *et al.,* (2017), Kuldeep *et al.,* (2022).

Interaction effect

The combination of RDF and FYM rates was not impacted at 30 DAS, and found significant at 60 and 90 DAS across the two years of research. Maximum leaf count plant^{-1} at 60 DAS (12.93 and 12.60 cm) and at 90 DAS (10.37 and 11.27) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. In first year, N_3F_2 notably greater than varying interactions at 60 DAS but at 90 DAS, it showed similarity to N_3F_1 and N_2F_2. During second year, N_3F_2 was comparable to N_3F_1 and N_2F_2 at 60 DAS but at 90 DAS it was similar with N_3F_1, N_3F_0 and N_2F_2. This findings are in accordance with Wagh (2002).

Table 12: Effect of integrated nutrient management on number of leaves of maize at varying morphological phases during 2023-24 and 2024-25

Treatments	**Number of leaves plant^{-1}**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	5.08	4.82	8.12	7.44	6.40	6.02
N_1 : 50 % RDF	5.60	5.67	8.74	8.81	7.67	7.88
N_2 : 75 % RDF	5.89	6.12	9.61	10.36	9.03	9.46
N_3 : 100 % RDF	6.28	6.40	11.36	11.73	9.78	10.81
SEm ±	0.09	0.07	0.14	0.25	0.23	0.38
CD 5%	NS	NS	0.49	0.87	0.79	1.32
FYM levels						
F_0 : Control	5.55	5.46	8.75	8.70	7.51	7.40
F_1 : 5 t ha^{-1} FYM	5.72	5.78	9.28	9.49	8.20	8.69
F_2 : 10 t ha^{-1} FYM	5.87	6.02	10.35	10.56	8.96	9.55
SEm ±	0.09	0.08	0.13	0.15	0.08	0.17
CD 5%	NS	NS	0.40	0.44	0.24	0.52
Interaction N*F						
SEm ±	0.17	0.16	0.26	0.30	0.16	0.35
CD 5%	NS	NS	0.79	0.89	0.47	1.04

Table 12 (a): Combinations of RDF and FYM levels on number of leaves of maize at 60 and 90 DAS during 2023-24 and 2024-25

Number of leaves plant^{-1} (60 DAS) (2023-24)					Number of leaves plant^{-1} (60 DAS) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	7.77	8.20	8.40	8.12	**N_0**	7.20	7.31	7.81	7.44
N_1	8.50	8.57	9.17	8.74	**N_1**	7.93	8.60	9.90	8.81
N_2	8.63	9.30	10.90	9.61	**N_2**	9.15	9.97	11.95	10.36
N_3	10.10	11.03	12.93	11.36	**N_3**	10.53	12.07	12.60	11.73
Mean	8.75	9.28	10.35		**Mean**	8.70	9.49	10.56	
SEm±	0.26				**SEm±**	0.30			
CD 5%	0.79				**CD 5%**	0.89			
Number of leaves plant^{-1} (90 DAS) (2023-24)					**Number of leaves plant^{-1} (90 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	5.50	6.59	7.11	6.40	**N_0**	4.49	6.71	6.87	6.02
N_1	7.23	7.34	8.44	7.67	**N_1**	6.98	7.40	9.27	7.88
N_2	8.37	8.82	9.91	9.03	**N_2**	7.85	9.73	10.80	9.46
N_3	8.94	10.03	10.37	9.78	**N_3**	10.27	10.90	11.27	10.81
Mean	7.51	8.20	8.96		**Mean**	7.40	8.69	9.55	
SEm±	0.16				**SEm±**	0.35			
CD 5%	0.47				**CD 5%**	1.04			

4.1.2.3 Stem girth (cm)

The stem girth recorded under different treatments and their combinations at varying morphometric stages is shown in Table 13 and 13 (a).

Effect of RDF levels

The application of RDF recorded significant effect on the stem girth at all developmental phases except 30 DAS, throughout the two years of research. Stem girth improved with increasing levels of RDF. The maximum stem girth (3.58, 3.66 at 60 DAS and 5.97, 6.23 at 90 DAS) was noted with the 100% RDF (N_3) across the two years of research. At 60 DAS, N_3 was statistically superior to the control (N_0), 50% RDF (N_1), but it was found similar with 75% RDF (N_2). However, at 90 DAS, N_3 was found statistically superior over control (F_0), 50 % (F_1) and 75% RDF (N_2) during first season and similar to 75 % RDF during next season. Minimum stem girth at both 60 DAS and 90 DAS noted under control (N_0).

At 60 DAS, N_3 was statistically superior to the control and 50% RDF but remained comparable with 75% RDF (N_2), indicating sufficient nutrient availability at the moderate nitrogen level. However, at 90 DAS, N_3 showed superiority in the first season, reflecting the sustained nitrogen requirement for late vegetative growth, while its similarity with N_2 in the next season suggests efficient nutrient utilization and residual soil fertility that maintained comparable growth even at reduced nitrogen levels. Supply of primary macronutrients promoted new cell formation, cell division, and multiplication, leading to vigorous root system development. This, in turn, enhanced nutrient absorption and utilization from applied fertilizers, resulting in improved plant growth, including increased plant height and stem girth (Nalini *et al.,* 2020). The similar findings observed by Jadav *et al.,* (2017), Manjunatha *et al.,* (2022).

Effect of FYM levels

FYM incorporation significantly increased the stem girth at morphometric stages except 30 DAS throughout the two years. The stem girth impacted with increasing levels of FYM. the maximum stem girth (3.03, 3.12 cm at 60 DAS and 4.80, 5.17 cm at 90 DAS) noted in 10 t ha^{-1} FYM (F_2), showed superiority to control (F_0), and 5 t ha^{-1} FYM (F_1) in initial and following year. Minimum stem girth at both 60 DAS and 90 DAS was noted in control (N_0).

Stem girth is a critical factor influencing the efficient transport of photosynthates, minerals, and water within the plant. A wider stem girth facilitates enhanced conductivity through the xylem and phloem, ensuring an uninterrupted supply of nutrients and assimilates to different plant parts. The application of organic manure further supports stem development by providing essential growth hormones and enzymes that stimulate cell division and elongation. This improved stem girth contributes to overall plant vigor, leading to better structural stability and higher productivity (Singh and Misal 2020). Results are similar with Jadav *et al.,* (2017).

Interaction effect

The combined influence of RDF and FYM levels was not significant at 30 and 90 DAS across first and second experimental years. However, it was insignificant in the first season but showed a marked effect during the second year at 60 DAS. The maximum stem girth at 90 DAS (3.77 cm) noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) and it showed similarity to N_3F_1, N_3F_0 and N_2F_2 during the second year. Similar findings are recorded by Naveena and Geetha (2022),

Table 13: Effect of integrated nutrient management on maize stem girth (cm) at various morphological stages during 2023-24 and 2024-25

Treatments	**Stem girth (cm)**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	1.41	1.32	2.05	1.98	2.86	2.48
N_1 : 50 % RDF	1.65	1.59	2.48	2.53	3.99	4.30
N_2 : 75 % RDF	1.89	1.95	3.20	3.29	5.04	5.57
N_3 : 100 % RDF	2.14	2.27	3.58	3.66	5.97	6.23
SEm ±	0.07	0.04	0.11	0.12	0.03	0.21
CD 5%	NS	NS	0.39	0.43	0.12	0.73
FYM levels						
F_0 : Control	1.71	1.63	2.65	2.60	4.11	4.05
F_1 : 5 t ha^{-1} FYM	1.78	1.80	2.80	2.88	4.48	4.72
F_2 : 10 t ha^{-1} FYM	1.83	1.92	3.03	3.12	4.80	5.17
SEm ±	0.03	0.04	0.06	0.04	0.02	0.09
CD 5%	NS	NS	0.17	0.12	0.07	0.27
Interaction N*F						
SEm ±	0.07	0.09	0.11	0.08	0.05	0.18
CD 5%	NS	NS	NS	0.25	NS	NS

Table 13 (a) : Interaction of RDF and FYM scales on maize stem girth at 60 DAS during 2024-25

Stem girth (cm) (60 DAS)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1.82	2.00	2.12	1.98
N_1	2.25	2.43	2.92	2.53
N_2	2.82	3.40	3.65	3.29
N_3	3.53	3.68	3.77	3.66
Mean	2.60	2.88	3.12	
SEm±	0.08			
CD 5%	0.25			

4.1.2.4 Leaf area plant^{-1} (cm^2)

LA recorded under various treatments and their combinations at different developmental phases is illustrated in Table 14 and 14(a).

Effect of RDF levels

Across the two years of study, RDF notably influenced the leaf area per plant at various developmental stages, excluding 30 DAS. The leaf area plant^{-1} increased in response to increasing levels of RDF. The maximum leaf area plant^{-1} (2944.59, 3118.25 cm at 60 DAS and 3692.57, 3890.25 cm at 90 DAS) was obtained in 100% RDF (N_3), showed statistical superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) during the first and second year. The minimum leaf area at both 60 and 90 DAS was noted in the control (N_0).

Leaf area estimation is a critical parameter for assessing photosynthetic efficiency, interception of light, utilization of water and nutrient, and overall crop growth and production capacity. A well-developed leaf area enhances radiation use efficiency (RUE), facilitating optimal photosynthetic activity and dry matter accumulation. It also important in transpiration and stomatal regulation, influencing water balance and nutrient uptake. The increase in leaf area with higher nitrogen application can be attributed to nitrogen's role in promoting cell division and elongation (Naveen *et al.,* 2023). These findings are also showed by Rajeshwari *et al.,* (2007), Mozafari *et al.,* (2018), Singh *et al.,* (2019), Naveen *et al.,* (2023).

Effect of FYM levels

Incorporation of FYM had a notable impact on leaf area at varying morphological phases except 30 DAS during two years experimental period. The leaf area plant^{-1} increased in response to increasing FYM levels. The maximum leaf area plant^{-1} (2451.31, 2593.43 cm at 60 DAS and 3118.12, 3244.90 cm at 90 DAS) registered in 10 t ha^{-1} FYM (F2), exceeding that of the control (F_0), and 5 t ha^{-1} FYM (F_1) across both study years. Minimum leaf area at both 60 and 90 DAS was measured in control (N_0).

The addition of organic sources enhances soil fertility by boosting the availability of key primary macronutrients. This enhanced nutrient availability ensures a steady supply of nutrients to plants, supporting better root development and early vegetative growth of maize. Stronger root systems improve nutrient and water uptake efficiency, leading to enhanced photosynthetic activity. As a result, plants experience improved growth attributes such as leaf area (Desai *et al.,* 2022). The similar findings reported by Khan and Jan (2018), Singh *et al.,* (2019).

Interaction effect

Interaction of varying RDF and FYM levels was not significantly affected at 30 DAS, and showing significance at 60 and 90 DAS across two years of research. Maximum leaf area at 60 DAS (3110.20 and 3271.35 cm) and at 90 DAS (4005.03 and 4220.90 cm) noted in 100 % RDF + 10 t FYM ha^{-1} (N_3F_2) across two seasons of research. In the first year, N_3F_2 showing superiority than varying treatment interactions. In next year, N_3F_2 similar to 100% dose of RDF in conjunction with 5 t FYM ha^{-1} (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). This findings are similar with Wagh (2002), Roopashree *et al.,* (2019), Naveena and Geetha (2022).

Table 14: Effect of integrated nutrient management on leaf area (cm^2) at varying morphological phases during 2023-24 and 2024-25

Treatments	**Leaf area plant^{-1} (cm^2)**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	1001.21	853.97	1454.42	1308.79	1804.18	1626.33
N_1 : 50 % RDF	1396.88	1360.85	1967.44	2053.74	2491.76	2531.59
N_2 : 75 % RDF	1758.70	1923.79	2517.91	2618.18	3132.54	3304.01
N_3 : 100 % RDF	2262.54	2420.41	2944.59	3118.25	3692.57	3890.25
SEm ±	69.91	89.82	32.54	67.89	21.65	76.22
CD 5%	NS	NS	112.59	234.94	74.92	263.74
FYM levels						
F_0 : Control	1483.65	1461.97	1996.81	1957.54	2428.58	2411.73
F_1 : 5 t ha^{-1} FYM	1556.55	1645.69	2215.15	2273.25	2794.09	2857.51
F_2 : 10 t ha^{-1} FYM	1774.29	1811.60	2451.31	2593.43	3118.12	3244.90
SEm ±	83.42	94.32	19.93	41.04	18.80	50.81
CD 5%	NS	NS	59.76	123.03	56.37	152.32
Interaction N*F						
SEm ±	166.83	188.65	39.87	82.08	37.61	101.62
CD 5%	NS	NS	119.53	246.06	112.74	304.64

Table 14 (a): Interaction of RDF and FYM levels on leaf area (cm^2) of maize at 60 and 90 DAS during 2023-24 and 2024-25

Leaf area per plant (cm^2) (60 DAS) (2023-24)					**Leaf area per plant (cm^2) (60 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1335.72	1453.42	1574.11	1454.42	**N_0**	1108.21	1253.68	1564.50	1308.79
N_1	1759.17	1847.14	2296.01	1967.44	**N_1**	1624.51	2056.04	2480.67	2053.74
N_2	2144.14	2584.68	2824.90	2517.91	**N_2**	2128.48	2668.87	3057.19	2618.18
N_3	2748.21	2975.36	3110.20	2944.59	**N_3**	2968.98	3114.41	3271.35	3118.25
Mean	1996.81	2215.15	2451.31		**Mean**	1957.54	2273.25	2593.43	
SEm±	39.87				**SEm±**	82.08			
CD 5%	119.53				**CD 5%**	246.06			
Leaf area per plant (cm^2) (90 DAS) (2023-24)					**Leaf area per plant (cm^2) (90 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1625.81	1843.55	1943.19	1804.18	**N_0**	1501.65	1585.24	1792.10	1626.33
N_1	2129.00	2423.02	2923.25	2491.76	**N_1**	1967.42	2588.01	3039.33	2531.59
N_2	2694.53	3102.07	3601.00	3132.54	**N_2**	2762.19	3222.57	3927.28	3304.01
N_3	3264.97	3807.72	4005.03	3692.57	**N_3**	3415.65	4034.20	4220.90	3890.25
Mean	2428.58	2794.09	3118.12		**Mean**	2411.73	2857.51	3244.90	
SEm±	37.61				**SEm±**	101.62			
CD 5%	112.74				**CD 5%**	304.64			

4.1.2.5 Leaf area index plant^{-1}

Leaf area index noted under different treatments and their combinations at various developmental phases is depicted in Table 15 and 15 (a).

Effect of RDF levels

The RDF significantly impacted the leaf area index at all morphological phases, except at 30 DAS across two study years. The maximum leaf area index plant^{-1} (2.45, 2.60 at 60 DAS and 3.08, 3.24 at 90 DAS) was obtained in 100% RDF (N_3), which was found statistically greater than control (N_0), 50% (N_1), and 75% RDF (N_2) across two study years. Least values noted in control at varying developmental phases.

Increase in soil nitrogen contributed to overall growth enhancement by boosting metabolic activities, assimilation rate, and cell division within the plant. This, in turn, led to a higher leaf area index (LAI), further supporting improved plant development (Verma 2011). Current outcomes are identical to Vadivel *et al.,* (2001), Rajeshwari *et al.,* (2007) and Iqbal *et al.,* (2020).

Effect of FYM levels

Application of FYM notably enhanced the leaf area index at all crop morphometric phases except 30 DAS throughout the two study years. Maximum leaf area index plant^{-1} (2.04, 2.16 at 60 DAS and 2.60, 2.70 at 90 DAS) was noted in 10 tonnes FYM ha^{-1} (F_2), showing superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two study seasons. Control noted the least values at varying morphometric phases.

The steady nutrient supply from FYM promotes robust root development and early vegetative growth in maize. Enhanced root systems improve nutrient and water absorption, leading to greater photosynthetic efficiency. As a result, plants achieve a higher leaf area index (LAI), optimizing light interception and overall growth (Desai *et al.,* 2022). The outcomes are similar to Vadivel *et al.,* (2001) and Sharma *et al.,* (2016)

Interaction effect

The combination of different RDF and FYM levels showed no significant effect at 30 DAS, but found statistically significant at 60 and 90 DAS across two years of research. Highest LAI at 60 DAS (2.59 and 2.73) and at 90 DAS (3.34 and 3.52) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 combination showed superiority to varying treatment combinations in initial year.

However, in following year, N_3F_2 similar with 100% RDF coupled with 5 t ha^{-1} FYM (N_3F_1), and 75% RDF with 10 t ha^{-1} FYM (N_2F_2). These results corroborates with Kumar *et al.,* (2005), Joshi *et al.,* (2013).

Table 15: Effect of integrated nutrient management on leaf area index at varying developmental phases in 2023-24 and 2024-25

Treatments	**Leaf area index plant^{-1}**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	0.83	0.71	1.21	1.09	1.50	1.36
N_1 : 50 % RDF	1.16	1.13	1.64	1.71	2.08	2.11
N_2 : 75 % RDF	1.46	1.60	2.10	2.18	2.61	2.75
N_3 : 100 % RDF	1.88	2.02	2.45	2.60	3.08	3.24
SEm ±	0.06	0.07	0.03	0.06	0.02	0.06
CD 5%	NS	NS	0.09	0.20	0.06	0.22
FYM levels						
F_0 : Control	1.23	1.22	1.66	1.63	2.02	2.01
F_1 : 5 t ha^{-1} FYM	1.29	1.37	1.85	1.89	2.33	2.38
F_2 : 10 t ha^{-1} FYM	1.47	1.51	2.04	2.16	2.60	2.70
SEm ±	0.07	0.08	0.02	0.03	0.02	0.04
CD 5%	NS	NS	0.05	0.10	0.05	0.13
Interaction N*F						
SEm ±	0.14	0.16	0.03	0.07	0.03	0.08
CD 5%	NS	NS	0.10	0.21	0.09	0.25

Table 15 (a): Interaction effect of RDF and FYM scales on LAI plant^{-1} at 60 and 90 DAS in 2023-24 and 2024-25

LAI (60 DAS) (2023-24)					LAI (60 DAS) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1.11	1.21	1.31	1.21	**N_0**	0.92	1.04	1.30	1.09
N_1	1.47	1.54	1.91	1.64	**N_1**	1.35	1.71	2.07	1.71
N_2	1.79	2.15	2.35	2.10	**N_2**	1.77	2.22	2.55	2.18
N_3	2.29	2.48	2.59	2.45	**N_3**	2.47	2.60	2.73	2.60
Mean	1.66	1.85	2.04		**Mean**	1.63	1.89	2.16	
SEm±	0.03				**SEm±**	0.07			
CD 5%	0.10				**CD 5%**	0.21			
LAI (90 DAS) (2023-24)					**LAI (90 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1.35	1.54	1.62	1.50	**N_0**	1.25	1.32	1.49	1.36
N_1	1.77	2.02	2.44	2.08	**N_1**	1.64	2.16	2.53	2.11
N_2	2.25	2.59	3.00	2.61	**N_2**	2.30	2.69	3.27	2.75
N_3	2.72	3.17	3.34	3.08	**N_3**	2.85	3.36	3.52	3.24
Mean	2.02	2.33	2.60		**Mean**	2.01	2.38	2.70	
SEm±	0.03				**SEm±**	0.08			
CD 5%	0.09				**CD 5%**	0.25			

4.1.2.6 Dry matter accumulation (g plant^{-1})

The dry matter accumulation noted under various treatments and their combinations at different developmental stages is depicted in Table 16, 16 (a) and figure 5.

Effect of RDF levels

RDF significantly increased dry matter accumulation at all morphometric phases, except at 30 DAS across the two years of research. Dry matter accumulation increased in response to increasing levels of RDF. Maximum dry matter accumulation (44.47, 48.40 g plant^{-1} at 60 DAS and 153.26, 156.15 g plant^{-1} at 90 DAS) was noted with 100% RDF (N_3), which showed statistical superiority over control (N_0), 50% (N_1), and 75% RDF (N_2) during both years. Minimum dry matter accumulation at both 60 DAS and 90 DAS was noted in the control (N_0).

Plants require essential nutrients for optimal growth, enabling greater height, increased leaf production, and a higher leaf area index (LAI). This improved canopy development enhances light interception, leading to increased dry matter accumulation. Higher nutrient application promotes leaf area expansion, which enhances photosynthetic efficiency, facilitates greater assimilation of photosynthates, and ultimately results in higher dry matter production (Naveen *et al.,* 2023). This finding are similar with Vadivel *et al.,* (2001), Rajeshwari *et al.,* (2007), Sharma *et al.,* (2016), Mozafari *et al.,* (2018), Singh *et al.,* (2019), Iqbal *et al.,* (2020) and Naveen *et al.,* (2023).

Effect of FYM levels

Application of FYM significant influence on dry matter accumulation at all developmental phases except 30 DAS throughout the two study years. Dry matter accumulation increased with increasing FYM levels. The maximum dry matter accumulation (37.45, 39.54 g plant^{-1} at 60 DAS and 139.79, 141.15 g plant^{-1} at 90 DAS) was noted 10 t ha^{-1} FYM (F_2), showed statistical superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across both study years. Minimum dry matter accumulation at both 60 DAS and 90 DAS was obtained in the control (N_0).

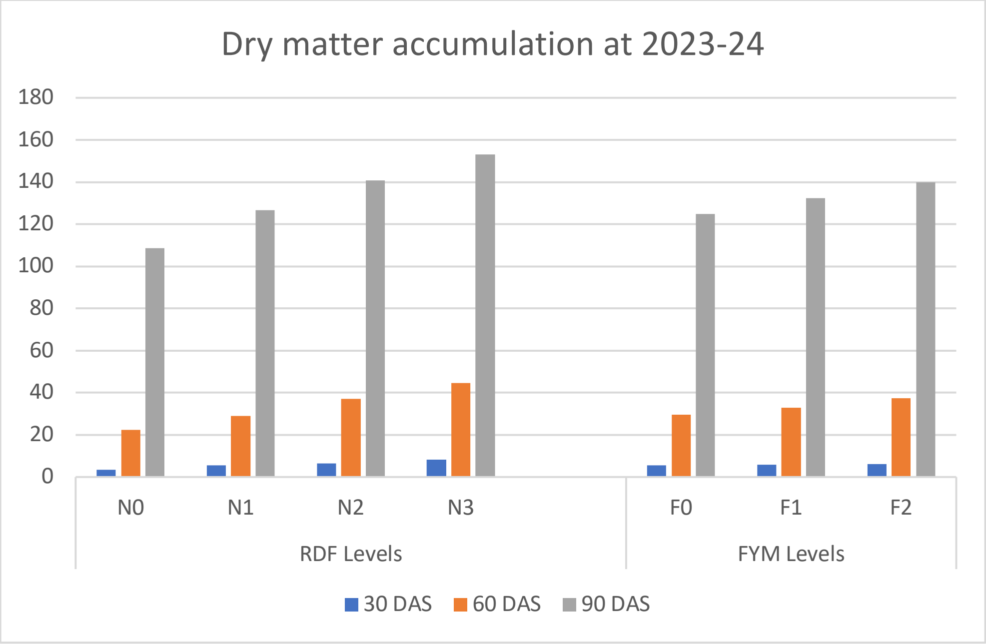
Farmyard manure (FYM) is closely linked to enhanced assimilation rates and improved assimilate partitioning, both of which play a crucial role in increasing dry matter accumulation (Nagar *et al.,* 2022). Organic manures act as a slow releasing nitrogen source, proving beneficial in the later stages of crop growth, which may have contributed to rise in dry matter (Nehra *et al.,* 2004). Similar results noted by Sharma *et al.,* (2016), Singh *et al.,* (2019), Prabhavati *et al.,* (2021) and Rangaswamy *et al.,* (2023).

Interaction effect

Combined impact of different RDF and FYM levels was not significantly affected at 30 DAS, and showed significance at 60 and 90 DAS across two years of research. The maximum dry matter accumulation at 60 DAS (50.53 and 52.34 g plant^{-1}) and at 90 DAS (157.94 and 160.57 g plant^{-1}) noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two seasons of research. In initial year, N_3F_2 was notably better to all various treatment interaction. However, in second year, N_3F_2 showed similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) at 60 DAS, and at 90 DAS, N_3F_2 was similar with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 75% RDF + 10 t ha^{-1} FYM (N_2F_2). findings are similar with Wagh (2002), Joshi *et al.,* (2013) and Roopashree *et al.,* (2019).

Table 16: Effect of integrated nutrient management on DMA of maize at varying developmental phases during 2023-24 and 2024-25

Treatments	**Dry matter accumulation (g plant^{-1})**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	3.46	3.04	22.49	19.28	108.67	99.80
N_1 : 50 % RDF	5.62	5.86	29.12	31.05	126.75	128.67
N_2 : 75 % RDF	6.39	8.41	37.02	40.32	140.83	144.81
N_3 : 100 % RDF	8.17	12.60	44.47	48.40	153.26	156.15
SEm ±	0.51	0.60	0.71	0.66	0.37	1.38
CD 5%	NS	NS	2.46	2.28	1.26	4.78
FYM levels						
F_0 : Control	5.68	5.52	29.55	29.47	124.84	122.70
F_1 : 5 t ha^{-1} FYM	5.79	7.84	32.83	35.29	132.51	133.22
F_2 : 10 t ha^{-1} FYM	6.25	9.08	37.45	39.54	139.79	141.15
SEm ±	0.16	0.99	0.71	0.42	0.33	0.81
CD 5%	NS	NS	2.12	1.25	1.00	2.44
Interaction N*F						
SEm ±	0.32	1.98	1.42	0.83	0.67	1.63
CD 5%	NS	NS	4.25	2.50	2.00	4.88



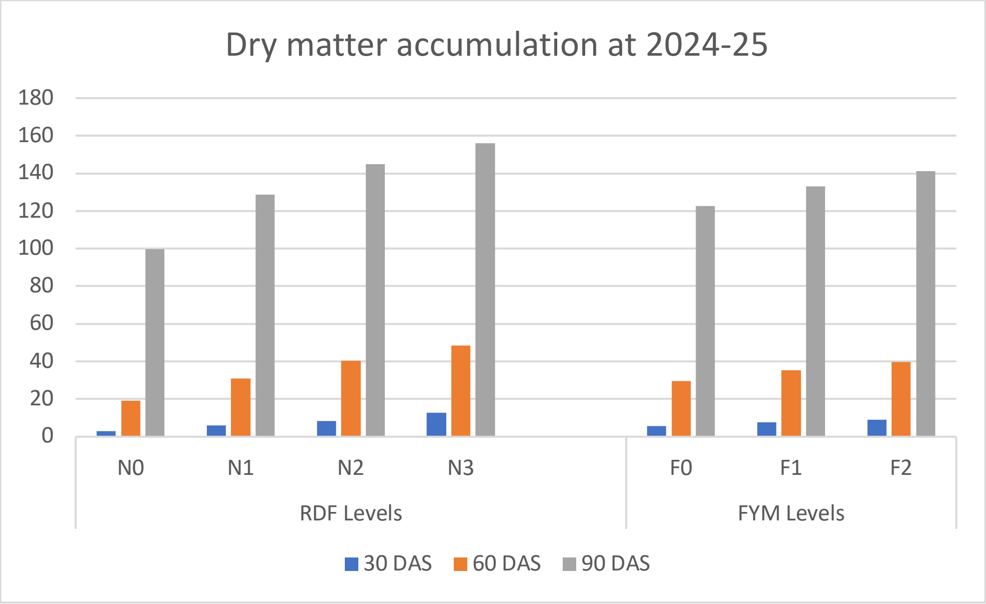


Fig. 5. Dry matter accumulation of maize at different developmental phases as impacted by various treatments

Table 16 (a): **Interaction of RDF and FYM rates on DMA (g plant^{-1}) at 60 and 90 DAS during 2023-24 and 2024-25**

Dry matter accumulation (g plant^{-1}) (60 DAS) (2023-24)					**Dry matter accumulation (g plant^{-1}) (60 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	22.15	22.33	22.99	22.49	**N_0**	17.20	19.55	21.10	19.28
N_1	24.02	28.79	34.55	29.12	**N_1**	25.19	30.54	37.42	31.05
N_2	32.34	37.00	41.72	37.02	**N_2**	32.77	40.90	47.29	40.32
N_3	39.68	43.19	50.53	44.47	**N_3**	42.70	50.16	52.34	48.40
Mean	29.55	32.83	37.45		**Mean**	29.47	35.29	39.54	
SEm±	1.42				**SEm±**	0.83			
CD 5%	4.25				**CD 5%**	2.50			
Dry matter accumulation (g plant^{-1}) (90 DAS) (2023-24)					**Dry matter accumulation (g plant^{-1}) (90 DAS) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	104.43	109.77	111.81	108.67	**N_0**	91.49	100.66	107.23	99.80
N_1	120.22	124.05	135.98	126.75	**N_1**	117.80	129.02	139.18	128.67
N_2	128.53	140.54	153.42	140.83	**N_2**	132.28	144.54	157.63	144.81
N_3	146.18	155.67	157.94	153.26	**N_3**	149.23	158.66	160.57	156.15
Mean	124.84	132.51	139.79		**Mean**	122.70	133.22	141.15	
SEm±	0.67				**SEm±**	1.63			
CD 5%	2.00				**CD 5%**	4.88			

4.1.2.7 Chlorophyll index

The chlorophyll index was recorded under various treatments and their combinations at various developmental phases is shown in Table 17 and 17 (a).

Effect of RDF levels

The RDF notably impacted the chlorophyll index at various developmental phases, except at 30 DAS across the two years of research. Chlorophyll index increased with higher levels of RDF. The highest chlorophyll index (36.62, 40.58 at 60 DAS and 37.99, 42.01 at 90 DAS) was registered in 100% RDF (N_3) across the two years of research. At 60 DAS, N_3 was statistically better than control (N_0), 50% RDF (N_1), but it was similar with 75% RDF (N_2). However, at 90 DAS, N_3 was found statistically superior over control (F_0), 50 % (F_1) and 75% RDF (N_2) during first year while it was found comparable with 75 % RDF during next year. Lowest chlorophyll index at both 60 DAS and 90 DAS was noted in control (N_0).

The use of nutrients, especially nitrogen, led to an increase in chlorophyll content, as nitrogen is essential for chlorophyll molecules and proteins synthesis. Higher nitrogen availability enhances chlorophyll production since nitrogen is a fundamental component of chlorophyll (Naveen et al.,, 2023). These results recorded by Lakum *et al.,* (2020) and Naveen *et al.,* (2023).

Effect of FYM levels

Application of FYM significantly enhanced the chlorophyll index at all crop morphometric phases except 30 DAS throughout the two study years. The chlorophyll index increased with increasing FYM levels. The highest chlorophyll index (33.61, 35.47 at 60 DAS and 35.12, 38.32 at 90 DAS) was noted under 10 t ha^{-1} FYM F2), which showed statistical superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across both study years. control recorded least chlorophyll index.

The use of organic manures notably enhances the soil's ability to retain moisture and vital nutrients, which supports improved plant water status. This favorable condition encourages quicker leaf expansion and opening, resulting in increased light interception and potentially boosting chlorophyll production in foliage (Lakum *et al.,* 2020). Parallel outcomes found by Lakum *et al.,* (2020).

Interaction effect

The combination of different RDF and FYM levels was not significantly affected at 30 DAS, and showed significance at 60 and 90 DAS across the two years of research. The highest chlorophyll index at 60 DAS (38.29 and 41.33) and at 90 DAS (40.18 and 43.50) was recorded under 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. N_3F_2 combination was statistically superior to varying treatment interactions in first experimental season. However, in next season, N_3F_2 was comparable with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 100% RDF (N_3F_0) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) at 60 DAS, and at 90 DAS, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 75% RDF + 10 t ha^{-1} FYM (N_2F_2). Experimental findings are similar with Joshi *et al.,* (2013) and Naveena and Geetha (2022).

Table 17: Effect of integrated nutrient management on chlorophyll index (SPAD) of maize at different developmental phases during 2023-24 and 2024-25

Treatments	**Chlorophyll index (SPAD)**					
	30 DAS		**60 DAS**		**90 DAS**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	24.97	22.91	28.18	23.93	30.05	28.14
N_1 : 50 % RDF	27.81	29.08	30.21	31.26	32.11	33.39
N_2 : 75 % RDF	30.09	32.74	33.14	36.84	34.57	37.95
N_3 : 100 % RDF	33.30	37.20	36.62	40.58	37.99	42.01
SEm ±	0.81	1.28	1.02	1.10	0.44	1.23
CD 5%	NS	NS	3.53	3.80	1.52	4.26
FYM levels						
F_0 : Control	27.79	26.64	30.57	30.12	32.00	31.86
F_1 : 5 t ha^{-1} FYM	29.24	31.70	31.94	33.88	33.91	35.94
F_2 : 10 t ha^{-1} FYM	30.09	33.12	33.61	35.47	35.12	38.32
SEm ±	0.62	1.80	0.23	0.43	0.19	0.39
CD 5%	NS	NS	0.70	1.28	0.57	1.16
Interaction N*F						
SEm ±	1.24	3.59	0.47	0.85	0.38	0.77
CD 5%	NS	NS	1.41	2.55	1.14	2.32

Table 17 (a): Interaction of RDF and FYM levels on chlorophyll index (SPAD) of maize at 60 and 90 DAS during 2023-24 and 2024-25

Chlorophyll index (SPAD) (60 DAS) (2023-24)					Chlorophyll index (SPAD) (60 DAS) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	27.77	28.09	28.68	28.18	**N_0**	21.99	24.74	25.06	23.93
N_1	28.75	30.25	31.64	30.21	**N_1**	27.06	31.58	35.13	31.26
N_2	30.92	32.66	35.84	33.14	**N_2**	31.79	38.40	40.34	36.84
N_3	34.83	36.74	38.29	36.62	**N_3**	39.63	40.79	41.33	40.58
Mean	30.57	31.94	33.61		**Mean**	30.12	33.88	35.47	
SEm±	0.47				**SEm±**	0.85			
CD 5%	1.41				**CD 5%**	2.55			

Chlorophyll index (SPAD) (90 DAS) (2023-24)					Chlorophyll index (SPAD) (90 DAS) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	29.14	30.25	30.76	30.05	**N_0**	23.72	29.64	31.05	28.14
N_1	31.22	31.93	33.17	32.11	**N_1**	31.34	31.95	36.90	33.39
N_2	32.49	34.84	36.38	34.57	**N_2**	32.73	39.28	41.85	37.95
N_3	35.13	38.64	40.18	37.99	**N_3**	39.66	42.88	43.50	42.01
Mean	32.00	33.91	35.12		**Mean**	31.86	35.94	38.32	
SEm±	0.38				**SEm±**	0.77			
CD 5%	1.14				**CD 5%**	2.32			

4.1.3 Yield attributes and yield

4.1.3.1 Number of cobs plant^{-1}

Cobs count noted under various treatments and their combinations is shown in Table 18, 18 (a) and figure 6.

Effect of RDF levels

The recommended dose of fertilizers (RDF) significantly impacted the cobs count plant^{-1} across two study years. The highest cobs count plant^{-1} (2.18 and 2.29) was obtained in 100% RDF (N_3), which showed superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) during first and next year. Lowest number of cobs was obtained in control (N_0).

Proper application of nutrient fertilizers is crucial for boosting vegetative development and production potential by ensuring availability of essential minerals needed for physiological and biochemical processes. An increased nutrient supply enhances dry matter accumulation by improving photosynthetic efficiency and carbon uptake. This improvement optimizes the distribution of photosynthates between the source and sink, promoting better nutrient transport and absorption. As a result, key yield traits, such as the cobs count are significantly improved (Shyam *et al.,* 2019). These findings were observed by Singh and Nepalia (2009), Verma *et al.,* (2018) and Roopashree *et al.,* (2019).

Effect of FYM levels

Application of FYM increased the cobs count across both study years. A progressive rise in cob number was observed with higher FYM levels. The maximum cobs count (1.87 and 1.92) was noted in 10 t ha^{-1} FYM (F_2), which showed statistically significant advantage over both the control (F_0) and the 5 t ha^{-1} FYM treatment (F_1) across both study years. Control (F_0) consistently recorded the least cobs count.

Organic sources like FYM release nutrients slowly, ensuring a sustained supply throughout crop growth. This steady nutrient availability supports better root development and plant vigor, ultimately enhancing assimilate production and remobilization. As a result, the balanced nutrition from organic sources contributes to an increase in the number of cobs per plant (Singh and Misal 2020). This findings are comparable with Mehta *et al.,* (2005) Jan *et al.,* (2014) and Khan *et al.,* (2017),

Interaction effect

Interaction of various RDF and FYM levels showed considerable impact across the two years of research. Maximum cobs count plant^{-1} (2.33 and 2.41) noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study seasons. The N_3F_2 combination showed superiority to varying treatment combinations in first season. In second season, N_3F_2 was comparable to that of 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). This results are comparable with Wagh (2002), Kumar *et al.,* (2005), Tetarwal *et al.,* (2011), Joshi *et al.,* (2013), Shinde *et al.,* (2014) and Roopashree *et al.,* (2019).

Table 18: Effect of integrated nutrient management on number of cobs, weight and length of cob of maize during 2023-24 and 2024-25

Treatments	**Number of cobs plant^{-1}**		**Weight of cobs plant^{-1} (g/plant)**		**Length of Cob (cm)**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	1.20	1.11	135.44	124.97	13.90	10.86
N_1 : 50 % RDF	1.58	1.55	146.62	145.20	15.50	15.31
N_2 : 75 % RDF	1.89	2.03	149.76	160.67	16.53	18.28
N_3 : 100 % RDF	2.18	2.29	157.30	170.71	17.78	19.05
SEm ±	0.03	0.05	0.95	1.38	0.17	0.24
CD 5%	0.10	0.17	3.27	4.77	0.59	0.85
FYM levels						
F_0 : Control	1.57	1.54	142.65	141.13	15.22	14.68
F_1 : 5 t ha^{-1} FYM	1.70	1.78	146.71	151.84	15.83	15.91
F_2 : 10 t ha^{-1} FYM	1.87	1.92	152.48	158.19	16.74	17.03
SEm ±	0.02	0.02	0.70	0.80	0.13	0.23
CD 5%	0.07	0.06	2.08	2.41	0.39	0.69
Interaction N*F						
SEm±	0.05	0.04	1.39	1.61	0.26	0.46
CD 5%	0.14	0.13	NS	4.82	NS	NS

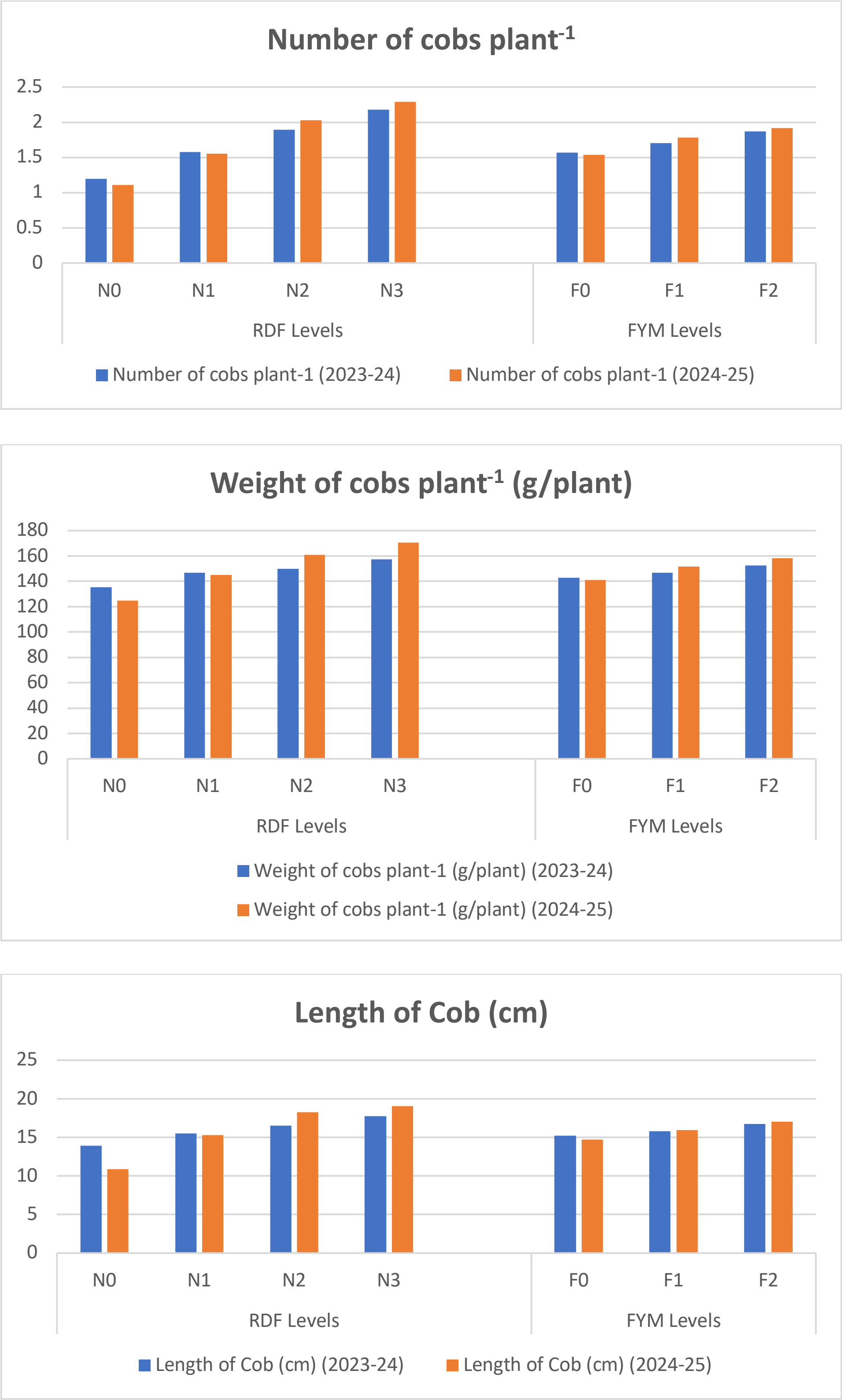


Fig. 6. Number of cobs, Weight and length of cob of maize as affected by varying treatments during 2023-24 and 2024-25

Table 18 (a): **Interaction of RDF and FYM levels on Number of cobs, Weight and Length of cob of maize during 2023-24 and 2024-25**

Number of cobs plant^{-1} (2023-24)					Number of cobs plant^{-1} (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1.13	1.20	1.27	1.20	**N_0**	1.05	1.10	1.18	1.11
N_1	1.47	1.53	1.73	1.58	**N_1**	1.32	1.56	1.78	1.55
N_2	1.60	1.93	2.13	1.89	**N_2**	1.67	2.09	2.32	2.03
N_3	2.07	2.13	2.33	2.18	**N_3**	2.12	2.35	2.41	2.29
Mean	1.57	1.70	1.87		**Mean**	1.54	1.78	1.92	
SEm±	0.05				**SEm±**	0.04			
CD 5%	0.14				**CD 5%**	0.13			

Weight of cobs plant^{-1} (g/plant) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**
N_0	116.70	127.28	130.92	124.97
N_1	133.18	145.33	157.09	145.20
N_2	149.29	162.62	170.10	160.67
N_3	165.36	172.13	174.64	170.71
Mean	141.13	151.84	158.19	
SEm±	1.61			
CD 5%	4.82			

Plate No. 5. Tasseling and cob initiation in maize

4.1.3.2 Weight of cobs plant^{-1} (g/plant)

Cob weight recorded under varying treatments and their combinations is shown in Table 19, 19 (a) and figure 6.

Effect of RDF levels

Application RDF notably impacted weight of cobs across two years of research. Weight of cobs plant^{-1} increased with higher levels of RDF. The highest cob weight per plant (157.30 and 170.71 g) noted in 100% RDF (N_3), showing a statistically significant advantage over the control (N_0), 50% RDF (N_1), and 75% RDF (N_2) in both years. Conversely, the lowest cob weight was noted under the control treatment (N_0).

Increase in cob weight of maize achieved by the enhanced availability of nitrogen, which is crucial for morphometric development of plant. Nitrogen supports vital physiological functions like division of cells, protein synthesis, and chlorophyll formation, leading to improved vegetative growth and efficient photosynthetic activity. This, in turn, enhances nutrient translocation and assimilation, ultimately contributing to greater cob development (Pratap *et al.,* 2016). Findings are similar with Vadivel *et al.,* (2001) and Roopashree *et al.,* (2019), Singh *et al.,* (2019).

Effect of FYM levels

FYM incorporation significantly impacted the cob weight across the two years of research. Cob weight increased with higher FYM levels. The maximum weight of cobs plant^{-1} (152.48 and 158.19 g plant^{-1}) reported under 10 t ha^{-1} FYM (F_2), which found statistically better than control (F_0), and 5 t ha^{-1} FYM (F_1) across the two years of research. Lowest cob weight noted in the control (N_0).

At growth and development of reproductive structures, FYM ensures a timely delivery of metabolites and nutrients in alignment with the crop's demand. This optimal nutrient availability leads to an increase in the cob weight (Mahesh *et al.,* 2010). These findings are similar to Mehta *et al.,* (2005) and Singh *et al.,* (2019).

Interaction effect

The combination of different RDF and FYM levels was not significantly affected in first year and found significant in the next year. Maximum cob weight (174.64 g plant^{-1}) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) during second year. The N_3F_2 combination similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). The findings are similar with Wagh (2002), Balai *et al.,* (2011) and Joshi *et al.,* (2013).

4.1.3.3 Length of cob (cm)

The cob length recorded under various treatments and their combinations is depicted in Table 19 and figure 6.

Effect of RDF levels

Application of RDF notably enhanced cob length across the two years of research. Higher RDF levels led to an increase in cob length. The longest cob (17.78 and 19.05 cm) found in 100% RDF (N_3), which was statistically better than control (N_0), 50% (N_1), and 75% RDF (N_2) in first year but in next year, it showed similarity with 75 % RDF. The minimum length of cob was registered in the control (N_0).

The fertilizers added to the soil enhance its natural nutrient reserves, providing a steady nutrient supply during the crop's growth cycle. This results in better photosynthesis, leading to increased energy production and, ultimately, the length of the maize cob (Verma *et al.,* 2018). This findings are comparable with Vadivel *et al.,* (2001), Kataraki *et al.,* (2004), Singh and Nepalia (2009), Verma *et al.,* (2018), Roopashree *et al.,* (2019), Singh *et al.,* (2019), Sharma *et al.,* (2020) and Karki *et al.,* (2020).

Effect of FYM levels

FYM incorporation had a considerable impact on cob length over the two years of the study. As the FYM levels increased, cob length also increased. The longest cobs (16.74 and 17.03 cm) were observed with 10 t ha^{-1} FYM (F_2), which showed markedly better than control (F_0) and 5 t ha^{-1} FYM (F_1) across both study years. Shortest cob length was recorded in the control treatment (F_0).

The improved cob length can likely be attributed to enhanced photosynthesis in maize plants resulting from an increased nitrogen supply, as N is a vital element for crop development. Additionally, gradual release of nutrients from FYM ensures a sustained supply of essential elements throughout the growth period. This steady nutrient availability supports better plant development, ultimately leading to the formation of longer cobs (Ahmed *et al.,* 2024). These results are comparable with Vadivel *et al.,* (2001), Singh and Nepalia (2009) and Singh *et al.,* (2019).

Interaction effect

Combination of various RDF and FYM levels was not significantly affected across the two years of experimentation.

4.1.3.4 Number of grain rows cob^{-1}

Grain rows noted in varying treatments and their combinations is shown in Table 19.

Effect of RDF levels

Use of RDF significantly affected the grain rows across the two years of research. The highest grain rows count (12.72 and 13.76) was noted in 100% RDF (N_3), showing a significant advantage than the control (N_0), 50% RDF (N_1), and 75% RDF (N_2) during the first year. In the second year, however, this treatment performed on par with the 75% RDF level. The control (N_0) consistently recorded the least grain rows count.

Increased nitrogen fertilization enhances chlorophyll concentration, enzymatic functions, and the rate of photosynthesis, resulting in a higher number of kernel rows per ear (Karki *et al.,* 2020). Experimental findings are similar with Kataraki *et al.,* (2004), Singh *et al.,* (2019), Iqbal *et al.,* (2020) and Karki *et al.,* (2020).

Effect of FYM levels

FYM application notably influenced grain rows count per cob across two-years of study period. The highest grain rows per cob (12.27 and 12.66) noted in 10 t ha^{-1} FYM (F_2), which outperformed the control (F_0) and 5 t ha^{-1} FYM (F_1) in first season. However, next season, this treatment was statistically similar to 5 t ha^{-1} FYM (F_1). Control (F_0) consistently noted the lowest grain rows count

Enhanced synthesis of photosynthates in the source organs and their efficient translocation to the sink organs, coupled with improved availability and sustained supply of nutrients, likely contributed to an increase in grain rows count and grains count of rows (Sunda, 2023). These results are consistent with Mehta *et al.,* (2005), Mozafari *et al.,* (2018) and Singh *et al.,* (2019).

Interaction effect

Mutual influence of varying rates of RDF and FYM was insignificant across both study years.

4.1.3.5 Number of grains row^{-1}

Grains count per row noted under varying treatments and their combinations depicted in Table 19.

Effect of RDF levels

RDF application significantly impacted the grains count row^{-1} across both study years. The maximum grains count row^{-1} (32.09 and 33.43) was noted under 100% RDF (N_3), showed superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. The control (N_0) recorded least grains count per row.

Supplying primary macronutrients together improves plant mineral availability and facilitates their effective movement to photosynthetic tissues. This enhanced nutrient supply fosters plant growth and development, leading to improved yield traits, including a higher number of grains per row (Kumawat *et al.,* 2020). Findings are similar to Singh *et al.,* (2019), Kataraki *et al.,* (2004), Iqbal *et al.,* (2020) and Karki *et al.,* (2020).

Effect of FYM levels

Application of FYM significantly increased the grain numbers row^{-1} across the two years of research. Grain numbers row^{-1} increased with higher levels of FYM. Highest grain numbers row^{-1} (31.04 and 31.20) was noted under 10 t FYM ha^{-1} (F_2), which was notably superior than F_0 and F_1 in both years. Lowest grains count row^{-1} was noted in the control (N_0).

The application of organic manure ensured a consistent and sufficient delivery of vital nutrients throughout the crop's growing season. This enhanced nutrient availability promoted vigorous vegetative expansion and root growth, which boosted the plant’s photosynthetic capacity. Consequently, a greater amount of photosynthates was synthesized and moved to the developing grains at the time of the grain development stage, thereby supporting better grain development and ultimately increasing the number of grains (Lakum, 2017). These results are similar with Singh *et al.,* (2019).

Interaction effect

Combination of various RDF and FYM rates showed insignificance across two seasons of research.

4.1.3.6 Number of grains cob^{-1}

Grains count noted under varying treatments and their combinations is shown in Table 19, 19(a) and figure 7.

Effect of RDF levels

Application of RDF showed considerable effect on grains count per cob across both study years. Highest number of grains per cob (408.55 and 460.34) was observed with 100% RDF (N_3), showed superiority than control (N_0), 50% RDF (N_1), and 75% RDF (N_2) in both years. The N_0 noted the lowest values.

Cobs with greater length and girth resulted in more grain rows, while higher nitrogen levels enhanced pollination, fertilization, and seed development, ultimately leading to an increased number of bold grains per cob (Sudhakar *et al.,* 2018). This findings are comparable with Mozafari *et al.,* (2018), Verma *et al.,* (2018), Singh *et al.,* (2019), Iqbal *et al.,* (2020) and Karki *et al.,* (2020).

Effect of FYM levels

Application of FYM significantly increased the grain numbers cob^{-1} throughout the two study years. Grain numbers cob^{-1} increased with increasing FYM levels. Maximum grain numbers (381.92 and 400.45) registered in 10 t FYM ha^{-1} (F_2), showing superiority to control (F_0), and 5 t ha^{-1} FYM (F_1) across both seasons of research. The least value noted in control (N_0).

Increase in grain count may be due to the timely supply of N from FYM, which is crucial for robust plant growth and physiological development. Moreover, FYM application likely improved soil structure and water-holding capacity, fostering an environment conducive to efficient grain setting and development (Shah *et al.,* 2009). These results are similar to Jan *et al.,* (2014), Khan *et al.,* (2017) and Singh *et al.,* (2019).

Interaction effect

Combination of various levels of RDF and FYM exhibited a statistically significant influence across the two years of research. Maximum grain numbers cob^{-1} (438.93 and 481.95) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study seasons. The N_3F_2 combination showed superiority to varying treatment combinations during first season. In the second season, N_3F_2 showed similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These results are comparable with Wagh (2002), Tetarwal *et al.,* (2011), Balai *et al.,* (2011) and Joshi *et al.,* (2013).

4.1.3.7 Seed index (g)

The 100 grain weight recorded under various treatments and their combinations is presented in Table 19 and 19 (a).

Effect of RDF levels

Application RDF significantly affected weight of 100 grains across the two years of research of experimentation. The seed index increased with higher RDF levels. The highest seed index (30.33 and 31.30 g) was registered under the application of 100% RDF (N_3), showing a statistically significant advantage than control (N_0), 50% (N_1), and 75% RDF (N_2) in first year. In the next year, it showed similarity with 75 % RDF. The lowest seed index was registered in the control (N_0).

Greater levels of RDF are associated to enhanced nutrient uptake, which contributes to increased leaf area index, leaf area duration, and dry matter accumulation. This, in turn, facilitates improved translocation of assimilates to the grains, resulting in higher seed index and better overall grain development (Basu *et al.,* 2017). Consistent results noted by Vadivel *et al.,* (2001), Kataraki *et al.,* (2004), Singh and Nepalia (2009), Mozafari *et al.,* (2018), Verma *et al.,* (2018), Sharma *et al.,* (2020) and Karki *et al.,* (2020).

Effect of FYM levels

FYM integration exerted a pronounced influence on seed index across both study years. Seed index increased with higher FYM levels. The highest seed index (29.66 and 29.98 g) noted under 10 t ha^{-1} FYM (F_2), showing considerable superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two seasons of research.

Increase in seed index of maize can be attributed to the rich content of humus, essential macronutrients, and micronutrients in FYM, which likely boost photosynthetic activity and protein synthesis, resulting in enhanced grain development. FYM supplies nitrogen, phosphorus, and potassium that support overall plant growth and grain production. Additionally, the slow release of nitrogen from FYM aids in continuous protein synthesis, contributing to greater grain weight (Khan *et al.,* 2024). The findings are comparable with Mehta *et al.,* (2005) and Singh and Nepalia (2009)

Interaction effect

The combined use of various RDF and FYM showed markedly impact across two years of research. Highest seed index (31.46 and 31.79 g) was recorded under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study seasons. N_3F_2 combination was statistically superior to all other treatment combinations in first year. However, in the next year, N_3F_2 showed similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 100% RDF (N_3F_0) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These results are comparable with Wagh (2002), Tetarwal *et al.,* (2011), Balai *et al.,* (2011), Joshi *et al.,* (2013), Shinde *et al.,* (2014) and Sharma *et al.,* (2020).

Table 19: Effect of integrated nutrient management on number of grain rows, number of grains per row, number of grains and seed index of maize as affected by varying treatments during 2023-24 and 2024-25

Treatments	**Number of grain rows cob^{-1}**		**Number of grains row^{-1}**		**Number of grains cob^{-1}**		**Seed index (g)**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels								
N_0 : Control	10.83	9.94	27.65	24.70	300.04	246.40	28.03	26.71
N_1 : 50 % RDF	11.68	11.50	29.63	29.54	346.09	342.38	28.64	28.58
N_2 : 75 % RDF	12.10	13.03	30.87	31.81	373.72	416.17	29.28	30.22
N_3 : 100 % RDF	12.72	13.76	32.09	33.43	408.55	460.34	30.33	31.30
SEm ±	0.08	0.29	0.23	0.33	3.81	12.06	0.14	0.48
CD 5%	0.27	1.02	0.80	1.16	13.19	41.74	0.49	1.67
FYM levels								
F_0 : Control	11.44	11.20	29.16	28.33	334.83	322.93	28.54	28.30
F_1 : 5 t ha^{-1} FYM	11.79	12.31	29.98	30.09	354.55	375.59	29.01	29.32
F_2 : 10 t ha^{-1} FYM	12.27	12.66	31.04	31.20	381.92	400.45	29.66	29.98
SEm ±	0.04	0.14	0.12	0.17	1.70	4.28	0.08	0.18
CD 5%	0.13	0.42	0.34	0.50	5.09	12.84	0.25	0.55
Interaction N*F								
SEm±	0.09	0.28	0.23	0.33	3.39	8.56	0.17	0.37
CD 5%	NS	NS	NS	NS	10.17	25.67	0.51	1.11

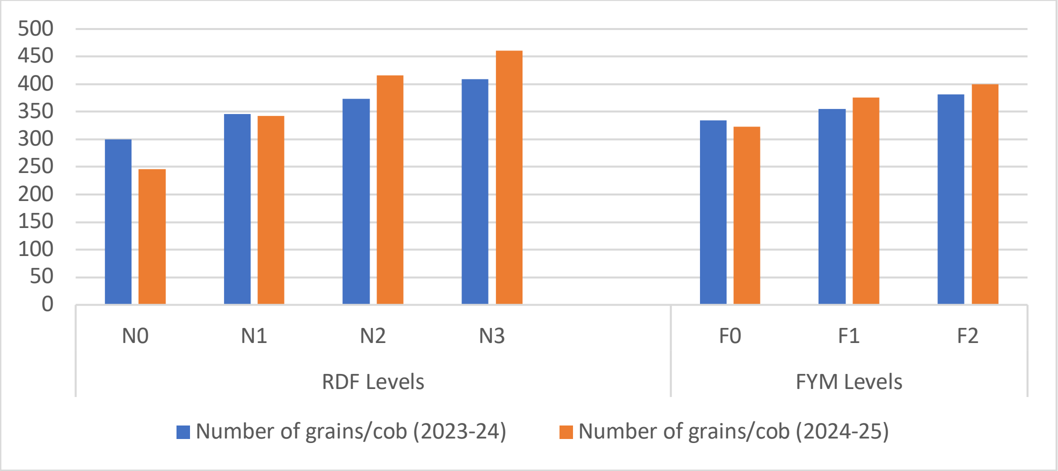


Fig. 7. Number of grains of maize as affected by varying treatments during 2023-24 and 2024-25

Table 19 (a): Interaction of RDF and FYM levels on Number of grains and Seed index during 2023-24 and 2024-25

Number of grains cob^{-1} (2023-24)					**Number of grains cob^{-1} (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	273.22	300.33	326.56	300.04	**N_0**	218.03	252.73	268.44	246.40
N_1	334.90	341.34	362.03	346.09	**N_1**	289.89	354.25	383.00	342.38
N_2	350.69	370.31	400.15	373.72	**N_2**	361.48	418.61	468.42	416.17
N_3	380.50	406.23	438.93	408.55	**N_3**	422.30	476.78	481.95	460.34
Mean	334.83	354.55	381.92		**Mean**	322.93	375.59	400.45	
SEm±	3.39				**SEm±**	8.56			
CD 5%	10.17				**CD 5%**	25.67			
Seed index (g) (2023-24)					**Seed index (g) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	27.63	28.22	28.26	28.03	**N_0**	26.54	26.68	26.91	26.71
N_1	28.40	28.56	28.96	28.64	**N_1**	27.03	28.69	30.00	28.58
N_2	28.74	29.15	29.96	29.28	**N_2**	28.85	30.59	31.22	30.22
N_3	29.40	30.12	31.46	30.33	**N_3**	30.79	31.33	31.79	31.30
Mean	28.54	29.01	29.66		**Mean**	28.30	29.32	29.98	
SEm±	0.17				**SEm±**	0.37			
CD 5%	0.51				**CD 5%**	1.11			

4.1.3.8 Grain yield (q ha^{-1})

The grain yield under varying treatments and their interactions is illustrated in Table 20, 20(a), and Figure 8.

Effect of RDF levels

Highest grain yield (55.38, 58.49 and 56.93 q ha^{-1}) were registered in 100% RDF (N_3), which was considerably greater than control (N_0), 50% RDF (N_1), and 75% RDF (N_2) across both study years and in pooled analysis. In contrast, the control (N_0) treatment noted the least grain yield.

Maximum grain output under 100% RDF application can be attributed to impact of fertilizer levels on the formation of photosynthetically active surfaces and enhanced sink strength. Traits such as the cob numbers and size, grain mass, seed index, and chlorophyll concentration are likely responsible for improved assimilate translocation and utilization. The cumulative effect of these physiological and morphological traits contributed to the yield advantage observed with 100% RDF (Lakum *et al*., 2020). These findings similar with Vadivel *et al*., (2001) and Mozafari *et al*., (2018), Verma *et al.,* (2018), Lakum *et al.,* (2020), Iqbal *et al.,* (2020) and Karki *et al.,* (2020).

Effect of FYM levels

Grain yield was notably improved with the incorporation of FYM across both study years and in combined analysis. An upward trend in yield was observed as FYM levels increased. The highest grain yield (49.61, 51.39, and 50.50 q ha^{-1}) noted in 10 t ha^{-1} FYM (F_2), showing a statistically significant advantage over control (F_0) and 5 t ha^{-1} FYM (F_1). Lowest yield consistently occurred in the control treatment (F_0).

The improvement in maize grain yield with farmyard manure application can be attributed to enhanced availability of both native and applied nutrients in the soil, which significantly enhanced nutrient intake by plants, resulting to better growth and yield attributing traits. Additionally, the highest yield observed under increasing FYM levels may be due to its beneficial effects, including the gradual and balanced release of nutrients, favorable shifts in microbial dynamics supporting crop growth, and the creation of an optimal soil environment conducive to plant development (Lakum *et al.,* 2020). Similar results documented by Mehta *et al.,* (2005), Jan *et al.,* (2014), Lakum *et al.,* (2020) and Rangaswamy *et al.,* (2023).

Interaction effect

Interaction of various levels of RDF and FYM was statistically significant across the two study years and in combined analysis. Highest grain yield (58.95, 61.25, and 60.10 q ha^{-1}) was recorded under 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research and in a pooled analysis. In first year, N_3F_2 was showed superiority than varying treatment combinations. However, in second year, N_3F_2 was at par with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). In pooled analysis, N_3F_2 remained markedly greater than varying treatment combinations. Similar results are recorded by Kumar *et al.,* (2005), Tetarwal *et al.,* (2011), Balai *et al.,* (2011), Joshi *et al.,* (2013), Shinde *et al.,* (2014), Pandey and Awasthi (2014), Yadav *et al.,* (2015), Lakum *et al.,* (2020) and Sharma *et al.,* (2020).

Table 20: Effect of integrated nutrient management on grain and stover yield (q ha^{-1}) of maize in 2023-24 and 2024-25

Treatments	Grain yield (q ha^{-1})			Stover yield (q ha^{-1})		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
Nutrient management levels						
N_0 : Control	37.40	35.06	36.23	80.44	75.90	78.17
N_1 : 50 % RDF	44.17	43.83	44.00	94.20	92.47	93.34
N_2 : 75 % RDF	49.22	51.90	50.56	101.07	106.14	103.60
N_3 : 100 % RDF	55.38	58.49	56.93	104.69	110.09	107.39
SEm ±	0.26	1.02	0.53	0.57	1.42	0.76
CD 5%	0.89	3.53	1.62	1.96	4.90	2.35
FYM levels						
F_0 : Control	43.45	42.71	43.08	91.39	91.05	91.22
F_1 : 5 t ha^{-1} FYM	46.57	47.85	47.21	95.22	96.77	96.00
F_2 : 10 t ha^{-1} FYM	49.61	51.39	50.50	98.70	100.62	99.66
SEm ±	0.23	0.55	0.30	0.41	0.83	0.46
CD 5%	0.68	1.66	0.86	1.22	2.49	1.33
Interaction N*F						
SEm±	0.45	1.11	0.60	0.82	1.66	0.92
CD 5%	1.36	3.32	1.72	2.45	4.97	2.66

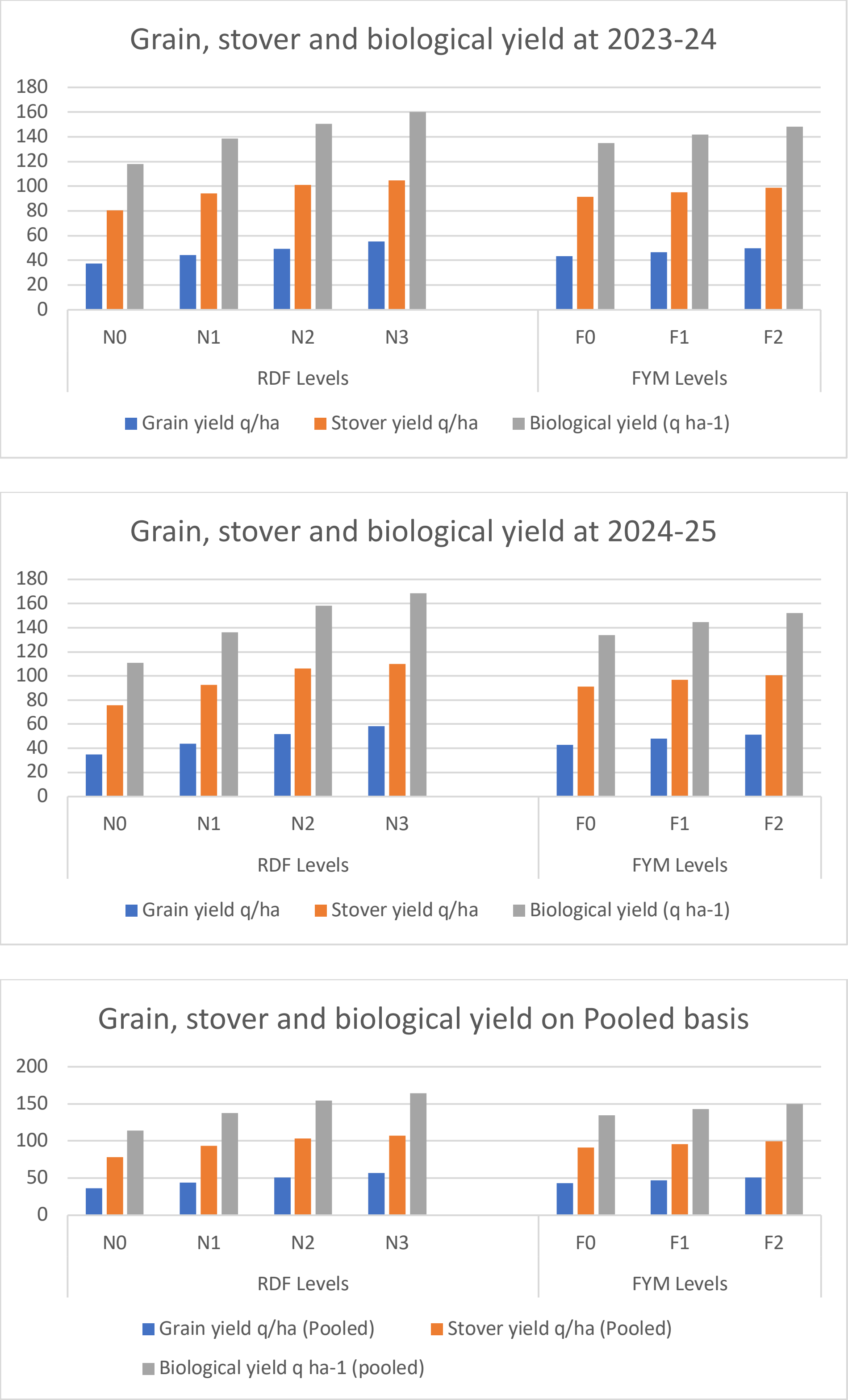


Fig. 8. Grain, Stover, and biological yield (q ha^{-1}) of maize as affected by varying treatments

Table 20 (a): Interaction of RDF and FYM levels on grain and stover yield (q ha^{-1}) of maize during 2023-24 and 2024-25

Grain yield (q ha^{-1}) (2023-24)					Grain yield (q ha^{-1}) (2024-25)					Grain yield (q ha^{-1}) (Pooled)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	35.26	37.78	39.15	37.40	**N_0**	31.88	36.28	37.01	35.06	**N_0**	33.57	37.03	38.08	36.23
N_1	42.91	43.56	46.05	44.17	**N_1**	39.05	43.93	48.49	43.83	**N_1**	40.98	43.75	47.27	44.00
N_2	44.74	48.64	54.29	49.22	**N_2**	45.13	51.76	58.80	51.90	**N_2**	44.93	50.20	56.55	50.56
N_3	50.87	56.31	58.95	55.38	**N_3**	54.78	59.42	61.25	58.49	**N_3**	52.83	57.87	60.10	56.93
Mean	43.45	46.57	49.61		**Mean**	42.71	47.85	51.39		**Mean**	43.08	47.21	59.50	
SEm±	0.45				**SEm±**	1.11				**SEm±**	0.60			
CD 5%	1.36				**CD 5%**	3.29				**CD 5%**	1.72			
Stover yield (q ha^{-1}) (2023-24)					**Stover yield (q ha^{-1}) (2024-25)**					**Stover yield (q ha^{-1}) (Pooled)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	77.18	80.75	83.40	80.44	**N_0**	71.84	76.40	79.46	75.90	**N_0**	74.51	78.58	81.43	78.17
N_1	87.63	93.70	101.27	94.20	**N_1**	83.17	92.06	102.19	92.47	**N_1**	85.40	92.88	101.73	93.34
N_2	97.88	101.40	103.92	101.07	**N_2**	100.73	108.26	109.42	106.14	**N_2**	99.31	104.83	106.67	103.60
N_3	102.86	105.01	106.20	104.69	**N_3**	108.47	110.38	111.41	110.09	**N_3**	105.66	107.70	108.80	107.39
Mean	91.39	95.22	98.70		**Mean**	91.05	96.77	100.62		**Mean**	91.22	96.00	99.66	
SEm±	0.82				**SEm±**	1.66				**SEm±**	0.92			
CD 5%	2.45				**CD 5%**	4.97				**CD 5%**	2.66			

4.1.3.9 Stover yield (q ha^{-1})

The stover yield recorded under various treatments and their combinations is depicted in Table 20, 20 (a) and figure 8.

Effect of RDF levels

The application of RDF significantly enhanced stover yield across both study years and also in a combined analysis. Stover yield increased progressively with higher RDF levels. The highest stover yield (104.69, 110.09 and 107.39 q ha^{-1}) was noted with 100% RDF (N_3) across both study years also in combined analysis. In the first year, 100% RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2). However in second year, 100% RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1) and at par with 75% RDF (N_2). In pooled analysis, 100% RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2). Least stover output was registered in the N_0.

The highest stover yield achieved with balanced and increased nutrient application can be attributed to its significant impact on the crop's vegetative growth. This enhancement in stover yield is probably attributed to the effective utilization of the crop's genetic potential for enhanced vegetative development under optimal fertilization (Yadav *et al.,* 2015). These findings are similar with Vadivel *et al.,* (2001), Mehta *et al.,* (2005), Mozafari *et al.,* (2018), Verma *et al.,* (2018), Lakum *et al.,* (2020) and Iqbal *et al.,* (2020).

Effect of FYM levels

FYM incorporation notably affected the stover yield throughout the two study years and on pooled analysis. Stover yield increased with higher FYM levels. The highest stover yield (98.70, 100.62, and 99.66 q ha^{-1}) was recorded under 10 t ha^{-1} FYM (F_2), which showed significant superiority than control (F_0) and 5 t ha^{-1} FYM (F_1) across both study years and in a pooled analysis. Control treatment (F_0) recorded the least stover yield.

Significant increase in stover yield due to the enhanced soil conditions by incorporation of farmyard manure. This provided a consistent nutrient supply to the plants and improved the soil's buffering capacity, promoting better plant growth and leading to higher fodder yield (Singh *et al*., 2018). These findings are consistent with Lakum *et al.,* (2020) and Rangaswamy *et al.,* (2023).

Interaction effect

The combination of varying levels of RDF and FYM showed a marked influence across two study years and on a pooled analysis. The highest stover yield (106.20, 111.41, and 108.80 q ha^{-1}) noted under 100% RDF + 10 t ha^{-1} FYM (N_3F_2) throughout two seasons of research and on a pooled basis. In first season, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). However, in the second year, N_3F_2 showed similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 100% RDF (N_3F_0), 75% RDF + 10 t ha^{-1} FYM (N_2F_2) and 75% RDF + 5 t FYM ha^{-1} FYM (N_2F_1). On pooled basis, N_3F_2 performed similarly to both 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These experimental results are in line with Balai *et al.,* (2011), Joshi *et al.,* (2013), Shinde *et al.,* (2014), Yadav *et al.,* (2015), Roopashree *et al.,* (2019), Lakum *et al.,* (2020) and Sharma *et al.,* (2020).

4.1.3.10 Biological yield (q ha^{-1})

Impact of varying treatments and their interactions on biological yield is illustrated in Table 21, 21(a), and Figure 8.

Effect of RDF levels

The application of RDF markedly enhanced the biological yield across the two seasons of research as well as in combined analysis. Biological yield increased significantly with higher levels of RDF. Highest biological yield (160.06, 168.57 and 164.32 q ha^{-1}) was achieved under 100% RDF (N_3), showing a statistically significant improvement over the control (N_0), 50% RDF (N_1), and 75% RDF (N_2) across both study seasons as well as in combined analysis. Least biological yield noted in control (N_0).

Application of inorganic fertilizers supplies readily available nutrients, promoting better root growth and development. As the roots expand and increased surface area, the capacity for cation exchange is enhanced, thereby improving the roots efficiency in absorbing vital nutrients from the soil. This increased nutrient uptake supports greater plant biomass production, leading to greater biological and economic yield (Lakum *et al.,* 2020). This findings are similar with Pandey and Awasthi (2014) and Iqbal *et al.,* (2020).

Effect of FYM levels

FYM incorporation markedly boosted the biological yield throughout the two study years and on pooled analysis. Biological yield increased progressively in response to higher FYM levels. The highest biological yield (148.31, 152.01, and 150.16 q ha^{-1}) was recorded under 10 t ha^{-1} FYM (F_2), which showed statistical superiority to control (F_0) and 5 t ha^{-1} FYM (F_1) across the two seasons of research and in a combined evaluation. Control (F_0) produced the minimum biological yield.

The enhanced growth seen in plots receiving FYM may attributed to improved soil moisture conditions in the root zone and effective absorption of nutrients gradually released through FYM breakdown. Furthermore, a higher leaf area index in manure-treated plots likely contributed to the increased biological yield by supporting a faster growth rate (Khan *et al.,* 2017). These results in accordance with Khan and Jan (2018).

Interaction effect

The combination of RDF and FYM exhibited a notable significant impact on biological yield across both study years and in a pooled evaluation. The highest biological yield (165.15, 172.66, and 168.90 q ha^{-1}) noted in 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research and in pooled analysis. During first year, N_3F_2 outperformed all varying treatment combinations. However, in the second year, N_3F_2 was at par with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). In pooled analysis, N_3F_2 remained significantly superior to all other treatment combinations. Findings are comparable with Tetarwal *et al.,* (2011), Pandey and Awasthi (2014), Yadav *et al.,* (2015).

4.1.3.11 Harvest index (%)

The harvest index obtained under varying treatments and their combinations shown in Table 21.

Effect of RDF levels

Application of RDF significantly enhanced the harvest index across two study years as well as in a pooled analysis. Highest harvest index (34.56, 34.70 and 34.63 %) was noted with 100% RDF (N_3) across the two study years and in pooled results. In first year, 100% RDF (N_3) was significantly superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2). However in second year, 100% RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1) and at par with 75% RDF (N_2). In pooled analysis, 100% RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2). The lowest harvest index was noted in control (N_0).

Harvest index is a critical agronomic parameter that quantifies the efficiency with which assimilated photosynthates are translocated from vegetative structures (source) to the harvested economic parts (sink) of the crop (Paikra *et al*., 2019). The increase in harvest index of maize under higher RDF levels indicates that the crop effectively used the supplied nitrogen to boost its physiological functions, resulting in efficient allocation of photosynthates towards grain formation (Sudhakar *et al.,* 2018). These findings are comparable with Yadav *et al.,* (2015) and Iqbal *et al.,* (2020).

Effect of FYM levels

FYM incorporation notably improve the HI throughout the two study years and in pooled results. An increase in FYM levels was associated with a corresponding increase in harvest index. The highest harvest index (33.30, 33.62, and 33.46 %) was noted under 10 t ha^{-1} FYM (F_2) in two years of study and in pooled results. In first year, 10 t ha^{-1} FYM (F_2) was statistically superior to the control (F_0) and 5 t ha^{-1} FYM (F_1). During second year and on pooled basis, 10 t ha^{-1} FYM (F_2) was statistically superior to the control (F_0) and similar with 5 t ha^{-1} FYM (F_1). Among the treatments, the control (F_0) exhibited the lowest value for harvest index.

The improvement in the harvest index of maize from organic manuring suggests that the crop was able to direct its energy and resources (photosynthates) toward grain production rather than vegetative growth. This is likely due to the enhanced soil environment provided by organic manures (Sudhakar *et al.,* 2018). These findings are comparable with Jan *et al.,* (2014).

Interaction effect

Influence of RDF and FYM combinations showing insignificance interaction over the study period or in cumulative analysis.

Table 21: Effect of integrated nutrient management on biological yield (q ha^{-1}) and HI (%) during 2023-24 and 2024-25

Treatments	Biological yield (q ha^{-1})			Harvest index (%)		
	2023-24	**2024-25**	**Pooled**	**2023-24**	**2024-25**	**Pooled**
Nutrient management levels						
N_0 : Control	117.84	110.96	114.40	31.72	31.55	31.63
N_1 : 50 % RDF	138.37	136.30	137.34	31.95	32.14	32.05
N_2 : 75 % RDF	150.29	158.03	154.16	32.70	32.78	32.74
N_3 : 100 % RDF	160.06	168.57	164.32	34.56	34.70	34.63
SEm ±	0.52	1.38	0.74	0.20	0.63	0.33
CD 5%	1.78	4.77	2.27	0.71	2.18	1.02
FYM levels						
F_0 : Control	134.83	133.76	134.30	32.17	31.77	31.97
F_1 : 5 t ha^{-1} FYM	141.79	144.62	143.21	32.73	32.98	32.86
F_2 : 10 t ha^{-1} FYM	148.31	152.01	150.16	33.30	33.62	33.46
SEm ±	0.39	0.88	0.48	0.18	0.39	0.22
CD 5%	1.17	2.64	1.39	0.54	1.17	0.62
Interaction N*F						
SEm±	0.78	1.76	0.96	0.36	0.78	0.43
CD 5%	2.33	5.29	2.78	NS	NS	NS

Table 21 (a): Interaction of RDF and FYM levels on biological yield (q ha^{-1}) during 2023-24 and 2024-25

Biological yield (q ha^{-1}) (2023-24)					**Biological yield (q ha^{-1}) (2024-25)**					**Biological yield (q ha^{-1}) (pooled)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	112.44	118.53	122.55	117.84	**N_0**	103.72	112.67	116.48	110.96	**N_0**	108.08	115.60	119.51	114.40
N_1	130.54	137.26	147.32	138.37	**N_1**	122.22	135.99	150.68	136.30	**N_1**	126.38	136.63	149.00	137.34
N_2	142.62	150.04	158.21	150.29	**N_2**	145.86	160.02	168.22	158.03	**N_2**	144.24	155.03	163.22	154.16
N_3	153.73	161.32	165.15	160.06	**N_3**	163.25	169.81	172.66	168.57	**N_3**	158.49	165.56	168.90	**164.32**
Mean	134.83	141.79	148.31		**Mean**	133.76	144.62	152.01		**Mean**	134.30	143.21	150.16	
SEm±	0.78				**SEm±**	1.76				**SEm±**	0.96			
CD 5%	2.33				**CD 5%**	5.29				**CD 5%**	2.78			

4.1.4 Qualitative observations

4.1.4.1 Protein content in grains (%)

The protein percent recorded under various treatments and their combinations is presented in Table 22 and 22 (a).

Effect of RDF levels

Application RDF significantly enhanced protein content in grains across the two years of research. Protein percentage significantly increase with higher RDF levels. Highest protein percent (10.45 and 10.65 %) was noted in 100% RDF (N_3), showing superiority than control (N_0), 50% (N_1), 75% RDF (N_2) during first year. In the next year, it showed similarity with 75 % RDF. The control (N_0) recorded the minimum protein percentage.

The crude protein percentage showed a notable increase as the levels of NPK fertilizer application were progressively enhanced. This improvement can be linked to the increased soil N presence, that is vital for protein synthesis in plants (Mamatha *et al.,* 2024). These results are comparable to Lakum *et al.,* (2020), Desai *et al.,* (2022), Kuldeep *et al.,* (2022) and Naveen *et al.,* (2023).

Effect of FYM levels

The incorporation of FYM notably affected the protein content in grains across the two years of research. The maximum protein percentages, 10.04% and 10.11%, were achieved in 10 t ha^{-1} FYM (F_2), showing notably greater results than control (F_0) and the 5 t ha^{-1} FYM (F_1) treatments over the two-year study period. In contrast, the control (F_0) consistently produced the lowest grain protein content.

Enhancement in grain protein levels likely stems from improved nitrogen accessibility, which promoted greater nitrogen assimilation and retention in plant tissues. This facilitated optimal biochemical activity, particularly under higher farmyard manure (FYM) application rates. The amplified uptake of nitrogen a fundamental constituent of amides, amino acids, and proteins resulted in boosting protein production mechanisms (Nagar *et al.,*, 2022). This findings are similar with Lakum *et al.,* (2020) and Kuldeep *et al.,* (2022).

Interaction effect

Combined use of RDF and FYM significantly influenced grain protein content over two years. The highest protein levels (10.64% and 10.80%) were achieved in 100%

RDF + 10 t ha^{-1} FYM (N_3F_2) in both years. In the first year, this treatment was statistically similar to both 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). In the next year, N_3F_2 showed similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 100% RDF alone (N_3F_0), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). Similar findings recorded by Shinde *et al.,* (2014).

4.1.4.2 Crude protein yield (kg ha^{-1})

Crude protein yield noted under different treatments and their combinations is presented in Table 22, 22 (a) and figure 9.

Effect of RDF levels

RDF significantly enhanced crude protein yield during the two year study. The crude protein yield increased with higher RDF levels. The maximum crude protein yields of 579.18 kg ha^{-1} and 623.86 kg ha^{-1} were achieved in 100% RDF (N_3) application, demonstrating significant superiority over the control (N_0), 50% RDF (N_1), and 75% RDF (N_2) treatments in both study years. Control (N_0) consistently produced the lowest crude protein output.

As nitrogen serves as a critical building block for proteins, amino acids, and amides, elevated nitrogen concentrations directly correlate with increased crude protein content (Sharma *et al*., 2016). This enhanced nitrogen availability not only elevates protein levels but also amplifies yield production, resulting in a marked rise in crude protein yield. These results matched with Desai *et al.,* (2022), Kuldeep *et al.,* (2022) and Naveen *et al.,* (2023).

Effect of FYM levels

FYM incorporation significantly influenced crude protein yield during the two year experimental period. Crude protein yield increased with higher FYM levels. Incorporating 10 t ha^{-1} FYM (F_2) noted maximum crude protein yields of 502.53 kg ha^{-1} and 527.09 kg ha^{-1}, which were statistically superior to both the control (F_0) and 5 t ha^{-1} FYM (F_1) across both study years. Least crude protein output consistently noted in the F_0.

Higher crude protein percent can be attributed to the enhanced availability of N, which facilitated greater nutrient uptake by plants. Furthermore, improved biochemical processes facilitated by elevated FYM application rates promoted enhanced protein synthesis, leading to measurable increment in crude protein yield (Sharma *et al.,* 2016).

Gradual release of nitrogen through FYM application not only enhances protein concentration but also supports overall morphology and production, resulting in substantial increase in crude protein yield. These results are similar with Kuldeep *et al.,* (2022).

Interaction effect

The combination of different RDF and FYM levels demonstrated significant statistical influence during the two year study. Highest crude protein yield (627.02 and 662.28 kg ha^{-1}) ware achieved under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study years. N_3F_2 combination was statistically superior to varying interactions in first year. In the next season, N_3F_2 remained statistically comparable to 100% RDF + 5 t ha^{-1} FYM (N_3F_1). These results are matched with Shinde *et al.,* (2014).

4.1.4.3 Ash content in grains (%)

The ash percentage observed in grains across various treatments and their combinations is detailed in Table 22.

Effect of RDF levels

Application RDF notably influenced ash percentage in grains across the two years of research of experimentation. The application of 100% RDF (N_3) recorded the highest ash content in grains (1.57% and 1.64%), as compared to control (N_0), 50% RDF (N_1), and 75% RDF (N_2) during the first year. In the next year, N_3 results aligned statistically with 75% RDF (N_2). Lowest ash content was consistently observed in the control (N_0).

Enhanced availability and uptake of mineral nutrients results in a higher mineral content in maize grain, demonstrating a direct relationship between the amount of available soil nutrients and the grain's ash content (Thakur *et al.,* 2021). Similar results reported by Sharma *et al.,* (2016).

Effect of FYM levels

The application of FYM significantly influenced the ash content in grains across the two years of research. Ash content in grains increased with higher levels of FYM. 10 t ha^{-1} FYM (F_2) noted highest ash content in grains (1.45% and 1.50%), significantly surpassing both the control (F_0) and 5 t ha^{-1} FYM (F_1) in first season. In next season, F_2 ash levels were statistically equivalent to those of 5 t ha^{-1} FYM (F_1). The F_0 consistently exhibited lowest ash content.

The beneficial impact of organic manure on the ash content of maize can be attributed to its ability to enhance soil nutrient availability. In contrast, the lower ash content observed in maize grain under the control treatment (F_0) likely results from continuous cropping without fertilization, which depletes soil nutrients and reduces fertility over time (Thakur *et al.,* 2021). These results are consistent with Sharma *et al.,* (2016).

Interaction effect

Combination of varying levels of RDF and FYM did not demonstrate statistical significance during the two year experimental period.

Table 22: Effect of integrated nutrient management on qualitative observations of maize during 2023-24 and 2024-25

Treatments	Protein content in grains (%)		Crude protein yield (kg ha^{-1})		Ash content in grains (%)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	8.88	8.50	332.58	298.41	1.14	1.03
N_1 : 50 % RDF	9.58	9.67	424.05	426.73	1.34	1.36
N_2 : 75 % RDF	10.11	10.34	499.40	538.12	1.45	1.57
N_3 : 100 % RDF	10.45	10.65	579.18	623.86	1.57	1.64
SEm ±	0.09	0.15	6.06	14.17	0.01	0.04
CD 5%	0.31	0.52	20.99	49.04	0.04	0.14
FYM levels						
F_0 : Control	9.50	9.40	416.41	409.37	1.30	1.28
F_1 : 5 t ha^{-1} FYM	9.73	9.86	457.47	478.88	1.38	1.42
F_2 : 10 t ha^{-1} FYM	10.04	10.11	502.53	527.09	1.45	1.50
SEm ±	0.04	0.06	2.95	5.92	0.01	0.03
CD 5%	0.12	0.19	8.83	17.74	0.02	0.08
Interaction N*F						
SEm±	0.08	0.13	5.89	11.83	0.01	0.05
CD 5%	0.25	0.39	17.66	35.47	NS	NS

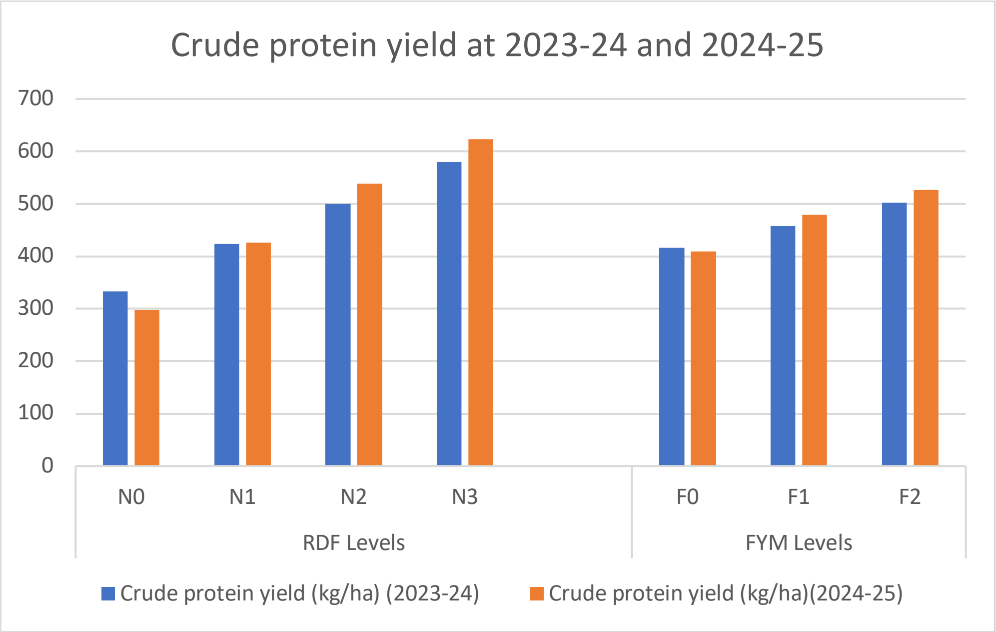


Fig. 9. Crude protein yield of maize as impacted by varying treatments

Table 22 (a): **Interaction of RDF and FYM levels on protein content in grains (%) and crude protein yield (kg ha^{-1}) of maize during 2023-24 and 2024-25**

Protein content in grains (%) (2023-24)					**Protein content in grains (%) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	8.74	8.88	9.02	8.88	**N_0**	8.16	8.57	8.77	8.50
N_1	9.19	9.46	10.10	9.58	**N_1**	8.92	9.79	10.30	9.67
N_2	9.79	10.15	10.40	10.11	**N_2**	10.05	10.40	10.58	10.34
N_3	10.27	10.44	10.64	10.45	**N_3**	10.46	10.68	10.80	10.65
Mean	9.50	9.73	10.04		**Mean**	9.40	9.86	10.11	
SEm±	0.08				**SEm±**	0.13			
CD 5%	0.25				**CD 5%**	0.38			
Crude protein yield (kg ha^{-1}) (2023-24)					**Crude protein yield (kg ha^{-1}) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	308.82	335.65	353.29	332.58	**N_0**	260.12	310.81	324.31	298.41
N_1	394.86	412.10	465.21	424.05	**N_1**	349.47	430.48	500.24	426.73
N_2	439.32	494.24	564.62	499.40	**N_2**	454.46	538.34	621.55	538.12
N_3	522.65	587.88	627.02	**579.18**	**N_3**	573.43	635.88	662.28	623.86
Mean	416.41	457.47	502.53		**Mean**	409.37	478.88	527.09	
SEm±	5.89				**SEm±**	11.83			
CD 5%	17.66				**CD 5%**	35.47			

4.1.5 Plant analysis (Content and uptake of nutrients)

4.1.5.1 Nutrient content

4.1.5.1.1 Nitrogen content (%) in maize

The N concentration in maize noted in varying treatments and their combinations illustrated in Table 23 and 23 (a).

Effect of RDF levels

Nitrogen content in grain and stover of maize was notably impacted by RDF across the two years of research. N content in maize increase with elevated levels of RDF. Highest N content in grains of maize (1.672 and 1.703 %) and stover (0.543 and 0.587 %) was noted in 100% RDF (N_3) across the two years of research. During first year, N_3 showed superiority than control (N_0), 50% (N_1), and 75% RDF (N_2). However, in the next year, N_3 similar to 75 % RDF in terms of grains nitrogen content. Regarding stover nitrogen content, N_3 showed superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. Minimum nitrogen percent in maize was registered in the control (N_0).

The inorganic component played a crucial role in supplying readily available nutrients during the early stages of crop growth. This immediate nutrient availability, particularly nitrogen, facilitated rapid uptake by plants, promoting early vegetative development. Nitrogen, being a key element in protein synthesis and chlorophyll formation, enhanced metabolic activities, cell division, and overall plant vigor, leading to an increment in nitrogen percent within plant (Madhurya *et al.,* 2021). These results showed similarity to Karki *et al.,* (2005), Desai *et al.,* (2022) and Kuldeep *et al.,* (2022).

Effect of FYM levels

FYM incorporation notably impacted the N content in maize across both study years. N content in maize increased when increasing FYM levels. Highest N content in grains of maize (1.606, 1.618 %) and stover (0.510 and 0.532 %) noted in 10 t ha^{-1} FYM (F_2), showing superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across the two years of research. Lowest N content in maize was record with control (F_0).

The incorporation FYM leads to the formation of clay-humus complexes, where organic colloids bind with soil minerals to improve CEC and nutrient retention. These complexes help in reducing losses of nutrients through leaching and volatilization, ensuring a gradual and prolonged nutrient delivery throughout the crop growing cycle

(Desai *et al.,* 2022). These results are related with Khan and Jan (2018) and Kuldeep *et al.,* (2022).

Interaction effect

The combination of varying levels of RDF and FYM showing notable impact across the two years of research. Maximum N content in grains of maize (1.702 and 1.728 %) and stover (0.567 and 0.611%) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. N_3F_2 combination was at par with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) in first year. In the next season, N_3F_2 showed parity to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), 100% RDF (N_3F_0) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) in terms of N content in grains. Regarding N content in stover, N_3F_2 combination showed parity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) across two years of research. This results are similar with Yadav and Singh (2022).

4.1.5.1.2 Phosphorus content (%) in maize

The phosphorus content in maize recorded under various treatments and their combinations is depicted in Table 23 and 23 (b).

Effect of RDF levels

Phosphorus content in maize were considerably increased with use of RDF across the two years of research. Phosphorus content in maize increased with elevated levels of RDF. The highest phosphorus content in maize grain (0.358 and 0.395 %) and stover (0.191 and 0.207 %) was registered under 100% RDF (N_3), showing evident superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across both study years. Least phosphorus content in maize was registered under the control (N_0).

Increase in nutrient levels with the application of recommended fertilizer doses boosts cation exchange capacity of roots, thereby improving nutrient absorption (Karki *et al.,* 2005). These results are similar to Karki *et al.,* (2005) and Kuldeep *et al.,* (2022).

Effect of FYM levels

FYM Incorporation notably impact the phosphorus content in maize across the two years of research. Phosphorus content in maize increased when applying higher FYM levels. The highest phosphorus content in maize grain (0.336 and 0.355 %) and stover (0.166 and 0.180 %) was noted with 10 t ha^{-1} FYM (F_2), showing superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across the two years of research. Minimum phosphorus content in maize was noted in the F_0.

Organic sources like FYM improves soil N, P_2O_5, and K_2O availability, ensuring a higher nutrient supply to plants. This leads to better root development and early morphometric development, which enhances light energy utilization. As a result, more metabolites move from the roots to the shoots, especially to the reproductive parts of maize, increasing the nutrient content (P) in the crop (Desai *et al.,* 2022). This results are supported by Kuldeep *et al.,* (2022).

Interaction effect

Combination of varying RDF and FYM showed significance across two years of research. Peak phosphorus content in grains of maize (0.382 and 0.415 %) and stover (0.213 and 0.225%) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research. N_3F_2 combination was markedly greater to varying treatment interaction in first season. In the next season, N_3F_2 showed parity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) in terms of phosphorus content in grains. Regarding phosphorus content in stover, N_3F_2 combination was statistically superior over all the treatment combination in first season but, it showed parity to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) during second year. These results are similar with Yadav and Singh (2022).

Table 23: Effect of integrated nutrient management on nutrient content of maize in 2023-24 and 2024-25

Treatments	Nitrogen content (%)				Phosphorus content (%)				Potassium content (%)			
	Grain		Stover		Grain		Stover		Grain		Stover	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels												
N_0 : Control	1.421	1.360	0.415	0.374	0.277	0.242	0.107	0.088	0.299	0.263	0.716	0.702
N_1 : 50 % RDF	1.533	1.547	0.472	0.481	0.315	0.321	0.139	0.145	0.363	0.370	0.781	0.799
N_2 : 75 % RDF	1.618	1.655	0.511	0.538	0.333	0.357	0.160	0.179	0.378	0.386	0.803	0.822
N_3 : 100 % RDF	1.672	1.703	0.543	0.587	0.358	0.395	0.191	0.207	0.399	0.418	0.826	0.850
SEm ±	0.014	0.024	0.008	0.005	0.007	0.005	0.004	0.004	0.003	0.006	0.004	0.006
CD 5%	0.049	0.083	0.029	0.017	0.023	0.019	0.014	0.014	0.010	0.021	0.015	0.021
FYM levels												
F_0 : Control	1.520	1.504	0.461	0.449	0.307	0.298	0.134	0.129	0.320	0.298	0.743	0.735
F_1 : 5 t ha^{-1} FYM	1.557	1.577	0.485	0.504	0.320	0.333	0.148	0.156	0.364	0.372	0.780	0.797
F_2 : 10 t ha^{-1} FYM	1.606	1.618	0.510	0.532	0.336	0.355	0.166	0.180	0.395	0.407	0.822	0.848
SEm ±	0.007	0.010	0.003	0.003	0.002	0.002	0.002	0.002	0.003	0.005	0.003	0.006
CD 5%	0.020	0.031	0.008	0.010	0.006	0.005	0.005	0.007	0.008	0.016	0.010	0.017
Interaction N*F												
SEm±	0.013	0.021	0.005	0.007	0.004	0.003	0.003	0.005	0.005	0.011	0.007	0.012
CD 5%	0.040	0.062	0.016	0.020	0.012	0.010	0.010	0.015	0.016	0.032	0.021	0.035

Table 23 (a): Combination of RDF and FYM levels on nitrogen content in grains and stover (%) of maize during 2023-24 and 2024-25

Grains nitrogen content (%) (2023-24)					**Grains nitrogen content (%) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	1.399	1.420	1.443	1.421	**N_0**	1.305	1.371	1.403	1.360
N_1	1.471	1.513	1.616	1.533	**N_1**	1.428	1.567	1.647	1.547
N_2	1.567	1.624	1.663	1.618	**N_2**	1.609	1.663	1.692	1.655
N_3	1.644	1.670	1.702	1.672	**N_3**	1.673	1.709	1.728	1.703
Mean	1.520	1.557	1.606		**Mean**	1.504	1.577	1.618	
SEm±	0.013				**SEm±**	0.021			
CD 5%	0.040				**CD 5%**	0.062			
Stover nitrogen content (%) (2023-24)					**Stover nitrogen content (%) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	0.398	0.408	0.439	0.415	**N_0**	0.314	0.394	0.413	0.374
N_1	0.453	0.475	0.487	0.472	**N_1**	0.438	0.480	0.524	0.481
N_2	0.481	0.505	0.546	0.511	**N_2**	0.492	0.543	0.580	0.538
N_3	0.510	0.553	0.567	0.543	**N_3**	0.550	0.600	0.611	0.587
Mean	0.461	0.485	0.510		**Mean**	0.449	0.504	0.532	
SEm±	0.005				**SEm±**	0.007			
CD 5%	0.016				**CD 5%**	0.020			

Table 23 (b): Combination of RDF and FYM levels on phosphorus content in grains and stover (%) of maize during 2023-24 and 2024-25

Grains phosphorus content (%) (2023-24)					Grains phosphorus content (%) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	0.264	0.280	0.286	0.277	**N_0**	0.216	0.247	0.263	0.242
N_1	0.309	0.314	0.321	0.315	**N_1**	0.285	0.324	0.355	0.321
N_2	0.317	0.328	0.354	0.333	**N_2**	0.328	0.357	0.387	0.357
N_3	0.337	0.357	0.382	0.358	**N_3**	0.363	0.406	0.415	0.395
Mean	0.307	0.320	0.336		**Mean**	0.298	0.333	0.355	
SEm±	0.004				**SEm±**	0.003			
CD 5%	0.012				**CD 5%**	0.010			
Stover phosphorus content (%) (2023-24)					**Stover phosphorus content (%) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	0.097	0.102	0.124	0.107	**N_0**	0.071	0.084	0.108	0.088
N_1	0.133	0.135	0.147	0.139	**N_1**	0.111	0.145	0.180	0.145
N_2	0.138	0.161	0.181	0.160	**N_2**	0.148	0.183	0.206	0.179
N_3	0.168	0.193	0.213	0.191	**N_3**	0.185	0.212	0.225	0.207
Mean	0.134	0.148	0.166		**Mean**	0.129	0.156	0.180	
SEm±	0.003				**SEm±**	0.005			
CD 5%	0.010				**CD 5%**	0.015			

Table 23 (c): Combination of RDF and FYM levels on potassium content in grains and stover (%) of maize during 2023-24 and 2024-25

Grains potassium content (%) (2023-24)					**Grains potassium content (%) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	0.276	0.304	0.317	0.299	**N_0**	0.230	0.265	0.293	0.263
N_1	0.311	0.369	0.409	0.363	**N_1**	0.283	0.394	0.433	0.370
N_2	0.339	0.380	0.417	0.378	**N_2**	0.322	0.400	0.436	0.386
N_3	0.354	0.403	0.438	0.399	**N_3**	0.357	0.431	0.466	0.418
Mean	0.320	0.364	0.395		**Mean**	0.298	0.372	0.407	
SEm±	0.005				**SEm±**	0.011			
CD 5%	0.016				**CD 5%**	0.032			
Stover potassium content (%) (2023-24)					**Stover potassium content (%) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	0.697	0.707	0.742	0.716	**N_0**	0.674	0.696	0.737	0.702
N_1	0.728	0.790	0.825	0.781	**N_1**	0.710	0.813	0.874	0.799
N_2	0.765	0.801	0.845	0.803	**N_2**	0.767	0.820	0.880	0.822
N_3	0.780	0.823	0.875	0.826	**N_3**	0.788	0.860	0.903	0.850
Mean	0.743	0.780	0.822		**Mean**	0.735	0.797	0.848	
SEm±	0.007				**SEm±**	0.012			
CD 5%	0.021				**CD 5%**	0.035			

4.1.5.1.3 Potassium content (%) in maize

The potassium content in maize recorded under various treatments and their combinations is depicted in Table 23 and 23 (c).

Effect of RDF levels

Potassium content in maize were notably impacted by the RDF application across the two years of research. Potassium content in maize increased with raising RDF levels. The highest potassium content in maize grain (0.399 and 0.418 %) and stover (0.826 and 0.850 %) was noted in 100% RDF (N_3), showed superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across both study years. The lowest potassium content were registered under control (N_0).

Increase in shoot growth, as indicated by higher dry matter accumulation, was influenced by balanced and elevated levels of fertilization. The mutual enhancement of shoot and root growth improved overall plant efficiency, as reflected in higher grain and stover yields. This, in turn, may have facilitated the supply of adequate metabolites to support root development and its functional activities, ultimately aiding in the greater percent and intake of potassium (Yadav and Singh 2022). These results are similar with Karki *et al.,* (2005) and Kuldeep *et al.,* (2022).

Effect of FYM levels

FYM incorporation significantly increased the potassium content in maize across the two years of research. Potassium content in maize increased when applying higher levels of FYM. The highest potassium content in maize grain (0.395 and 0.407 %) and stover (0.882 and 0.848 %) noted in 10 t ha^{-1} FYM (F_2), showing superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two seasons of research. Least potassium content in maize were recorded under the control (F_0).

Higher potassium content could be attributed to the organic manure incorporation, which enhances nutrient availability. This, in turn, improves nutrient absorption and facilitates the efficient translocation of potassium in the plant, particularly at the developmental phase (Nagar *et al.,* 2022). Findings are similar with Kuldeep *et al.,* (2022).

Interaction effect

The combination of varying RDF and FYM rates showed significance across the two years of research. Highest potassium content in maize grain (0.438 and 0.466

%) and stover (0.875 and 0.903%) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. N_3F_2 combination was notably greater over varying treatment interactions in first season. In the next season, N_3F_2 matched the performance of with 75% RDF + 10 t ha^{-1} FYM (N_2F_2) in terms of potassium content in grains. Regarding potassium content in stover, N_3F_2 combination was statistically superior over all the treatment combination in first year but, it matched the performance of 75% RDF + 10 t ha^{-1} FYM (N_2F_2) during second year. These results are similar with Yadav and Singh (2022)

4.1.5.2 Uptake of nutrients

4.1.5.2.1 Nitrogen uptake by maize (kg ha^{-1})

Nitrogen intake by maize recorded under various treatments and their combinations is presented in Table 24, 24 (a) and figure 10.

Effect of RDF levels

Nitrogen uptake by maize increased with RDF levels. The highest N uptake by maize grain (92.67 and 99.82 kg ha^{-1}), stover (56.93 and 64.74 kg ha^{-1}) and overall uptake (149.60 and 164.58 kg ha^{-1}) noted in 100% RDF (N_3), which was markedly greater than control (N_0), 50% (N_1), and 75% RDF (N_2) across both study years. Lowest nitrogen uptake by maize was registered under the control (N_0).

Use of mineral fertilizers provides nutrients in readily available forms, making them easily accessible to plants. This results in a notable accumulation of nutrients in both vegetative parts and the edible portion of maize (Jayanthi *et al.,* 2020). When nitrogen and phosphorus are applied together, grain nitrogen concentration tends to increase proportionally with rising nitrogen levels. However, in the absence of added phosphorus, increase in grain nitrogen content becomes nonlinear, likely due to a dilution effect (Schlegel and Havlin 2017). These outcomes are similar with Karki *et al.,* (2005), Lakum *et al.,* (2020), Manjunatha *et al.,* (2022), Desai *et al.,* (2022) and Kuldeep *et al.,* (2022).

Effect of FYM levels

FYM incorporation notably enhanced nitrogen uptake by maize across two years of research. Nitrogen uptake by maize rose with elevated FYM levels. The highest nitrogen uptake by maize grain (80.41 and 84.34 kg ha^{-1}), stover (50.72 and 54.60 kg ha^{-1}) and overall uptake (131.13 and 138.94 kg ha^{-1}) noted in 10 t ha^{-1} FYM (F_2), which was markedly greater than control (F_0), and 5 t ha^{-1} FYM (F_1) across two study years. Lowest nitrogen intake noted under the control (F_0).

FYM incorporation enhanced nitrogen concentration in maize by promoting better root establishment, which facilitated higher nitrogen absorption (Lakum *et al.,* 2020). The increased nitrogen intake observed with FYM may be due to the decomposition of native nutrients as well as enhanced movement and storage of nitrogen in plant (Sharma *et al.,* 2015). These results are parallel with Mehta *et al.,* (2005), Masood *et al.,* (2014), Lakum *et al.,* (2020) and Kuldeep *et al.,* (2022).

Interaction effect

Combination of various RDF and FYM levels was significant across the two years of research. Highest nitrogen uptake by maize grain (100.32 and 105.96 kg ha^{-1}), stover (60.22 and 68.17 kg ha^{-1}) and overall uptake (160.54 and 174.14 kg ha^{-1}) noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research. The N_3F_2 interaction was markedly greater over other treatment interaction in first season. In the next season, N_3F_2 showed parity to 100 % RDF + 5 t ha^{-1} FYM (N_3F_1) in nitrogen uptake by grains and stover. Regarding overall nitrogen intake, N_3F_2 combination was statistically superior over all the treatment combination across the two years of research. This results are similar with Wagh (2002), Sharma *et al.,* (2020), Lakum *et al.,* (2020) and Yadav and Singh (2022).

4.1.5.2.2 Phosphorus uptake by maize (kg ha^{-1})

Phosphorus intake by maize recorded under various treatments and their combinations is shown in Table 25, 25 (a) and figure 10.

Effect of RDF levels

The highest phosphorus uptake by maize grain (19.93 and 23.16 kg ha^{-1}), stover (20.06 and 22.89 kg ha^{-1}) and overall intake (39.98 and 46.05 kg ha^{-1}) were recorded under 100% RDF (N_3), which markedly superior than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. Least phosphorus intake by maize noted in control (N_0).

Higher RDF levels enhanced the nutrient content in maize, likely due to improved development of roots and shoots, which facilitated more efficient uptake of phosphorus from the soil (Kaur and Rani 2022). Similar results registered by Karki *et* *al.,* (2005), Lakum *et al.,* (2020), Manjunatha *et al.,* (2022), Desai *et al.,* (2022) and Kuldeep *et al.,* (2022).

Effect of FYM levels

FYM incorporation markedly influenced phosphorus uptake by maize across the two years of research. Phosphorus uptake by maize rise when FYM rates elevated. Highest phosphorus uptake by maize grain (16.94 and 18.79 kg ha^{-1}), stover (16.66 and 18.68 kg ha^{-1}) and overall intake (33.60 and 37.47 kg ha^{-1}) noted in 10 t ha^{-1} FYM (F_2), which showed superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across both study years. Least phosphorus uptake by maize was recorded in control (F_0).

Phosphorus concentration in grain and straw improved due to enhanced root proliferation, which aided in better phosphorus uptake (Lakum *et al.,* 2020). The higher nutrient intake observed under the organic matter is caused by multiple factors. These include the solubilization of native soil nutrients through microbial activity and the enhanced mobilization and translocation of essential nutrients to plant. Additionally, the improved soil microbial population and enzymatic activity facilitated by organic amendments likely contributed to greater nutrient availability and uptake efficiency (Dwivedi *et al.,* 2015). These results are similar to Mehta *et al.,* (2005), Masood *et al.,* (2014), Lakum *et al.,* (2020) and Kuldeep *et al.,* (2022).

Interaction effect

Combination of different RDF and FYM levels was significant across the two years of research. Highest phosphorus uptake by maize grain (22.55 and 25.43 kg ha^{-1}), stover (22.62 and 25.08 kg ha^{-1}) and overall uptake (45.17 and 50.51 kg ha^{-1}) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research, which found statistically superior over all the treatment combination. These results are similar with Wagh (2002), Sharma *et al.,* (2020) Lakum *et al.,* (2020), and Yadav and Singh (2022).

4.1.5.2.3 Potassium uptake by maize (kg ha^{-1})

Potassium intake by maize recorded under various treatments and their combinations is shown in Table 26, 26 (a) and figure 10.

Effect of RDF levels

Potassium uptake by maize was markedly improved by RDF application across the two years of research. Highest potassium uptake by maize grain (22.19 and 24.61

kg ha^{-1}), stover (86.53 and 93.96 kg ha^{-1}) and overall uptake (108.72 and 118.57 kg ha^{-1}) noted under 100% RDF (N_3) across the two years of research. The N_3 was markedly superior than control (N_0), 50% (N_1), and 75% RDF (N_2) during the first year and second season, in terms of grains and overall potassium uptake. However, 100 % RDF (N_3) was significantly superior in first season but it showed parity to 75 % RDF in next season, in terms of potassium uptake by stover. The lowest potassium uptake by maize was rerecorded under the control (N_0).

Application of higher potassium doses, which enhanced nutrient uptake and led to greater accumulation of potassium in both the grain and stover (Hasan *et al.,* 2023). Additionally, the increase may also be explained by the phenomenon of luxury consumption of potassium, as noted by Brady and Weil (2007), where plants absorb more potassium than immediately needed when it is abundantly available in the soil. These results are corroborate with Karki *et al.,* (2005), Lakum *et al.,* (2020), Manjunatha *et al.,* (2022), Desai *et al.,* (2022) and Kuldeep *et al.,* (2022)

Effect of FYM levels

FYM incorporation markedly improved potassium uptake by maize across the two years of research. The highest potassium intake by maize grains (19.94 and 21.52 kg ha^{-1}), stover (81.55 and 86.41 kg ha^{-1}) and overall uptake (101.49 and 107.92 kg ha^{-1}) was noted under10 t ha^{-1} FYM (F_2), showing statistical superiority over control (F_0), and 5 t ha^{-1} FYM (F_1) across the two study years. Least potassium intake noted in control (F_0).

The increased potassium concentration in grain and straw resulted from improved root activity, which enhanced potassium absorption (Lakum *et al.,* 2020). The greater accessibility of nutrients due to the residual impact of organic matter may have enhanced plant physiological and metabolic functions, thereby improving nutrient uptake (Singh *et al.,* 2018). Organic amendments contribute to sustained nutrient release through mineralization, improving nutrient solubility and microbial activity in the rhizosphere. This, in turn, supports key physiological processes such as enzyme activation, chlorophyll synthesis, and root proliferation, ultimately facilitating greater absorption and translocation of nutrients within the plant. Similar results reported by Masood *et al.,* (2014), Lakum *et al.,* (2020) and Kuldeep *et al.,* (2022).

Interaction effect

Combination of varying RDF and FYM levels showed significance across the two years of research. Highest potassium uptake by maize grain (25.85 and 28.57 kg ha^{-1}), stover (92.89 and 100.91 kg ha^{-1}) and overall intake (118.74 and 129.48 kg ha^{-1}) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research. The N_3F_2 combination was considerably effective than other treatment interaction during first year, in terms of grains, stover and overall uptake of potassium. However, in the next season, N_3F_2 was significantly superior over all combinations in terms of grain and overall potassium uptake but the highest potassium uptake by stover found similar with 100 % RDF + 5 t ha^{-1} FYM (N_2F_2) and 75% RDF + 10 t ha^{-1} FYM. This results are similar with Wagh (2002), Sharma *et al.,* (2020), Lakum *et al.,* (2020) and Yadav and Singh (2022).

Table 24: Effect of integrated nutrient management on nitrogen uptake (kg ha^{-1}) of maize in 2023-24 and 2024-25

Treatments	**N uptake (kg ha^{-1})**					
	Grain		**Stover**		**Total**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	53.21	47.75	33.48	28.59	86.69	76.34
N_1 : 50 % RDF	67.85	68.28	44.51	44.82	112.36	113.09
N_2 : 75 % RDF	79.90	86.10	51.65	57.43	131.55	143.53
N_3 : 100 % RDF	92.67	99.82	56.93	64.76	149.60	164.58
SEm ±	0.970	2.27	0.73	0.92	1.15	2.48
CD 5%	3.36	7.85	2.53	3.17	3.97	8.58
FYM levels						
F_0 : Control	66.63	65.50	42.52	42.18	109.15	107.68
F_1 : 5 t ha^{-1} FYM	73.19	76.62	46.69	49.92	119.88	126.54
F_2 : 10 t ha^{-1} FYM	80.41	84.34	50.72	54.60	131.13	138.94
SEm ±	0.471	0.95	0.32	0.54	0.46	0.97
CD 5%	1.41	2.84	0.96	1.63	1.38	2.90
Interaction N*F						
SEm±	0.943	1.89	0.64	1.09	0.92	1.93
CD 5%	2.83	5.68	1.91	3.26	2.75	5.79

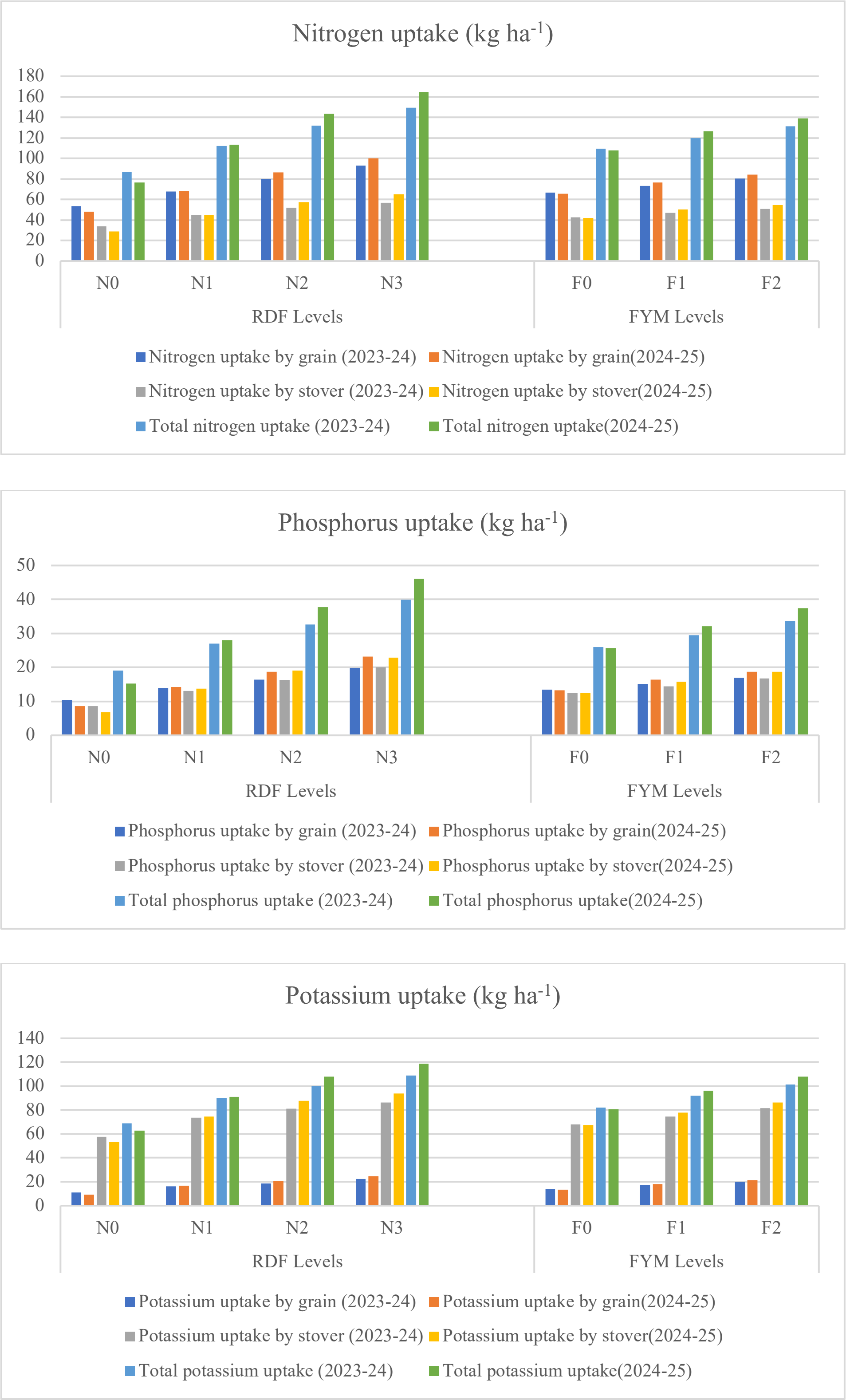


Fig. 10. Nitrogen, phosphorus and potassium uptake (kg ha^{-1}) of maize as impacted by varying treatments

Table 24 (a): Combination impact of RDF and FYM rates on nitrogen uptake (kg ha^{-1}) by grains and stover (%) of maize during 2023-24 and 2024-25

N uptake by grains (kg ha^{-1}) (2023-24)					**N uptake by grains (kg ha^{-1})(2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	49.41	53.70	56.53	53.21	**N_0**	41.62	49.73	51.89	47.75
N_1	63.18	65.94	74.43	67.85	**N_1**	55.92	68.88	80.04	68.28
N_2	70.29	79.08	90.34	79.90	**N_2**	72.71	86.13	99.45	86.10
N_3	83.62	94.06	100.32	92.67	**N_3**	91.75	101.74	105.96	99.82
Mean	66.63	73.19	80.41		**Mean**	65.50	76.62	84.34	
SEm±	0.94				**SEm±**	1.89			
CD 5%	2.83				**CD 5%**	5.68			

N uptake by stover (%) (2023-24)					**N uptake by stover (%) (2024-25)**				
Interaction N*F	F_0	F_1	F_2	Mean	**Interaction N*F**	F_0	F_1	F_2	Mean
N_0	30.79	32.99	36.66	33.48	**N_0**	22.64	30.21	32.94	28.59
N_1	39.74	44.50	49.30	44.51	**N_1**	36.55	44.20	53.70	44.82
N_2	47.06	51.17	56.71	51.65	**N_2**	49.72	58.99	63.59	57.43
N_3	52.49	58.09	60.22	56.93	**N_3**	59.80	66.30	68.17	64.76
Mean	42.52	46.69	50.72		**Mean**	42.18	49.92	54.60	
SEm±	0.64				**SEm±**	1.09			
CD 5%	1.91				**CD 5%**	3.26			

Overall N uptake (kg ha^{-1}) (2023-24)					**Overall N uptake (kg ha^{-1})(2024-25)**				
Interaction N*F	F_0	F_1	F_2	Mean	**Interaction N*F**	F_0	F_1	F_2	Mean
N_0	80.20	86.70	93.18	86.69	**N_0**	64.25	79.94	84.83	76.34
N_1	102.92	110.44	123.73	112.36	**N_1**	92.47	113.08	133.73	113.09
N_2	117.35	130.25	147.05	131.55	**N_2**	122.43	145.13	163.04	143.53
N_3	136.12	152.15	160.54	149.60	**N_3**	151.55	168.04	174.14	164.58
Mean	109.15	119.88	131.13		**Mean**	107.68	126.54	138.94	
SEm±	0.92				**SEm±**	1.93			
CD 5%	2.75				**CD 5%**	5.79			

Table 25: Effect of integrated nutrient management on phosphorus uptake (kg ha^{-1}) of maize during 2023-24 and 2024-25

Treatments	Phosphorus uptake (kg ha^{-1})					
	Grain		Stover		Total	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	10.37	8.59	8.68	6.72	19.06	15.31
N_1 : 50 % RDF	13.91	14.23	13.10	13.70	27.01	27.93
N_2 : 75 % RDF	16.48	18.68	16.22	19.13	32.70	37.80
N_3 : 100 % RDF	19.93	23.16	20.06	22.89	39.98	46.05
SEm ±	0.37	0.23	0.41	0.62	0.23	0.75
CD 5%	1.29	0.78	1.40	2.15	0.78	2.59
FYM levels						
F_0 : Control	13.49	13.24	12.51	12.40	25.99	25.65
F_1 : 5 t ha^{-1} FYM	15.10	16.46	14.38	15.74	29.47	32.20
F_2 : 10 t ha^{-1} FYM	16.94	18.79	16.66	18.68	33.60	37.47
SEm ±	0.11	0.18	0.16	0.25	0.16	0.24
CD 5%	0.34	0.53	0.49	0.74	0.47	0.71
Interaction N*F						
SEm±	0.23	0.35	0.33	0.49	0.32	0.47
CD 5%	0.69	1.05	0.99	1.47	0.95	1.42

Table 25 (a) : Combination impact of RDF and FYM levels on phosphorus uptake (kg ha^{-1}) by grains and stover (%) of maize during 2023-24 and 2024-25

P uptake by grains (kg ha^{-1}) (2023-24)					P uptake by grains (kg ha^{-1}) (2024-25)				
Interaction N*F	F$_0$	F$_1$	F$_2$	Mean	Interaction N*F	F$_0$	F$_1$	F$_2$	Mean
N$_0$	9.34	10.57	11.20	10.37	N$_0$	7.02	8.97	9.79	8.59
N$_1$	13.26	13.70	14.77	13.91	N$_1$	11.18	14.28	17.23	14.23
N$_2$	14.20	16.02	19.23	16.48	N$_2$	14.87	18.46	22.70	18.68
N$_3$	17.14	20.09	22.55	19.93	N$_3$	19.91	24.13	25.43	23.16
Mean	13.49	15.10	16.94		Mean	13.24	16.46	18.79	
SEm±	0.23				SEm±	0.35			
CD 5%	0.69				CD 5%	1.05			

P uptake by stover (%) (2023-24)					P uptake by stover (%) (2024-25)				
Interaction N*F	F$_0$	F$_1$	F$_2$	Mean	Interaction N*F	F$_0$	F$_1$	F$_2$	Mean
N$_0$	7.49	8.22	10.34	8.68	N$_0$	5.15	6.40	8.62	6.72
N$_1$	11.69	12.71	14.90	13.10	N$_1$	9.31	13.36	18.43	13.70
N$_2$	13.53	16.34	18.78	16.22	N$_2$	14.97	19.79	22.62	19.13
N$_3$	17.31	20.24	22.62	20.06	N$_3$	20.19	23.41	25.08	22.89
Mean	12.51	14.38	16.66		Mean	12.40	15.74	18.68	
SEm±	0.33				SEm±	0.49			
CD 5%	0.99				CD 5%	1.47			

Overall P uptake (kg ha^{-1}) (2023-24)					Overall P uptake (kg ha^{-1}) (2024-25)				
Interaction N*F	F$_0$	F$_1$	F$_2$	Mean	Interaction N*F	F$_0$	F$_1$	F$_2$	Mean
N$_0$	16.83	18.79	21.54	19.06	N$_0$	12.16	15.37	18.40	15.31
N$_1$	24.95	26.41	29.67	27.01	N$_1$	20.49	27.64	35.66	27.93
N$_2$	27.74	32.35	38.01	32.70	N$_2$	29.84	38.26	45.31	37.80
N$_3$	34.45	40.34	45.17	39.98	N$_3$	40.10	47.54	50.51	46.05
Mean	25.99	29.47	33.60		Mean	25.65	32.20	37.47	
SEm±	0.32				SEm±	0.47			
CD 5%	0.95				CD 5%	1.42			

Table 26: Effect of integrated nutrient management on potassium uptake (kg ha^{-1}) of maize in 2023-24 and 2024-25

Treatments	Potassium uptake (kg ha^{-1})					
	Grain		Stover		Total	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	11.23	9.33	57.62	53.45	68.85	62.78
N_1 : 50 % RDF	16.10	16.50	73.80	74.51	89.90	91.01
N_2 : 75 % RDF	18.77	20.28	81.27	87.64	100.04	107.92
N_3 : 100 % RDF	22.19	24.61	86.53	93.96	108.72	118.57
SEm ±	0.11	0.52	0.57	1.91	0.56	2.04
CD 5%	0.37	1.79	1.99	6.59	1.95	7.07
FYM levels						
F_0 : Control	14.08	13.20	68.17	67.70	82.25	80.89
F_1 : 5 t ha^{-1} FYM	17.20	18.34	74.70	78.06	91.90	96.40
F_2 : 10 t ha^{-1} FYM	19.94	21.52	81.55	86.41	101.49	107.92
SEm ±	0.15	0.26	0.46	1.03	0.41	1.02
CD 5%	0.44	0.79	1.38	3.08	1.23	3.06
Interaction N*F						
SEm±	0.29	0.52	0.92	2.06	0.82	2.04
CD 5%	0.88	1.57	2.75	6.17	2.46	6.11

Table 26 (a): Interaction effect of RDF and FYM levels on potassium uptake (kg ha^{-1}) by grains and stover (%) of maize during 2023-24 and 2024-25

K uptake by grains (kg ha^{-1}) (2023-24)					K uptake by grains (kg ha^{-1})(2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	9.76	11.52	12.40	11.23	**N_0**	7.50	9.63	10.88	9.33
N_1	13.37	16.07	18.86	16.10	**N_1**	11.15	17.32	21.03	16.50
N_2	15.17	18.50	22.63	18.77	**N_2**	14.56	20.71	25.58	20.28
N_3	18.02	22.71	25.85	22.19	**N_3**	19.58	25.69	28.57	24.61
Mean	14.08	17.20	19.94		**Mean**	13.20	18.34	21.52	
SEm±	0.29				**SEm±**	0.52			
CD 5%	0.88				**CD 5%**	1.57			
K uptake by stover ((kg ha^{-1}) (2023-24)					**K uptake by stover (kg ha^{-1}) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	53.84	57.13	61.90	57.62	**N_0**	48.45	53.25	58.64	53.45
N_1	63.80	74.03	83.56	73.80	**N_1**	59.17	74.80	89.56	74.51
N_2	74.79	81.18	87.84	81.27	**N_2**	77.48	88.93	96.52	87.64
N_3	80.24	86.46	92.89	86.53	**N_3**	85.69	95.27	100.91	93.96
Mean	68.17	74.70	81.55		**Mean**	67.70	78.06	86.41	
SEm±	0.92				**SEm±**	2.06			
CD 5%	2.75				**CD 5%**	6.17			
Overall K uptake (kg ha^{-1}) (2023-24)					**Overall K uptake (kg ha^{-1}) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	63.60	68.65	74.30	68.85	**N_0**	55.95	62.88	69.51	62.78
N_1	77.17	90.10	102.42	89.90	**N_1**	70.33	92.12	110.59	91.01
N_2	89.96	99.68	110.47	100.04	**N_2**	92.03	109.63	122.10	107.92
N_3	98.25	109.17	118.74	108.72	**N_3**	105.27	120.96	129.48	118.57
Mean	82.25	91.90	101.49		**Mean**	80.89	96.40	107.92	
SEm±	0.82				**SEm±**	2.04			
CD 5%	2.46				**CD 5%**	6.11			

4.1.6 Soil analysis

4.1.6.1 Physical properties of soil

4.1.6.1.1 Bulk density (g cm^{-3})

Bulk density recorded under varying treatments is shown in Table 27.

Effect of RDF levels

Bulk density after harvesting of maize insignificant in the application of RDF across the two years of research.

Effect of FYM levels

FYM incorporation notably affects bulk density of soil across both study years. Highest bulk density (1.35 and 1.34 g cm^{-3}) noted in control (F_0), which showed parity to 5 t ha^{-1} FYM (F_1) and 10 t ha^{-1} FYM (F_0) across the two years of research. Lowest bulk density was noted in 10 t ha^{-1} FYM (F_2).

Addition of FYM, which contains organic carbon, improves structure of soil by minimizing bulk density, thereby enhancing aeration and infiltration of water. This reduction in bulk density creates a more porous soil environment, facilitating root penetration and expansion (Desai *et al.,* 2022). These findings are similar with Masood *et al.,* (2014), Parewa *et al.,* (2014) and Fageria *et al.,* (2023).

Interaction effect

The combination of different RDF and FYM levels was found to have no significant effect across the two years of research.

4.1.6.1.2 Particle density (g cm^{-3})

Particle density noted under varying treatments is shown in Table 27. Soil particle density after harvesting of maize was found non significant in the RDF application, FYM levels and their interactions across the two years of research.

4.1.6.1.3 Porosity (%)

The soil porosity registered under varying treatments is displayed in Table 27. Porosity of soil after harvesting of maize found insignificant under application of RDF and FYM and their interactions across the two years of research.

Table 27: Effect of integrated nutrient management on physical properties of soil at maize harvest during 2023-24 and 2024-25

Treatments	Physical properties of soil					
	BD (g cm^{-3})		PD (g cm^{-3})		Porosity (%)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	1.33	1.33	2.61	2.61	49.06	49.12
N_1 : 50 % RDF	1.34	1.33	2.62	2.61	48.85	49.01
N_2 : 75 % RDF	1.34	1.35	2.62	2.63	48.60	48.73
N_3 : 100 % RDF	1.35	1.37	2.62	2.63	48.26	47.93
SEm ±	0.01	0.02	0.01	0.03	0.54	1.04
CD 5%	NS	NS	NS	NS	NS	NS
FYM levels						
F_0 : Control	1.35	1.34	2.62	2.62	48.34	48.85
F_1 : 5 t ha^{-1} FYM	1.34	1.33	2.61	2.61	48.80	48.91
F_2 : 10 t ha^{-1} FYM	1.34	1.32	2.61	2.60	48.93	49.14
SEm ±	0.01	0.01	0.01	0.02	0.25	0.35
CD 5%	0.02	0.03	NS	NS	NS	NS
Interaction N*F						
SEm±	0.01	0.02	0.02	0.04	0.50	0.70
CD 5%	NS	NS	NS	NS	NS	NS
Initial value	**1.35**		**2.62**		**48.47**	

4.1.6.2 Chemical properties of soil

4.1.6.2.1 Soil pH

The soil pH noted in varying treatments is shown in Table 28 and figure 11.

Effect of RDF levels

Soil pH was notably impacted by RDF levels both study years. The minimum soil pH (7.69 and 7.68) was registered under the application of 100% RDF (N_3) in the first and second season. The highest soil pH was recorded under the control (N_0).

The drop in pH following the application of nitrogen alone is due to acid-forming characteristics of urea-based nitrogen fertilizers. During the nitrification process, urea releases hydrogen ions (H^+), which contribute to increased soil acidity (Shambhavi *et al.,* 2017). Similar outcomes recorded by Parewa *et al.,* (2014) and Fageria *et al.,* (2023).

Effect of FYM levels

FYM incorporation notably impacted soil pH across the both study years. The lowest soil pH (7.69 and 7.68) was obtained in 10 t ha^{-1} FYM (F_2). Highest soil pH noted in control (F_0).

FYM application leads to a reduced pH, likely due to production of organic acids during microbial breakdown. This change in pH could also be due to the oxidation of OM and subsequent release of CO_2 into soil (Dhaliwal *et al.,* 2021). This results are similar with Masood *et al.,* (2014), Parewa *et al.,* (2014), Mian *et al.,* (2021), Kuldeep *et al.,* (2022), Rangaswamy *et al.,* (2023) and Fageria *et al.,* (2023).

Interaction effect

Interaction of different RDF and FYM levels showing insignificance across the two years of research.

4.1.6.2.2 Electrical conductivity (dSm^{-1})

The soil EC noted in varying treatments is illustrated in Table 28 and figure 11.

Effect of RDF levels

Electrical conductivity of soil was markedly impacted by RDF levels across the two years of research. The highest electrical conductivity (0.25 and 0.27 dSm^{-1}) was found under the application of 100% RDF (N_3), showing considerable superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) in first season but it showed comparability with 75% RDF (N_2) in the next season of experimentation. The lowest electrical conductivity was recorded in the control (N_0).

The gradual increase in EC can be attributed to accumulation of soluble salts introduced through higher doses of inorganic fertilizers. These fertilizers contain various ionic compounds, such as nitrates, sulfates, and chlorides, which dissolve in soil solution, increasing the concentration of dissolved ions. As a result, the electrical conductivity of the soil rises, reflecting an overall increase in soil salinity with higher fertilizer application rates (Pratap *et al.,* 2016). Similar findings are recorded by Pandey and Awasthi (2014), Parewa *et al.,* (2014), Singh *et al.,* (2022), Fageria *et al.,* (2023) and Naveen *et al.,* (2023).

Effect of FYM levels

FYM application notably impacted electrical conductivity of soil across the two years of research. Highest electrical conductivity (0.21 and 0.24 dSm^{-1}) noted in 10 t ha^{-1} FYM (F_0), showing similarity to 5 t ha^{-1} FYM (F_1) across two seasons of research. Lowest electrical conductivity was noted under the control (F_0).

As FYM decomposed, it released organic acids and similar compounds that helped dissolve the slightly soluble salts in soil. This process either transformed them into soluble salts or made them more soluble, which in turn noticeably raised the soil's electrical conductivity (Manimaran *et al.,* 2022). These results are similar with Parewa *et al.,* (2014) and Fageria *et al.,* (2023).

Interaction effect

The interaction of various RDF and FYM had no noticeable effect on electrical conductivity over the two years of study.

4.1.6.2.3 Organic carbon (%)

The soil organic carbon recorded in varying treatments is illustrated in Table 28 and figure 11.

Effect of RDF levels

Organic carbon of soil was notably influenced by RDF levels across the two years of research. The highest organic carbon (0.43 and 0.44 %) was registered under 100% RDF (N_3), showing similarity with control (N_0), 50% (N_1), and 75% RDF (N_2) in the first year. However, it is similar to 50% (N_1) and 75% RDF (N_2) in the next season of experimentation. Lowest organic carbon noted in N_0.

Higher fertilizer levels may have contributed to an increase in soil organic carbon content. This enhancement could be attributed to greater biomass production, leading to higher inputs of organic residues such as dry leaves, roots, and other plant materials, which decompose and integrate into the soil organic matter (Meshram *et al.,* 2016). This results similar to Dubey *et al.,* (2012), Parewa *et al.,* (2014), Sharma *et al.,* (2020), Fageria *et al.,* (2023) and Naveen *et al.,* (2023).

Effect of FYM levels

Applying FYM noticeably improved the soil's organic carbon both study years. Highest organic carbon (0.45 and 0.47 %) noted in 10 t FYM ha^{-1} (F_0), showing similarity to 5 t ha^{-1} FYM (F_1) across two years of research. Lowest organic carbon was recorded under control (F_0).

Higher carbon content in plots amended with FYM may be attributed to increased carbon input from organic matter addition, reduced decomposition rates, or a balanced mineralization process that regulates the liberation of organic carbon in soil (Yadav *et al.,* 2017). These results are consistent with Parewa *et al.,* (2014), Mian *et al.,* (2021), Kuldeep *et al.,* (2022) and Fageria *et al.,* (2023).

Interaction effect

Combination of varying rates of RDF and FYM had no noticeable impact on organic carbon content across both study years.

4.1.6.2.4 Available nitrogen (kg ha^{-1})

Available nitrogen recorded under various treatments and their combinations is presented in Table 28, 28 (a) and figure 11.

Effect of RDF levels

The RDF notably enhanced the available nitrogen of soil across two years of research. The available N rose with elevated RDF levels. The highest available nitrogen (181.96 and 190.03 kg ha^{-1}) noted in 100% RDF (N_3), showed statistical dominance than control (N_0), 50% (N_1), and 75% RDF (N_2) during first and next season. Lowest available nitrogen obtained under the control (N_0).

Higher nitrogen application resulted in greater accumulation of nitrogen in the soil, enhancing its overall nitrogen status. The increased nitrogen availability contributed to improved soil fertility. This indicates that higher nitrogen doses positively influence the soil's total N content (Rawal *et al*., 2022). These outcomes are in accordance with Dubey *et al.,* (2012), Parewa *et al.,* (2014), Fageria *et al.,* (2023) and Naveen *et al.,* (2023).

Effect of FYM levels

Application of FYM markedly improves available soil nitrogen throughout the two study years. The highest available nitrogen (178.38 and 184.80 kg ha^{-1}) noted under 10 t ha^{-1} FYM (F_2), showing statistical superiority over control (F_0), and 5 t FYM ha^{-1} (F_1) across both study years. Minimum available nitrogen noted under control (N_0).

The rise in soil available nitrogen was mainly due to breakdown of nitrogen rich organic matter in the farmyard manure that was applied. As these compounds break down, the soil available nitrogen also increases and release nitrogen in plant available forms (Bhuva and detroja, 2018). Similar results noted by Parewa *et al.,* (2014), Mian *et al.,* (2021), Rangaswamy *et al.,* (2023) and Fageria *et al.,* (2023).

Interaction effect

Interaction of various RDF and FYM was statistically considerable across the two years of research. The highest available nitrogen (202.19 and 205.62 kg ha^{-1}) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 superior to varying combinations in first season. In the second season, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). Similar effects were documented by Kumar *et al.,* (2002), Tetarwal *et al.,* (2011) and Manimaran *et al.,* (2022).

Table 28: Effect of integrated nutrient management on soil chemical properties at maize harvest during 2023-24 and 2024-25

Treatments	Soil chemical properties											
	pH		**EC (dSm^{-1})**		**OC (%)**		**Available N (kg ha^{-1})**		**Available P (kg ha^{-1})**		**Available K (kg ha^{-1})**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels												
N_0 : Control	7.70	7.70	0.12	0.11	0.41	0.40	134.69	127.47	13.99	12.56	311.45	294.29
N_1 : 50 % RDF	7.70	7.70	0.16	0.18	0.42	0.42	157.84	160.70	17.78	18.34	341.80	343.12
N_2 : 75 % RDF	7.69	7.69	0.21	0.24	0.42	0.44	170.71	178.15	21.18	23.02	356.06	364.44
N_3 : 100 % RDF	7.69	7.68	0.25	0.27	0.43	0.44	181.96	190.03	23.85	26.57	374.93	381.77
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	0.94	2.403	0.46	0.44	1.20	3.27
CD 5%	0.03	0.04	0.02	0.03	0.02	0.03	3.26	8.32	1.59	1.52	4.15	11.30
FYM levels												
F_0 : Control	7.70	7.70	0.15	0.13	0.40	0.39	144.73	141.36	17.45	16.66	325.14	315.50
F_1 : 5 t ha^{-1} FYM	7.70	7.69	0.19	0.21	0.43	0.44	160.80	166.11	19.14	20.58	345.71	348.74
F_2 : 10 t ha^{-1} FYM	7.69	7.68	0.21	0.24	0.45	0.47	178.38	184.80	21.01	23.13	367.33	373.48
SEm ±	0.01	0.01	0.01	0.01	0.01	0.02	0.66	1.54	0.27	0.38	0.92	2.41
CD 5%	0.03	0.02	0.02	0.03	0.03	0.05	1.96	4.62	0.82	1.13	2.74	7.22
Interaction N*F												
SEm±	0.01	0.01	0.01	0.01	0.02	0.03	1.31	3.081	0.55	0.75	1.83	4.82
CD 5%	NS	NS	NS	NS	NS	NS	3.93	9.24	1.64	2.25	5.49	14.44
Initial value	**7.70**		**0.15**		**0.42**		**175.62**		**19.26**		**360.08**	

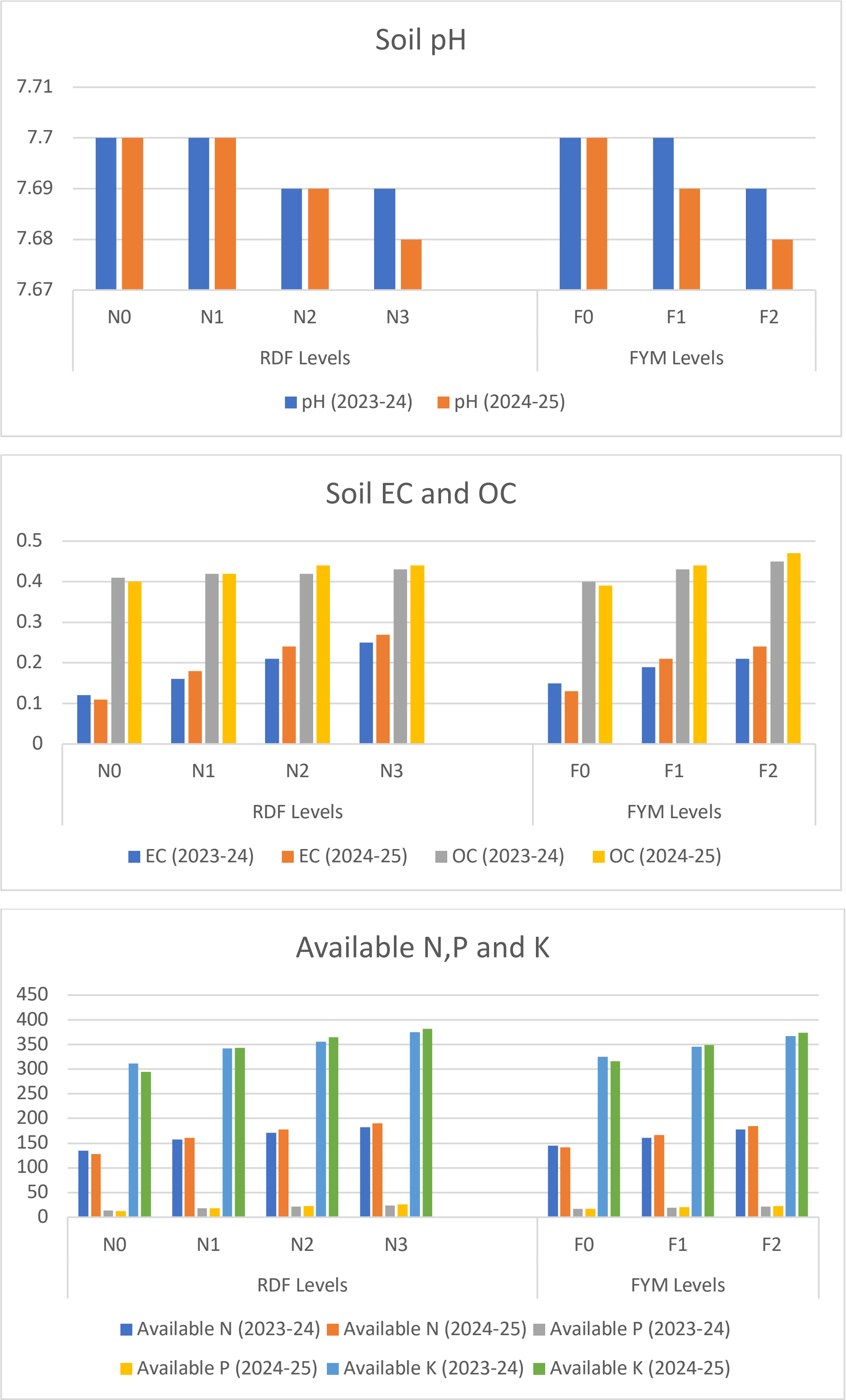


Fig. 11. Soil chemical properties at maize harvest as impacted by various treatments

Table 28 (a): Combined influence of RDF and FYM levels on available N, P and K (kg ha^{-1}) at maize harvest during 2023-24 and 2024-25

Available N (kg ha^{-1}) (2023-24)					**Available N (kg ha^{-1})(2024-25)**				
Interaction N*F	F_0	F_1	F_2	Mean	**Interaction N*F**	F_0	F_1	F_2	Mean
N_0	119.16	135.75	149.15	134.69	**N_0**	110.21	122.39	149.80	127.47
N_1	142.67	155.44	175.42	157.84	**N_1**	134.23	163.84	184.04	160.70
N_2	152.97	172.43	186.74	170.71	**N_2**	153.83	180.90	199.73	178.15
N_3	164.13	179.56	202.19	181.96	**N_3**	167.17	197.30	205.62	190.03
Mean	144.73	160.80	178.38		**Mean**	141.36	166.11	184.80	
SEm±	1.31				**SEm±**	3.08			
CD 5%	3.93				**CD 5%**	9.24			

Available P (kg ha^{-1}) (2023-24)					**Available P (kg ha^{-1}) (2024-25)**				
Interaction N*F	F_0	F_1	F_2	Mean	**Interaction N*F**	F_0	F_1	F_2	Mean
N_0	13.47	13.98	14.54	13.99	**N_0**	10.23	13.07	14.39	12.56
N_1	15.36	17.31	20.66	17.78	**N_1**	14.54	17.89	22.58	18.34
N_2	18.83	21.41	23.31	21.18	**N_2**	18.03	23.73	27.30	23.02
N_3	22.15	23.84	25.54	23.85	**N_3**	23.85	27.62	28.23	26.57
Mean	17.45	19.14	21.01		**Mean**	16.66	20.58	23.13	
SEm±	0.55				**SEm±**	0.75			
CD 5%	1.64				**CD 5%**	2.25			

Available K (kg ha^{-1}) (2023-24)					**Available K (kg ha^{-1}) (2024-25)**				
Interaction N*F	F_0	F_1	F_2	Mean	**F_0**	F_1	F_2	Mean	F_0
N_0	296.01	311.79	326.55	311.45	**N_0**	270.41	292.65	319.82	294.29
N_1	317.22	340.89	367.29	341.80	**N_1**	300.02	349.20	380.13	343.12
N_2	333.71	355.31	379.16	356.06	**N_2**	336.51	364.24	392.56	364.44
N_3	353.63	374.84	396.32	374.93	**N_3**	355.04	388.86	401.40	381.77
Mean	325.14	345.71	367.33		**Mean**	315.50	348.74	373.48	
SEm±	1.83				**SEm±**	4.82			
CD 5%	5.49				**CD 5%**	14.44			

4.1.6.2.5 Available phosphorus (kg ha^{-1})

Available phosphorus noted under various treatments and their combinations is presented in Table 28, 28 (a) and figure 11.

Effect of RDF levels

The recommended dose of fertilizers (RDF) notably impact available phosphorus of soil across the two years of research. The highest available phosphorus (23.85 and 26.57 kg ha^{-1}) noted in 100% RDF (N_3), showing superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. N_0 noted lowest available phosphorus.

Noticeable improvement in soil phosphorus levels at harvest could be due to the buildup of phosphorus from the phosphorus applied through the RDF, which helped raise the quantity of available phosphorus in the soil (Patidar and Mali, 2001). These results are in accordance with Dubey *et al.,* (2012), Parewa *et al.,* (2014), Sharma *et al.,* (2020), Kuldeep *et al.,* (2022), Fageria *et al.,* (2023) and Naveen *et al.,* (2023).

Effect of FYM levels

Application of FYM improved the soils available phosphorus throughout the two study years. Available phosphorus increased with FYM levels. Highest available phosphorus (21.01 and 23.13 kg ha^{-1}) noted in 10 t ha^{-1} FYM (F_2), showing statistical superiority than control (F_0), and 5 t FYM ha^{-1} (F_1) across both study years. Minimum available phosphorus noted in the control (N_0).

The enhanced phosphorus availability was due to combined action of organic acids and organic anions discharged during the breakdown of farmyard manure (FYM), which facilitated the solubilization and mobilization of phosphorus in the soil (Bhuva and Detroja 2018). Results are similar with Parewa *et al.,* (2014), Mian *et al.,* (2021), Kuldeep *et al.,* (2022), Rangaswamy *et al.,* (2023) and Fageria *et al.,* (2023).

Interaction effect

Combination of various RDF and FYM showing statistical significance across the two years of research. The highest available phosphorus (25.54 and 28.23 kg ha^{-1}) registered in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 combination was significantly superior to all other treatment combinations in first season. In the next season, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75%

RDF + 10 t ha^{-1} FYM (N_2F_2). These results comparable with Kumar *et al.,* (2002), Tetarwal *et al.,* (2011), Sharma *et al.,* (2020) and Manimaran *et al.,* (2022).

4.1.6.2.6 Available Potassium (kg ha^{-1})

Available soil potassium noted under various treatments and their combinations is shown in Table 28, 28 (a) and figure 11.

Effect of RDF levels

The RDF markedly influenced available soil potassium across the two years of research. Available potassium increased with increasing RDF levels. The highest available potassium (374.93 and 381.77 kg ha^{-1}) noted in 100% RDF (N_3), showing marked significance than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. Lowest available potassium was registered under the control (N_0).

Increased NPK application led to higher potassium buildup in the soil, thereby improving its overall available potassium levels. The reduction in available potassium content was observed in plots that receives lower potassium application. Even at lower recommended application rates, native potassium reserves declined, primarily because crop uptake is more than the amount of potassium added in soil (Sathish *et al*., 2016). These results comparable with Dubey *et al.,* (2012), Parewa *et al.,* (2014), Sharma *et al.,* (2020), Fageria *et al.,* (2023) and Naveen *et al.,* (2023).

Effect of FYM levels

FYM significantly increase available potassium of soil throughout the two study years. Available potassium increased under higher FYM levels. The highest available potassium (367.33 and 373.48 kg ha^{-1}) noted in 10 t ha^{-1} FYM (F_2), showing greater influence than control (F_0), and 5 t FYM ha^{-1} (F_1) across the two years of research. Lowest available potassium registered under the control (N_0).

The enhanced availability of potassium from FYM can be linked to a decrease in potassium fixation and the improved release of potassium due to the interaction between organic matter and clay (Yadav *et al.,* 2009). Similar results noted by Parewa *et al.,* (2014), Mian *et al.,* (2021), Kuldeep *et al.,* (2022), Rangaswamy *et al.,* (2023) and Fageria *et al.,* (2023).

Interaction effect

Combination of various RDF and FYM levels showing statistical significance across the two years of research. The highest available potassium (396.32 and 401.40

kg ha^{-1}) obtained under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study seasons. The N_3F_2 combination showing superiority to varying combinations in first season. In the next season, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). Similar results align with Kumar *et al.,* (2002), Sharma *et al.,* (2020) and Manimaran *et al.,* (2022).

4.1.6.3 Microbial properties of soil

4.1.6.3.1 Bacterial count (cfu × 10^6 g^{-1} soil)

The population of bacteria recorded under various treatments and their combinations is depicted in Table 29 and 29 (a).

Effect of RDF levels

The RDF significantly influenced bacterial population in soil across the two years of research. The bacterial population increased with higher levels of RDF. Maximum bacterial count (22.38 and 23.76 × 10^6 cfu g^{-1} soil) noted in 100% RDF (N_3), showed considerable superiority than control (N_0), 50% RDF (N_1), and similar to 75% RDF (N_2) during first and next season. Least bacterial count in soil found in control (N_0).

Mineral fertilization alters the presence of nitrogen and phosphorus leading to changes in soil fertility that can act as a selective pressure, resulting in structural and functional changes within the soil microbial community. Moreover, combined application of nitrogen, phosphorus, and potassium has been shown to increase soil microbial biomass and promote greater diversity among bacterial populations (Dinca *et al.,* 2022). Similar outcomes are registered by Parewa *et al.,* (2014), Sangeeta *et al.,* (2019) and Naveen *et al.,* (2023).

Effect of FYM levels

FYM incorporation significantly increased the bacterial population throughout the two study years of experimentation. The bacterial population increased with raising FYM levels. The maximum bacterial population (25.31 and 27.35 × 10^6 cfu g^{-1} soil) noted in application of 10 t ha^{-1} FYM (F_2), showed statistical superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across the two years of research. Minimum bacterial population registered under the control (N_0).

The addition of FYM, which contains carbon, enhances soil microbial activity by providing an energy source for bacteria, leading to an increase in bacterial count.

The reduction in bulk density improves soil aeration and water infiltration, Creating ideal conditions for microbial growth (Desai *et al.,* 2022). Additionally, the improved soil porosity supports better root-microbe interactions, further stimulating bacterial growth and activity, which contribute to enhanced nutrient cycling and soil fertility. Similar outcomes are registered by Parewa *et al.,* (2014).

Interaction effect

The interaction of various levels of RDF and FYM was significant across the two years of research. The highest bacterial population in soil (27.98 and 30.58 × 10^6 cfu g^{-1} soil) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 combination was statistically better to varying combinations in first year. In next year, N_3F_2 similar to 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These results are corelated with Meshram *et al.,* (2016), Sangeeta *et al.,* (2019), Sharma *et al.,* (2020) and John *et al.,* (2023).

4.1.6.3.2 Fungal count (cfu × 10^4 g^{-1} soil)

The fungal population noted in varying treatments and their combinations is illustrated in Table 29 and 29 (a).

Effect of RDF levels

RDF significantly influenced fungal count across two study seasons. Highest fungal count (10.68 and 11.32 × 10^4 cfu g^{-1} soil) noted in 100% RDF (N_3), showing significant superiority than control (N_0), 50% RDF (N_1), and similar to 75% RDF (N_2) during first and next season. The lowest fungal population in soil was noted in control (N_0).

Inorganic fertilizers also contributes to increase in fungal population compared to the control. This rise is not solely due to the direct nutrient supply but largely influenced by the microbial oxidation of ammonium salts present in the fertilizers. This process leads to the formation of nitric acid, which creates favourable conditions for fungal proliferation in the soil (Meshram *et al.,* 2016). Similar results are registered by Parewa *et al.,* (2014), Sangeeta *et al.,* (2019) and Naveen *et al.,* (2023).

Effect of FYM levels

FYM incorporation considerably impacted the fungal count throughout the two study years. The fungal count increased with FYM levels. The highest fungal count (12.76 and 13.61 × 10^4 cfu g^{-1} soil) noted in 10 t ha^{-1} FYM (F_2), showing superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two seasons of research. The lowest fungal count was recorded in the control (N_0).

FYM application increasing fugal count. Fungi, like bacteria and actinomycetes, play a crucial role in organic matter decomposition and nutrient cycling. Organic carbon present in FYM serves as an energy source for fungal growth, supporting their proliferation in the soil (Meshram *et al.,* 2016). Additionally, improved soil conditions such as higher moisture retention and better aeration due to FYM application create a favorable environment for fungal activity. Many beneficial soil fungi, including decomposers and mycorrhizal fungi, thrive in these conditions, aiding in the breakdown of complex organic compounds, enhancing nutrient availability, and improving soil structure. Similar results are registered by Parewa *et al.,* (2014) and Meshram *et al.,* (2016).

Interaction effect

The combination of various RDF and FYM levels was significant across the two years of research. The highest fungal count in soil (13.92 and 15.10 × 10^4 cfu g^{-1} soil) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 combination was statistically better to varying combinations in first year. In next year, N_3F_2 similar to 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These findings are similar with Sangeeta *et al.,* (2019), Sharma *et al.,* (2020) and John *et al.,* (2023).

4.1.6.3.3 Actinomycetes count (cfu × 10^5 g^{-1} soil)

Actinomycetes population recorded under various treatments and their combinations depicted in Table 29 and 29 (a).

Effect of RDF levels

The RDF significantly influenced the actinomycetes count in soil across the two years of research of experimentation. The actinomycetes count increased with increasing levels of RDF. The highest actinomycetes count (14.76 and 15.20 × 10^5 cfu g^{-1} soil) obtained in 100% RDF (N_3), showing significant superiority than control (N_0), 50% RDF (N_1), and 75% RDF (N_2) in first season and it was similar to 75% RDF (N_2) in next season. The lowest actinomycetes count in soil was found in the control (N_0).

Prolonged use of mineral fertilizers, especially nitrogen, tends to enhance microbial biomass, as soil microbes often face limitations in carbon or nitrogen availability. This increase is more pronounced when the soil pH is above 5; however, in more acidic conditions, fertilization may actually lead to a reduction in microbial biomass (Dinca *et al.,* 2022). These findings are similar with Sangeeta *et al.,* (2019) and Naveen *et al.,* (2023).

Effect of FYM levels

FYM incorporation significantly increased the actinomycetes popu;ation throughout the two study years. Highest actinomycetes count (17.98 and 18.86 × 10^5 cfu g^{-1} soil) noted in 10 t ha^{-1} FYM (F_2), showed superiority than control (F_0), and 5 t FYM ha^{-1} (F_1) across both study years. Minimum actinomycetes count registered under the control (N_0).

The addition of organic manure like FYM and vermicompost, along with NPK fertilizers, helps create a balanced soil air and moisture condition (Vapsa) by reducing BD. This improves microbial activity, as the organic matter decomposes to form humus, which serves as a primary food source for soil microbes (Desai *et al.,* 2022). These findings are similar with Meshram *et al.,* (2016).

Interaction effect

The combination of different RDF and FYM levels showing significance across the two years of research. The highest actinomycetes count in soil (20.25 and 21.85 × 10^5 cfu g^{-1} soil) noted in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across two study seasons. The N_3F_2 showing superiority to varying combinations in first season. In the next season, N_3F_2 similar to 75% RDF + 10 t ha^{-1} FYM (N_2F_2). similar outcomes are noted by Meshram *et al.,* (2016), Sangeeta *et al.,* (2019), Sharma *et al.,* (2020) and John *et al.,* (2023).

Table 29: Effect of integrated nutrient management on soil microbial properties after maize harvest during 2023-24 and 2024-25

Treatments	**Microbial properties of soil**					
	Bacteria (cfu × 10^6 g^{-1} soil)		**Fungi (cfu × 10^4 g^{-1} soil)**		**Actinomycetes (cfu × 10^5 g^{-1} soil)**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	18.58	18.13	8.76	8.53	11.54	11.09
N_1 : 50 % RDF	19.50	19.70	9.37	9.65	12.71	12.76
N_2 : 75 % RDF	21.03	22.34	10.13	10.70	13.66	14.12
N_3 : 100 % RDF	22.38	23.76	10.68	11.32	14.76	15.20
SEm ±	0.66	0.43	0.26	0.24	0.15	0.39
CD 5%	2.29	1.49	0.90	0.82	0.53	1.36
FYM levels						
F_0 : Control	15.96	15.03	7.11	6.80	8.90	8.24
F_1 : 5 t ha^{-1} FYM	19.86	20.57	9.33	9.74	12.62	12.78
F_2 : 10 t ha^{-1} FYM	25.31	27.35	12.76	13.61	17.98	18.86
SEm ±	0.23	0.27	0.12	0.15	0.17	0.35
CD 5%	0.68	0.80	0.35	0.44	0.51	1.05
Interaction N*F						
SEm±	0.45	0.54	0.23	0.29	0.34	0.70
CD 5%	1.36	1.61	0.70	0.88	1.02	2.10
Initial value	**18**		**7**		**11**	

Table 29 (a): Combined effect of RDF and FYM on microbial properties of soil at harvest of maize during 2023-24 and 2024-25

Bacteria (cfu × 10^6 g^{-1} soil) (2023-24)					Bacteria (cfu × 10^6 g^{-1} soil) (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	15.15	17.51	23.08	18.58	**N_0**	11.51	19.08	23.79	18.13
N_1	15.52	18.83	24.14	19.50	**N_1**	13.88	19.44	25.77	19.70
N_2	16.11	20.97	26.02	21.03	**N_2**	16.59	21.20	29.25	22.34
N_3	17.05	22.11	27.98	22.38	**N_3**	18.16	22.54	30.58	23.76
Mean	15.96	19.86	25.31		**Mean**	15.03	20.57	27.35	
SEm±	0.45				**SEm±**	0.54			
CD 5%	1.36				**CD 5%**	1.61			
Fungi (cfu × 10^4 g^{-1} soil) (2023-24)					**Fungi (cfu × 10^4 g^{-1} soil) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	6.80	7.93	11.54	8.76	**N_0**	6.07	7.91	11.60	8.53
N_1	7.03	8.59	12.49	9.37	**N_1**	6.18	9.29	13.48	9.65
N_2	7.23	10.05	13.10	10.13	**N_2**	7.37	10.49	14.25	10.70
N_3	7.37	10.77	13.92	10.68	**N_3**	7.59	11.27	15.10	11.32
Mean	7.11	9.33	12.76		**Mean**	6.80	9.74	13.61	
SEm±	0.23				**SEm±**	0.29			
CD 5%	0.70				**CD 5%**	0.88			
Actinomycetes (cfu × 10^5 g^{-1} soil) (2023-24)					**Actinomycetes (cfu × 10^5 g^{-1} soil) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	8.07	10.67	15.90	11.54	**N_0**	7.32	10.89	15.05	11.09
N_1	8.47	12.41	17.25	12.71	**N_1**	7.75	12.73	17.80	12.76
N_2	9.13	13.30	18.53	13.66	**N_2**	8.69	12.95	20.72	14.12
N_3	9.93	14.09	20.25	14.76	**N_3**	9.21	14.54	21.85	15.20
Mean	8.90	12.62	17.98		**Mean**	8.24	12.78	18.86	
SEm±	0.34				**SEm±**	0.70			
CD 5%	1.02				**CD 5%**	2.10			

4.2 Residual impact of integrated nutrient management on *rabi* chickpea

4.2.1 Yield parameters

4.2.1.1 Number of pods plant^{-1}

Pods count of chickpea as influenced by carryover impact of varying treatments and their combinations is presented in Table 30, 30 (a) and figure 12.

Residual effect of RDF levels

The carryover impact of RDF significantly increased pod numbers plant^{-1} across the two years of research. The pods numbers increased with RDF levels applied to preceding crop. Highest pods plant^{-1} (56.21 and 58.42) noted in residual effect of 100% RDF (N_3), showing greater significance over control (N_0), 50% RDF (N_1), and 75% RDF (N_2) during the first and next season. Control (N_0) recorded least pods per plant.

The residual application of recommended nitrogen and potassium, combined with phosphorus fertilization and seed inoculation, supports the development of a robust root system. This improved root growth enhances nutrient uptake efficiency from both the soil solution and applied phosphorus along with nitrogen and potassium (Kumawat *et al.,* 2020). As a result, the crop exhibits better overall growth, improved yield traits, particularly as increased pods count. Comparable results noted by Elamin *et al.,* (2015), Sonboir *et al.,* (2020) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

Residual effect of FYM significantly increased pods plant^{-1} throughout the two study years. Pods plant^{-1} increased with increasing FYM levels applied to previous crop. Maximum pod numbers plant^{-1} (47.28 and 49.02) was noted in the leftover impact of 10 t FYM ha^{-1} (F_2), showed considerable superiority than control (F_0), and 5 t FYM ha^{-1} (F_1) across two years of research. Least pod numbers noted in the control (N_0).

Improvement in number of pods by the residual effect of FYM is due to enhanced nutrient accessibility in the soil, derived both from the native nutrient pool and its residual effect through mineralization. Furthermore, the enhancement of the soil's physico-chemical properties improved its water and nutrient retention capacity, ultimately contributing for increasing number of pods (Sindhi *et al.,* 2016). The present results are supported by Rathore *et al.,* (2014) and Bhuva and Detroja (2018).

Interaction effect

Combination of carryover effect of RDF and FYM showing statistical significance across the two years of research. Highest pods plant^{-1} (59.82 and 62.12) registered in residual impact of 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 combination is similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) applied to preceding crop during first season. However, In the next season, N_3F_2 similar to residual effect of 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These results similar with Gudadhe *et al*., (2011) and Sonboir *et al.,* (2020).

4.2.1.2 Weight of pods plant^{-1} (g)

Pods weight noted under residual effect of various treatments and their combinations is presented in Table 30, 30 (a) and figure 12.

Residual effect of RDF levels

The RDF given to previous maize considerably impacted pods weight of chickpea across the two years of research. Pods weight plant^{-1} of chickpea increased with higher RDF levels applied to preceding maize. Highest pods weight plant^{-1} (33.20 and 39.81 g) recorded with the residual effect of 100% RDF (N_3), showing marked significance than (N_0), 50% (N_1), and 75% RDF (N_2) during both years. Control (N_0) noted lowest pods weight.

Increase in weight of pods possible due to beneficial residual influence of treatments, which supported improved crop growth. This enhanced growth positively influenced yield components such as pod weight per plant, ultimately leading to increased overall yield (Pagar, 2021). Comparable results was observed by Chhipa *et al.,* (2017).

Residual effect of FYM levels

FYM given to preceding maize significantly impacted the pods weight throughout the two study years. Maximum pods weight plant^{-1} (30.22 and 33.19 g) registered in 10 t ha^{-1} FYM (F_2) application to previous maize, showing considerable superiority than control (F_0), and 5 t FYM ha^{-1} (F_1) across the two years of research. Least pods weight plant^{-1} noted in control (N_0).

Increase in yield attributes, particularly pod weight increases due to mineralization of undecomposed FYM or the slow decomposition of residual FYM left in soil after the prior crop harvest (Sindhi *et al.,* 2016). Similar results observed by Chhipa *et al.,* (2017).

Interaction effect

Combination between leftover RDF and FYM not significantly affected in first season and showed statistical significance in next season. The maximum pods weight plant^{-1} (42.95 g) obtained in residual impact of 100 % RDF + 10 t ha^{-1} FYM (N_3F_2), showing similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). These results similar with Gudadhe *et al*., (2011).

4.2.1.3 Seed index (g)

Seed index recorded under residual impact of various treatments is illustrated in Table 30.

Residual effect of RDF levels

The residual effect of recommended dose of fertilizers (RDF) had a significant effect on seed index of chickpea across the two years of research. Seed index increased with higher RDF levels applied to previous crop. The highest seed index (29.46 and 30.24 g) was registered with the residual effect of 100% RDF (N_3), showed noticeable significance than control (N_0), 50% RDF (N_1), and similar to 75% RDF (N_2) across the two years of research. Least seed index noted under control (N_0).

Residual effect of RDF contributed to better plant growth, ensuring an adequate supply of photosynthates for grain development. This enhanced physiological performance and efficient assimilate translocation to the sink ultimately resulted in higher seed index (Lakum *et al.,* 2020). Similar results noted by Elamin *et al.,* (2015).

Residual effect of FYM levels

FYM incorporation to previous maize significantly influenced the seed index throughout the two study years. The highest seed index (28.76 and 29.10 g) noted in residual effect of 10 t ha^{-1} FYM (F_2), which was found significantly superior over control (F_0) and found at par with 5 t ha^{-1} FYM (F_1) applied to preceding maize across the two years of research. The least 100 seed weight was recorded under the control (N_0).

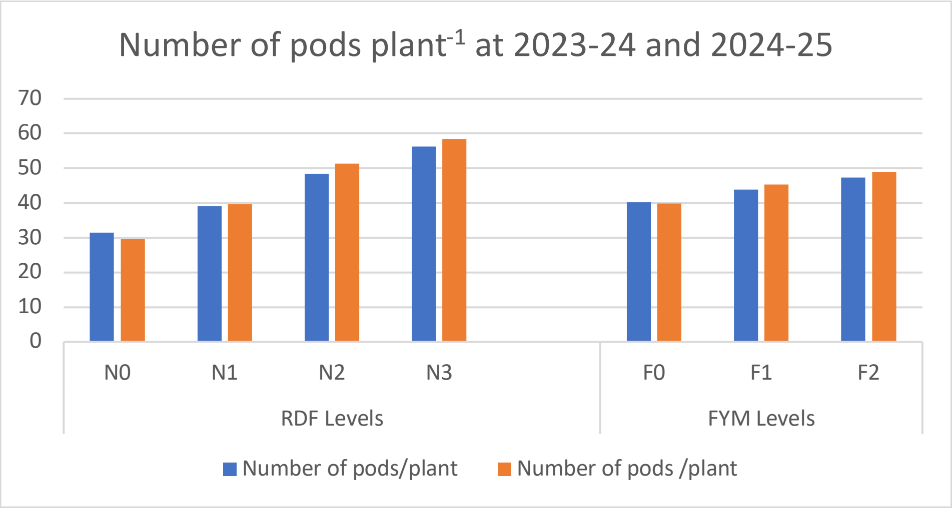
Leftover impact of organic manure ensured a continuous and balanced nutrient supply over a prolonged period, which enhanced vegetative and reproductive development, ultimately improved grain filling and increased seed index in the succeeding crop (Samant *et al.,* 2023). Similar results were observed by Bhuva and Detroja (2018), Jat and Praharaj (2018) and Lakum *et al.,* (2020).

Interaction effect

The combination between residual impact of varying RDF and FYM levels showed non significance during first and second year.

Table 30: Residual effect of integrated nutrient management on number of pods, weight of pods (g) and seed index (g) of chickpea during 2023-24 and 2024-25

Treatments	Number of pods plant^{-1}		Weight of pods plant^{-1} (g)		Seed index (g)	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	31.40	29.57	23.20	18.80	27.20	25.95
N_1 : 50 % RDF	39.07	39.64	25.87	25.98	27.97	27.61
N_2 : 75 % RDF	48.43	51.29	29.73	34.44	28.61	29.20
N_3 : 100 % RDF	56.21	58.42	33.20	39.81	29.46	30.24
SEm ±	0.83	1.36	0.40	0.99	0.37	0.69
CD 5%	2.88	4.72	1.39	3.43	1.28	2.38
FYM levels						
F_0 : Control	40.14	39.91	25.81	25.52	27.80	27.05
F_1 : 5 t ha^{-1} FYM	43.92	45.25	27.96	30.56	28.38	28.61
F_2 : 10 t ha^{-1} FYM	47.28	49.02	30.22	33.19	28.76	29.10
SEm ±	0.39	0.67	0.31	0.52	0.25	0.25
CD 5%	1.16	2.02	0.93	1.55	0.74	0.76
Interaction N*F						
SEm±	0.78	1.35	0.62	1.04	0.50	0.51
CD 5%	2.33	4.04	NS	3.10	NS	NS



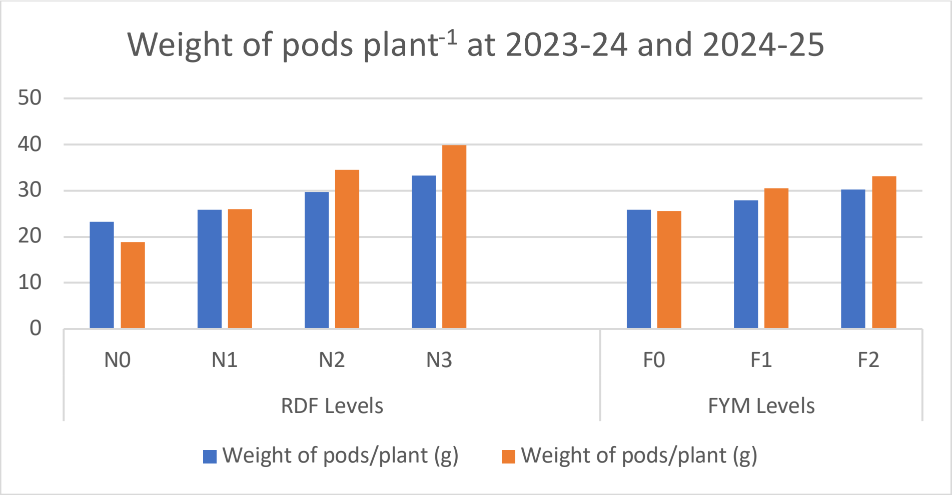


Fig. 12. Number of pods and Weight of pods (g) of chickpea as impacted by residual effect of varying treatments

Table 30 (a): Interaction effect of residual RDF and FYM on number of pods plant^{-1} and weight of pods plant^{-1} (g) of chickpea during 2023-24 and 2024-25

Number of pods plant^{-1} (2023-24)					Number of pods plant^{-1} (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	29.44	30.92	33.84	31.40	**N_0**	27.12	30.55	31.03	29.57
N_1	35.97	38.99	42.27	39.07	**N_1**	34.68	39.71	44.52	39.64
N_2	44.09	48.02	53.18	48.43	**N_2**	45.22	50.23	58.41	51.29
N_3	51.06	57.76	59.82	56.21	**N_3**	52.62	60.51	62.12	58.42
Mean	40.14	43.92	47.28		**Mean**	39.91	45.25	49.02	
SEm±	0.78				**SEm±**	1.35			
CD 5%	2.33				**CD 5%**	4.04			

Weight of pods plant^{-1} (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**
N_0	16.60	19.01	20.80	18.80
N_1	22.04	26.92	28.99	25.98
N_2	29.14	34.17	40.01	34.44
N_3	34.32	42.16	42.95	39.81
Mean	25.52	30.56	33.19	
SEm±	1.04			
CD 5%	3.10			

Plate No. 6. Flower initiation and pod development of chickpea

4.2.1.4 Seed yield (q ha^{-1})

Residual effects from different treatments and their combinations on seed yield is illustrated in Table 31, 31(a), and Figure 13.

Residual effect of RDF levels

Residual effect of RDF notably enhanced seed yield of chickpea across both study years as well as in pooled evaluation. Higher RDF rates applied to preceding maize markedly increased seed yield. The highest seed yield (19.94, 21.30 and 20.62 q ha^{-1}) noted under residual effect of 100% RDF (N_3) during the two years and in pooled data. In first year and on pooled basis, 100 % RDF (N_3) applied to preceding maize was found statistically superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2). During the second year, 100 % RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1), and at par with 75% RDF (N_2). Least seed yield registered in N_0.

Increase in seed yield due to the enhanced availability and nutrients uptake from residual applied fertilizers. This facilitated an accelerated photosynthetic rate, leading to higher carbohydrate production, which subsequently improved growth parameters and yield attributes, ultimately contributing to greater seed yield (Nalini *et al.,* 2020). Similar results noted by Rajkumara *et al.,* (2012), Elamin *et al.,* (2015), Chhipa *et al.,* (2017), Paikra *et al.,* (2019), Lakum *et al.,* (2020), Sonboir *et al.,* (2020) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

FYM incorporation to preceding maize notably influenced the seed yield throughout two study years and in pooled basis. The highest seed yield (17.10, 18.05, and 17.58 q ha^{-1}) registered residual effect of 10 t ha^{-1} FYM (F_2), showing superiority to control (F_0) and 5 t ha^{-1} FYM (F_1) throughout two study years and in pooled basis. Control (F_0) noted least seed yield.

Increase in chickpea seed yield is the result of the leftover effect of FYM could be attributed to enhancements in physical, chemical, and biological properties of soil. Additionally, it provides an energy source for soil microflora, promoting better root nodulation and nitrogen fixation (Lakum *et al.,* 2020). The resistant components in organic manures take longer to decompose, making only about 25 to 33% of nitrogen and small portion of phosphorus and potassium immediately available to first crop, such as maize, while the remaining nutrients benefit subsequent crops, thereby sustaining productivity (Inoko, 1984). Additionally, The use of atmospheric nitrogen through BNF is essential for preserving soil health. These findings are consistent with Chhipa *et al.,* (2017), Bhuva and detroja (2018) and Lakum *et al.,* (2020).

Interaction effect

The combination of RDF and FYM given to prior crop showed marked significance across both study years and in a pooled data. The highest seed yield (20.87, 22.62, and 21.75 q ha^{-1}) registered in residual impact of 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research and in a pooled data. In both seasons, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) applied to preceding maize. However, on pooled basis, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1). These observed results are similar with Gudadhe *et al*., (2011). Lakum *et al.,* (2020) and Sonboir *et al.,* (2020).

Table 31: Residual effect of integrated nutrient management on seed and haulm yield (q ha^{-1}) of chickpea during 2023-24 and 2024-25

Treatments	**Seed yield (q ha^{-1})**			**Haulm yield (q ha^{-1})**		
	2023-24	**2024-25**	**Pooled**	**2023-24**	**2024-25**	**Pooled**
Nutrient management levels						
N_0 : Control	10.74	8.61	9.67	21.12	18.80	19.96
N_1 : 50 % RDF	14.35	14.87	14.61	24.96	25.41	25.18
N_2 : 75 % RDF	17.72	19.44	18.58	29.79	31.37	30.58
N_3 : 100 % RDF	19.94	21.30	20.62	32.31	33.63	32.97
SEm ±	0.34	0.56	0.33	0.74	0.69	0.51
CD 5%	1.16	1.94	1.01	2.58	2.38	1.56
FYM levels						
F_0 : Control	14.24	13.83	14.03	25.23	24.94	25.08
F_1 : 5 t ha^{-1} FYM	15.72	16.29	16.01	27.28	27.52	27.40
F_2 : 10 t ha^{-1} FYM	17.10	18.05	17.58	28.62	29.45	29.03
SEm ±	0.18	0.22	0.14	0.23	0.21	0.16
CD 5%	0.55	0.67	0.42	0.69	0.62	0.45
Interaction N*F						
SEm±	0.37	0.45	0.29	0.46	0.42	0.31
CD 5%	1.10	1.35	0.83	1.38	1.25	0.89

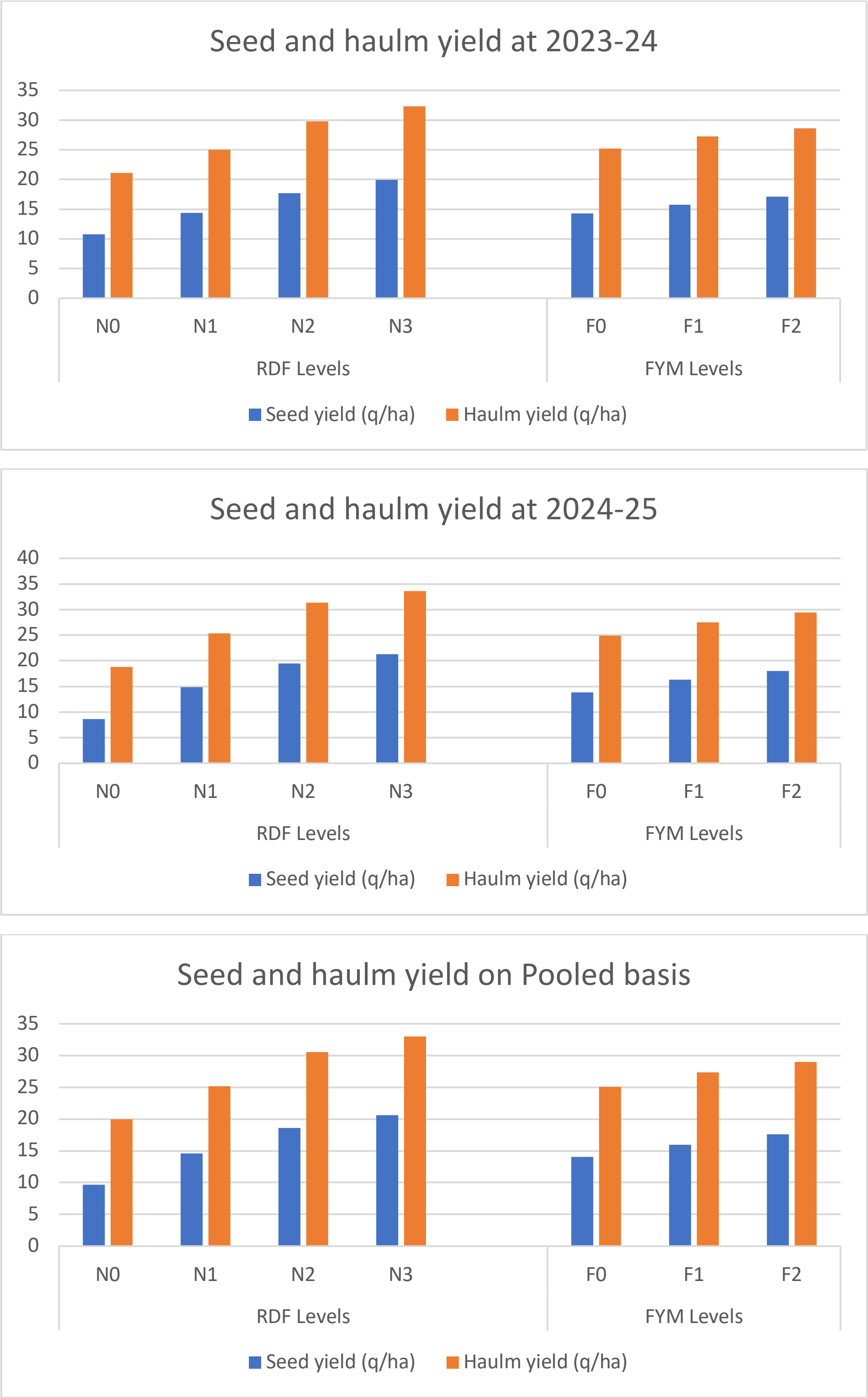


Fig. 13. Seed and Haulm yield (q ha^{-1}) of chickpea as impacted by residual effect of various treatments

Table 31 (a): Combined impact of residual RDF and FYM on seed and haulm yield (q ha^{-1}) of chickpea during 2023-24 and 2024-25

Seed yield (q ha^{-1}) (2023-24)					Seed yield (q ha^{-1}) (2024-25)					Seed yield (q ha^{-1}) (Pooled)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	8.71	10.87	12.64	10.74	**N_0**	6.77	8.46	10.59	8.61	**N_0**	7.74	9.67	11.61	9.67
N_1	13.74	14.26	15.06	14.35	**N_1**	11.72	15.66	17.23	14.87	**N_1**	12.73	14.96	16.14	14.61
N_2	15.97	17.37	19.84	17.72	**N_2**	17.84	18.73	21.77	19.44	**N_2**	16.90	18.05	20.80	18.58
N_3	18.54	20.40	20.87	19.94	**N_3**	18.98	22.30	22.62	21.30	**N_3**	18.76	21.35	21.75	20.62
Mean	14.24	15.72	17.10		**Mean**	13.83	16.29	18.05		**Mean**	14.03	16.01	17.58	
SEm±	0.37				**SEm±**	0.45				**SEm±**	0.29			
CD 5%	1.10				**CD 5%**	1.35				**CD 5%**	0.83			
Haulm yield (q ha^{-1}) (2023-24)					**Haulm yield (q ha^{-1}) (2024-25)**					**Haulm yield (q ha^{-1}) (Pooled)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	18.66	22.22	22.47	21.12	**N_0**	15.93	19.22	21.25	18.80	**N_0**	17.29	20.72	21.86	19.96
N_1	23.99	24.81	26.07	24.96	**N_1**	22.26	25.94	28.02	25.41	**N_1**	23.12	25.38	27.05	25.18
N_2	27.85	29.15	32.39	29.79	**N_2**	29.71	30.64	33.77	31.37	**N_2**	28.78	29.89	33.08	30.58
N_3	30.43	32.96	33.54	32.31	**N_3**	31.84	34.30	34.75	33.63	**N_3**	31.14	33.63	34.14	32.97
Mean	25.23	27.28	28.62		**Mean**	24.94	27.52	29.45		**Mean**	25.08	27.40	29.03	
SEm±	0.46				**SEm±**	0.42				**SEm±**	0.31			
CD 5%	1.38				**CD 5%**	1.25				**CD 5%**	0.89			

4.2.1.5 Haulm yield (q ha^{-1})

Haulm yield recorded under carryover effect of various treatments and their combinations is shown in Table 31, 31 (a) and figure 13.

Residual effect of RDF levels

The leftover impact of RDF notably enhanced the haulm yield during two years as well as on a pooled basis. Higher RDF levels applied to previous crop gradually increased the haulm yield. The highest haulm yield (32.31, 33.63 and 32.97 q ha^{-1}) noted with 100% RDF (N_3) across the two years of research and on pooled basis. In first and second season, residual effect of 100 % RDF (N_3) considerably superior to control (N_0), 50% RDF (N_1), and found at par with 75% RDF (N_2). In pooled analysis, the leftover impact of 100 % RDF (N_3) was statistically superior to the control (N_0), 50% RDF (N_1), and 75% RDF (N_2). Control (N_0) noted least haulm yield.

This was primarily due to the improved plant growth, which ensured a sufficient supply of photosynthates for sink development. As a result, enhanced overall growth performance and increased yield-related traits contributed to higher seed and stover yields (Lakum *et al.,* 2020). This findings are similar with Gable *et al.,* (2008), Elamin *et al.,* (2015), Paikra *et al.,* (2019), Lakum *et al.,* (2020), Sonboir *et al.,* (2020) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

FYM incorporation to preceding maize significantly increased the haulm yield throughout the two study years and in pooled data. Haulm yield increased with residual effect of higher FYM levels. The highest haulm yield (28.62, 29.45, and 29.03 q ha^{-1}) was noted in carryover impact of 10 t ha^{-1} FYM (F_2), showing considerable superiority to control (F_0) and 5 t ha^{-1} FYM (F_1) across the two years of research and in pooled analysis. Control (F_0) recorded lowest haulm yield.

Organic amendments enhance the soil's water holding capacity, thereby minimizing moisture stress in plant tissues. This stabilization of moisture levels helps maintain optimal photosynthetic activity, leading to increased accumulation of photosynthates. As a result, an efficient source and sink relationship is sustained, ensuring better nutrient distribution, overall plant growth, and ultimately contributing to rise in seed and haulm yield (Bana *et al.,* 2016). Comparable results were recorded by Bhuva and Detroja (2018) and Lakum *et al.,* (2020).

Interaction effect

Combination of various RDF and FYM levels applied to preceding maize showed significance across two study years and in pooled data. Highest haulm yield (33.54, 34.75, and 34.14 q ha^{-1}) registered with 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years and on pooled evaluation. In first and next season, N_3F_2 showing similarity to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) applied to preceding maize. However, on pooled basis, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1). These results are similar to Gudadhe *et al*., (2011), Lakum *et al.,* (2020) and Sonboir *et al.,* (2020).

4.2.1.6 Biological yield (q ha^{-1})

Biological yield recorded under residual effect of different treatments and their combinations is presented in Table 32, 32 (a) and figure 14.

Residual effect of RDF levels

Recommended dose of fertilizers (RDF) applied to preceding maize significantly enhanced the biological yield of chickpea across the two years of research as well as in a pooled evaluation. Biological yield increased with residual effect of higher levels of RDF. The highest biological yield (52.25, 54.93 and 53.59 q ha^{-1}) noted in residual effect of 100% RDF (N_3) showing statistical superiority than control (N_0), 50% RDF (N_1), and 75% RDF (N_2), across the two years of research and on pooled evaluation. Control (N_0) registered lowest biological yield.

The adequate application of plant nutrients to the preceding crop positively impacted the overall development of the succeeding plants by promoting increased chlorophyll content. This, in turn, accelerated the rate of photosynthesis, leading to greater carbohydrate synthesis and translocation. The improved assimilate availability contributed to higher biomass accumulation, thereby resulting in a notable increase in the biological yield of succeeding crop (Sunda, 2023). This results are similar with Gable *et al.,* (2008) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

FYM incorporation to preceding maize significantly enhanced the biological yield of chickpea throughout the two study years and in pooled evaluation. Biological yield increased with higher FYM levels applied to preceding crop. The highest biological yield (45.72, 47.50, and 46.61 q ha^{-1}) noted in carryover impact of 10 t FYM ha^{-1} (F_2), showing superiority to control (F_0) and 5 t ha^{-1} FYM (F_1) across the two years of research and on a pooled study. The lowest biological yield was noted in the control (F_0).

The beneficial effects of residual organic manures, especially farmyard manure (FYM), promoted better rhizospheric development and improved nutrient uptake, which in turn led to increase biomass yield in chickpea (Meena *et al.,* 2023). The present results are similar to Rathore *et al.,* (2014).

Interaction effect

Combination of varying RDF and FYM levels applied to preceding maize was showed significance across the two years of research and in a pooled study. The highest biological yield (54.41, 57.36, and 55.89 q ha^{-1}) was noted under residual effect of 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of experimentation and on pooled investigation. In first year and on pooled basis, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) However, in second year, N_3F_2 was at par with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) applied to preceding maize. Comparable results were observed by Hasan (2020).

4.2.1.7 Harvest Index (%)

The harvest index obtained under residual effect of various treatments and their combinations is shown in Table 32.

Residual effect of RDF levels

The application of RDF to previous maize significantly enhanced the HI of chickpea across both study years also in a combined investigation Highest harvest index (38.13, 38.72 and 38.43 %) was noted with carryover impact of 100% RDF (N_3), showed similarity with 50% RDF (N_1), and 75% RDF (N_2). Lowest harvest index was noted in control (N_0).

Harvest index (HI) serves as an important indicator for evaluating the efficiency of crop plants in translocating assimilates from source to economic yield (Paikra *et al.*, 2019). An increase in the harvest index under the residual effect of RDF levels suggests that the crop efficiently utilized the available nitrogen to enhance its physiological processes, leading to improved partitioning of photosynthates toward grain development (Sudhakar *et al.,* 2018). Comparable results noted by Elamin *et al.,* (2015).

Residual effect of FYM levels

FYM incorporation to preceding corn notably improved harvest index of chickpea across both study years and on combined evaluation. Highest harvest index (37.10, 37.34, and 37.22 %) was noted under leftover impact of 10 t ha^{-1} FYM (F_2) across the two years of research and in pooled study. During both years, residual impact of 10 t ha^{-1} FYM (F_2) showed superiority than control (F_0) similar to 5 t ha^{-1} FYM (F_1). In pooled analysis, carryover impact of 10 t ha^{-1} FYM (F_2) showing considerable improvement than control (F_0), 5 t ha^{-1} (F_1). Control (F_0) recorded lower values of harvest index.

Increase in harvest index due to FYM incorporation indicates that crop allocated a greater proportion of its energy and assimilates (photosynthates) toward grain formation instead of vegetative growth. This effect is likely due to better soil health created by the use of organic manures (Sudhakar *et al.,* 2018). Comparable results were noted by Srinivasarao *et al.,* (2010), Jat and Praharaj (2018).

Interaction effect

The combined residual impact of different RDF and FYM levels did not show any statistically significant effect over the two year study or in the pooled evaluation.

Table 32: Residual effect of integrated nutrient management on biological yield (q ha^{-1}) and HI (%) of chickpea during 2023-24 and 2024-25

Treatments	Biological yield (q ha^{-1})			Harvest Index (%)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
Nutrient management levels						
N_0 : Control	31.86	27.40	29.63	33.09	30.14	31.61
N_1 : 50 % RDF	39.31	40.28	39.79	36.32	36.51	36.42
N_2 : 75 % RDF	47.52	50.82	49.17	37.18	38.16	37.67
N_3 : 100 % RDF	52.25	54.93	53.59	38.13	38.72	38.43
SEm ±	0.65	0.78	0.51	1.30	2.07	1.22
CD 5%	2.23	2.70	1.56	4.49	7.16	3.76
FYM levels						
F_0 : Control	39.47	38.76	39.12	35.42	34.22	34.82
F_1 : 5 t ha^{-1} FYM	43.01	43.81	43.41	36.02	36.09	36.06
F_2 : 10 t ha^{-1} FYM	45.72	47.50	46.61	37.10	37.34	37.22
SEm ±	0.26	0.32	0.21	0.45	0.62	0.38
CD 5%	0.78	0.96	0.60	1.34	1.86	1.10
Interaction N*F						
SEm±	0.52	0.64	0.41	0.89	1.24	0.76
CD 5%	1.56	1.93	1.19	NS	NS	NS

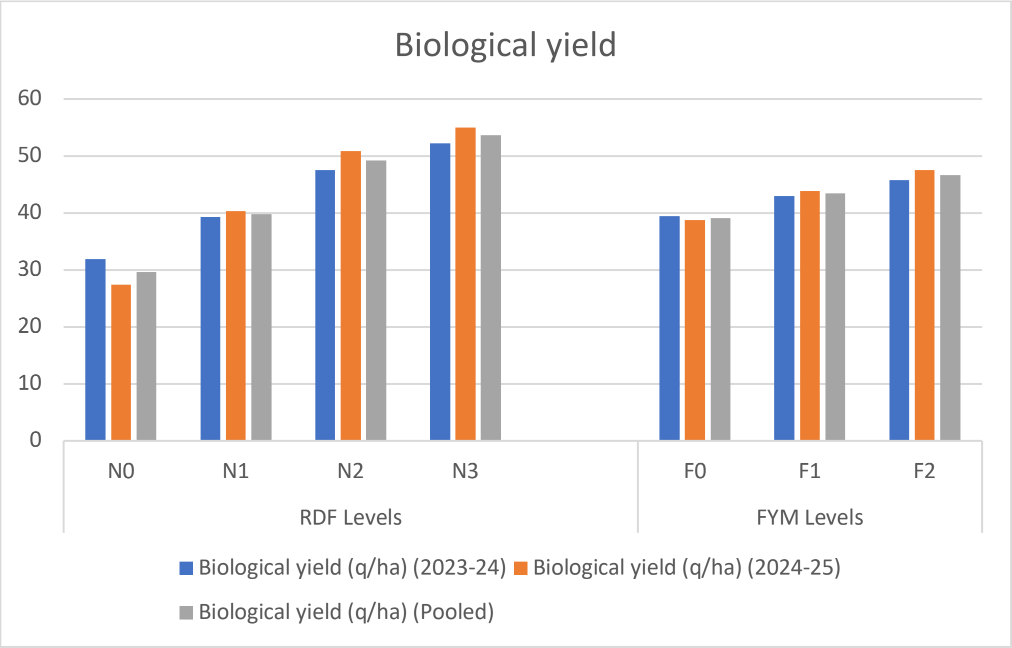


Fig. 14. Biological yield (q ha^{-1}) of chickpea as impacted by carryover impact of varying treatments

Table 32 (a): Combined impact of residual RDF and FYM on biological yield (q ha^{-1}) of chickpea during 2023-24 and 2024-25

Biological yield (q ha^{-1}) (2023-24)					Biological yield (q ha^{-1}) (2024-25)					Biological yield (q ha^{-1}) (Pooled)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	27.37	33.09	35.11	31.86	**N_0**	22.70	27.68	31.84	27.40	**N_0**	25.03	30.39	33.47	29.63
N_1	37.73	39.07	41.13	39.31	**N_1**	33.97	41.60	45.25	40.28	**N_1**	35.85	40.34	43.19	39.79
N_2	43.82	46.51	52.23	47.52	**N_2**	47.55	49.37	55.53	50.82	**N_2**	45.69	47.94	53.88	49.17
N_3	48.97	53.36	54.41	52.25	**N_3**	50.82	56.59	57.36	54.93	**N_3**	49.89	54.98	55.89	53.59
Mean	39.47	43.01	45.72		**Mean**	38.76	43.81	47.50		**Mean**	39.12	43.41	46.61	
SEm±	0.52				**SEm±**	0.64				**SEm±**	0.41			
CD 5%	1.56				**CD 5%**	1.93				**CD 5%**	1.19			

4.2.2 Plant analysis (Content and uptake of nutrients)

4.2.2.1 Nutrient content

4.2.2.1.1 Nitrogen content (%) in chickpea

The nitrogen content in chickpea seed and haulm recorded under residual effect of different treatments and their combinations is illustrated in Table 33 .

Residual effect of RDF levels

Nitrogen content in chickpea was notably enhanced by the residual effect of the recommended dose of fertilizers (RDF) across the two years of research. Highest nitrogen content in chickpea seeds (2.549 and 2.602 %) and haulm (0.840 and 0.871 %) was noted in residual effect of 100% RDF (N_3) across the two years of research. During first year, N_3 notably greater than control (N_0), 50% (N_1), and 75% RDF (N_2). However, in next season, it showed similarity to residual effect of 75 % RDF (F_2) in terms of nitrogen content in seeds and haulm. Least N content in chickpea seed and haulm was registered in the control (N_0).

Leguminous crops establish a symbiotic association with NFB called rhizobia, which colonize the roots and form nodules. Inside these nodules, rhizobia fix atmospheric nitrogen by converting it into available form of nitrogen, thereby contributing to increase in nitrogen content (Ciampitti *et al.,* 2021). Similar results noted by Sohu *et al.,* (2015).

Residual effect of FYM levels

The application of FYM given to prior corn significantly increased nitrogen content in chickpea across the two years of experimentation. Highest nitrogen content in chickpea seeds (2.352 and 2.371 %) and haulm (0.747 and 0.758 %) was recorded in 10 t ha^{-1} FYM (F_2) applied to preceding maize. In first year, carryover impact of 10 t FYM ha^{-1} which showing notable superiority than control (F_0), and 5 t FYM ha^{-1} (F_1) in terms of nitrogen content in seed. However, in second year, 10 t ha^{-1} FYM (F_2) given to prior corn showing comparability with 5 t ha^{-1} FYM (F_1). In terms of nitrogen content in haulm, residual impact of 10 t ha^{-1} FYM showed superiority to control (F_0) and 5 t ha^{-1} FYM (F_1). Least nitrogen content in chickpea was recorded in the control (F_0).

Greater availability of macronutrients in the soil, particularly nitrogen, due to the FYM incorporation to preceding crop, improved the soil environment and promoted enhanced root development, which in turn led to more efficient absorption of moisture and minerals by crop (Bhuva and detroja, 2018). The present results are supported by Jat and Praharaj (2018), Arunkumar and Thippeshappa (2020) and Mandanbhai (2022).

Interaction effect

The interaction of carryover impact of varying levels of RDF and FYM showed non significance impact across bot study years.

4.2.2.1.2 Phosphorus content (%) in chickpea

The phosphorus content in chickpea seed and haulm recorded under residual effect of different treatments and their combinations is illustrated in Table 33.

Residual effect of RDF levels

Phosphorus content in chickpea notably impacted by leftover effect of the RDF across the two years of research. Phosphorus content in chickpea increased with higher levels of RDF applied to preceding maize. The highest phosphorus content in chickpea seed (0.341 and 0.382 %) and haulm (0.171 and 0.181 %) was recorded in residual effect of 100% RDF (N_3) across the two years of research and it showed parity to residual effect of 75 % RDF (F_2). The lowest phosphorus content in chickpea seed and haulm was registered in the control (N_0).

The carryover impact of RDF application positively influenced the growth of the subsequent crop by enhancing root development and increasing root surface area, which in turn contributed to a notable rise in phosphorus concentration compared to the control. This enhancement in phosphorus content can be ascribed to its vital role in supporting root function and facilitating efficient nutrient uptake from the soil (Patidar and Mali, 2002). The present results are supported by Sohu *et al.,* (2015).

Residual effect of FYM levels

FYM given to prior corn significantly enhanced phosphorus content in chickpea across the two years of research. The highest phosphorus content in chickpea seed (0.327 and 0.352 %) and haulm (0.156 and 0.167 %) was recorded in 10 t ha^{-1} FYM (F_2) given to prior maize. In first and second year, residual effect of 10 t FYM ha^{-1} similar to 5 t ha^{-1} FYM (F_1) in terms of phosphorus content in seed. In terms of phosphorus content in haulm, the leftover impact of 10 t FYM ha^{-1} showed superiority to control (F_0) and 5 t ha^{-1} FYM (F_1). Least phosphorus content in chickpea was recorded in the control (F_0).

The application of FYM in corn contributed to increased nitrogen, phosphorus, and potassium contents in succeeding crop by building organic carbon, enhancing solubilization of nutrients into more available forms, and through its acidifying effect during decomposition, which made native phosphorus more accessible. These processes, along with the residual nutrients left in the root zone, resulted in greater availability and absorption of minerals by crops (Sinha, 2017). These findings similar to the results of Jat and Praharaj (2018), Arunkumar and Thippeshappa (2020) and Mandanbhai (2022).

Interaction effect

Combination of varying rates of RDF and FYM given to prior crop showed insignificant impact over the two years of study.

4.2.2.1.3 Potassium content (%) in chickpea

The potassium content in chickpea seeds and haulm, influenced by the leftover impact of different treatments and their combinations is detailed in Table 33.

Residual effect of RDF levels

Potassium content in chickpea notably increased by leftover impact of RDF across the two years of research. The potassium content in chickpea increased with residual effect of higher levels of RDF. The highest potassium content in chickpea seed (0.600 and 0.622 %) and haulm (1.252 and 1.284 %) was recorded in residual effect of 100% RDF (N_3) across the two years of research. The residual effect of 100 % RDF (F_3) notably superior than control (F_0), 50 % RDF (F_1) and 75 % RDF (F_2) in terms of potassium content in seed across the two years of research. The 100 % RDF (F_3) showing parity with residual effect of 75 % RDF (F_2) in term of potassium content in haulm across the two years of research. The lowest potassium content in chickpea seed and haulm was registered in the control (N_0).

The leftover impact of RDF positively influenced potassium uptake, likely due to a better nutrient environment around the roots and within the plant. This improved condition facilitated efficient absorption of potassium. Enhanced nutrient availability also promoted better translocation to different plant parts. Ultimately, this led to improved overall potassium utilization by the plant (Sunda, 2023). Similar results noted by Sohu *et al.,* (2015).

Residual effect of FYM levels

FYM given to prior corn significantly enhanced potassium content in chickpea across the two years of research. Highest K content in chickpea seed (0.542 and 0.557 %) and haulm (1.176 and 0.181 %) was recorded in 10 t ha^{-1} FYM (F_2) given to prior maize. In first and second year, carryover impact of 10 t FYM ha^{-1} showed significant superiority than control (F_0) and 5 t ha^{-1} FYM (F_1) in terms of K content in seed. In terms of potassium content in haulm, the residual impact of 10 t ha^{-1} FYM showing superiority to control (F_0) and 5 t ha^{-1} FYM (F_1) in first season but it showing parity with 5 t ha FYM (F_1) during second year. The lowest potassium content in chickpea seed and haulm was recorded in the control (F_0).

The residual effect of FYM applied to corn was more pronounced in terms of nutrient accumulation in the succeeding corn. This effect can be linked to the presence of persistent organic materials like cellulose in FYM, which decompose slowly over time. As a result, nutrients are released gradually and remain available for an extended period, supporting continuous nutrient uptake and accumulation of potassium in the following crop (Preetham *et al.,* 2020). Comparable outcomes were noted by Jat and Praharaj (2018), Arunkumar and Thippeshappa (2020) and Mandanbhai (2022).

Interaction effect

The combined influence of leftover RDF and FYM from previous applications didn't show any noticeable effect in either year of the study.

Table 33: Residual effect of integrated nutrient management on nutrient content in chickpea during 2023-24 and 2024-25

Treatments	Nitrogen content (%)				Phosphorus content (%)				Potassium content (%)			
	Seed		Haulm		Seed		Haulm		Seed		Haulm	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels												
N_0 : Control	1.952	1.791	0.557	0.490	0.289	0.255	0.127	0.112	0.426	0.391	0.954	0.840
N_1 : 50 % RDF	2.147	2.155	0.644	0.649	0.316	0.320	0.142	0.146	0.485	0.508	1.100	1.109
N_2 : 75 % RDF	2.352	2.448	0.761	0.784	0.335	0.359	0.160	0.169	0.553	0.570	1.189	1.237
N_3 : 100 % RDF	2.549	2.602	0.840	0.871	0.341	0.382	0.171	0.181	0.600	0.622	1.252	1.284
SEm ±	0.032	0.071	0.008	0.028	0.005	0.017	0.004	0.004	0.005	0.010	0.019	0.050
CD 5%	0.110	0.246	0.029	0.095	0.017	0.060	0.013	0.015	0.019	0.033	0.064	0.173
FYM levels												
F_0 : Control	2.159	2.102	0.653	0.625	0.313	0.297	0.144	0.134	0.489	0.479	1.064	1.033
F_1 : 5 t ha^{-1} FYM	2.240	2.275	0.703	0.713	0.321	0.338	0.150	0.155	0.517	0.532	1.132	1.138
F_2 : 10 t ha^{-1} FYM	2.352	2.371	0.747	0.758	0.327	0.352	0.156	0.167	0.542	0.557	1.176	1.181
SEm ±	0.020	0.033	0.007	0.010	0.003	0.011	0.001	0.002	0.006	0.003	0.013	0.020
CD 5%	0.059	0.100	0.022	0.029	0.009	0.034	0.004	0.007	0.017	0.010	0.038	0.060
Interaction N*F												
SEm±	0.039	0.067	0.015	0.019	0.006	0.023	0.003	0.005	0.011	0.007	0.025	0.040
CD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.2.2.2 Uptake of nutrients

4.2.2.2.1 Nitrogen uptake by chickpea (kg ha^{-1})

The N intake by chickpea recorded under residual effect of various treatments and their combinations is presented in Table 34, 34 (a) and figure 15.

Residual effect of RDF levels

Nitrogen uptake by chickpea seed and haulm was notably impacted by the application of the RDF to prior corn across the two years of research. Nitrogen uptake by chickpea increased with raising RDF levels applied to preceding maize. The highest nitrogen uptake by chickpea seed (51.07 and 55.95 kg ha^{-1}), haulm (27.23 and 29.41 kg ha^{-1}) and overall intake (78.30 and 85.37 kg ha^{-1}) noted in 100% RDF (N_3) applied to preceding maize, exhibiting dominance over control (N_0), 50% (N_1), and 75% RDF (N_2) in first year and next season. Least nitrogen uptake of chickpea seed, haulm and overall uptake was registered in the control (N_0).

Applying a well-balanced and adequate dose of NPK to the previous crop enriched the soil with essential nutrients, which in turn supported the next crop by improving nutrient availability and uptake. this practice also helped maintain a richer nutrient reserve in soil by the time of harvest (Rawal *et al.,* 2022). legume crops develop a mutually beneficial relationship with NFB called rhizobia. these bacteria colonize the plant roots and form nodules, where they convert atmospheric nitrogen into ammonia (a form that plants can easily absorb). This process naturally boosts the nitrogen concentration in both soil and plant system (Ciampitti et al., 2021). Similar results was noted by Nawle *et al.,* (2009), Hiremath *et al.,* (2016) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

The FYM incorporation to preceding maize significantly improved nitrogen intake by chickpea across two study seasons. Highest nitrogen intake by chickpea seed (41.20 and 44.91 kg ha^{-1}), haulm (21.95 and 23.12 kg ha^{-1}) and overall uptake (63.15 and 68.03 kg ha^{-1}) noted in residual effect of 10 t ha^{-1} FYM (F_2), which showed superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two seasons of research. Least nitrogen uptake by chickpea seed, haulm and overall uptake was recorded in the control (F_0).

Manure plays a vital role in rejuvenating nutrient depleted soils by improving the uptake of nitrogen and phosphorus, particularly in legume-cereal crop rotations. It enhances the crop's ability to respond to other essential nutrients by addressing nutrient imbalances. Additionally, manure supports effective nodulation of legume and nitrogen fixation by supplying exchangeable cations and essential micronutrients, thereby fostering overall fertility of soil and performance of plants (Olfati *et al.,* 2012). The present results are supported by Arunkumar and Thippeshappa (2020).

Interaction effect

The combination of leftover impact of various levels of RDF and FYM had a notable impact across the two years of research. Highest nitrogen uptake of chickpea seed (56.13 and 61.57 kg ha^{-1}), haulm (29.68 and 31.96 kg ha^{-1}) and overall uptake (85.81 and 93.52 kg ha^{-1}) noted in residual effect of 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two seasons of research. During the first year, the N_3F_2 treatment showed a clear advantage over all other combinations in terms of nitrogen uptake by chickpea seed. however, its performance was statistically similar to that of 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF+ 10 t ha^{-1} FYM (N_2F_2). However, in both the first and second years, the N_3F_2 (100% RDF + 10 t ha^{-1} FYM) showed similar nitrogen intake by haulm to that of the N_3F_1 (100% RDF + 5 t ha^{-1} FYM). Regarding overall N uptake, N_3F_2 combination was statistically superior over all the treatment combination in first season and similar to 100 % RDF + 5 t ha^{-1} FYM (N_3F_1) during second year of experimentation. The present outcomes are similar with Gudadhe *et al.,* (2011).

4.2.2.2.2 Phosphorus uptake by chickpea (kg ha^{-1})

The phosphorus intake by chickpea recorded under various treatments applied to preceding maize and their combinations is shown in Table 35, 35 (a) and figure 15.

Residual effect of RDF levels

Phosphorus uptake by chickpea seed and haulm was notably affected by carryover impact of RDF across two years of research. The phosphorus uptake by chickpea seed and haulm increased with raising levels of RDF applied to preceding maize. The maximum phosphorus uptake by chickpea seed (6.86 and 8.26 kg ha^{-1}), haulm (5.53 and 6.14 kg ha^{-1}) and overall uptake (12.39 and 14.40 kg ha^{-1}) noted under 100% RDF (N_3) applied to preceding maize, which was statistically superior over control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. The lowest phosphorus uptake by chickpea seed, haulm and overall uptake was recorded in the control (N_0).

Fertilizing previous crop with 75% or 100% RDF showed positive residual effect on growth of next crop, significantly increasing phosphorus accumulation compared to the control. This boost in phosphorus uptake is likely due to its key role in enhancing root development and function, which improved nutrient absorption from the soil (Patidar and Mali 2002). Similar results noted by Nawle *et al.,* (2009), Hiremath *et al.,* (2016) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

The residual effect of FYM considerably enhanced phosphorus uptake by chickpea across the two years of research. Phosphorus uptake by chickpea seed and haulm increased with increasing FYM levels applied to preceding maize. Highest phosphorus uptake by chickpea seed (5.72 and 6.68 kg ha^{-1}), haulm (4.56 and 5.08 kg ha^{-1}) and overall uptake (10.29 and 11.76 kg ha^{-1}) registered in residual effect of 10 t ha^{-1} FYM (F_2), showing considerable significance than control (F_0), and 5 t ha^{-1} FYM (F_1) across both study years. Least phosphorus uptake by chickpea seed, haulm and overall uptake was recorded in the control (F_0).

The positive impact of residual effect of organic sources extends to the availability of both primary and secondary nutrients while also enhancing the overall properties of the soil. These improvements create a favorable environment for root proliferation, which in turn facilitates more efficient nutrient uptake by plants (Chhipa *et al.,* 2017). Similar results reported by Arunkumar and Thippeshappa (2020).

Interaction effect

The combined carryover impact of different RDF and FYM showing significant influence across the two years of research. Highest phosphorus uptake by chickpea seed (7.27 and 9.12 kg ha^{-1}), haulm (5.92 and 6.77 kg ha^{-1}) and overall uptake (13.19 and 15.89 kg ha^{-1}) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research. In terms of phosphorus uptake by seed, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF+10 t ha^{-1} FYM (N_2F_2) across the two years of research. In terms of phosphorus uptake by haulm, N_3F_2 similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) during first season and showing parity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF+10 t ha^{-1} FYM (N_2F_2) during second year. The overall phosphorus uptake found highest under N_3F_2 and showed similarity with 100% RDF + 5 t ha^{-1} FYM across two years of research. Similar results were recorded by Gudadhe *et al.,* (2011).

4.2.2.2.3 Potassium uptake by chickpea (kg ha^{-1})

The potassium intake by chickpea recorded under residual effect of various treatments and their combinations is shown in Table 36, 36 (a) and figure 15.

Residual effect of RDF levels

Potassium uptake by chickpea seed and haulm was significantly increased by the leftover impact of RDF across the two years of research. The potassium uptake by chickpea seed and haulm increased with raising levels of RDF applied to preceding maize. The highest potassium uptake by chickpea seed (12.21 and 13.45 kg ha^{-1}), haulm (40.69 and 43.18 kg ha^{-1}) and overall uptake (52.89 and 56.64 kg ha^{-1}) noted in 100% RDF (N_3) applied to preceding maize. In terms of potassium uptake by seed, N_3 was found significantly superior across the two years of research. In terms of potassium uptake by the haulm and overall uptake, the 100% RDF (N_3) treatment was significantly better in initial year. In following year, it was similar to the 75% RDF (N_2) treatment. Lowest potassium uptake by chickpea seed, haulm and overall uptake was noted in the control (N_0).

Carryover impact of higher doses of nitrogen, phosphorus and potassium were given to prior corn, they improved nutrient availability in the soil. As a result, the succeeding crop was able to absorb more of these nutrients. The better nutrient availability also contributed to increased yield and higher nutrient concentration in the plant tissues of the next crop. Essentially, the leftover impact of fertilizing earlier crop benefited the next crop by enhancing its nutrient uptake and overall performance (Chavan *et al*., 2014). Similar results were noted by Nawle *et al.,* (2009), Hiremath *et al.,* (2016) and Kumawat *et al.,* (2020).

Residual effect of FYM levels

Residual effect of FYM notably impacted the potassium intake by chickpea across two study years. Highest potassium intake by chickpea seed (9.75 and 10.68 kg ha^{-1}), haulm (34.21 and 35.62 kg ha^{-1}) and overall uptake (43.96 and 46.30 kg ha^{-1}) noted in residual effect of 10 t ha^{-1} FYM (F_2), showed considerable significance over control (F_0), and 5 t ha^{-1} FYM (F_1) across two seasons of research. Least potassium uptake by chickpea seed, haulm and overall uptake was recorded in the control (F_0).

FYM not only enhances solubility of unavailable nutrients but also supplies considerable amounts of nitrogen, phosphorus, potassium, and essential micronutrients.

Consequently, FYM application leads to a notable improvement in nutrient intake, offering a cost effective and sustained source of nutrients over an extended period (Hasan *et al.,* 2023). Similar results were observed by Arunkumar and Thippeshappa (2020).

Interaction effect

Combination of carryover impact of RDF and FYM levels showed significance across the two years of research. Highest potassium uptake by chickpea seed (13.36 and 14.81 kg ha^{-1}), haulm (43.50 and 45.58 kg ha^{-1}) and total uptake (56.86 and 60.39 kg ha^{-1}) was noted under 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research. In terms of potassium uptake by seed, N_3F_2 considerably similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) across the two years of research. In terms of potassium uptake by haulm and overall uptake, N_3F_2 showed parity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1) in first season and it was similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) and 75% RDF+10 t ha^{-1} FYM (N_2F_2) during second year. Similar results were recorded by Gudadhe *et al.,* (2011).

Table 34: Residual effect of integrated nutrient management on nitrogen uptake (kg ha^{-1}) of chickpea during 2023-24 and 2024-25

Treatments	Nitrogen uptake (kg ha^{-1})					
	Seed		Haulm		Total	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	21.44	16.38	11.83	9.34	33.27	25.72
N_1 : 50 % RDF	30.91	33.10	16.14	16.67	47.05	49.78
N_2 : 75 % RDF	42.02	48.23	22.86	24.80	64.87	73.03
N_3 : 100 % RDF	51.07	55.95	27.23	29.41	78.30	85.37
SEm ±	0.81	0.76	0.78	0.97	0.99	1.44
CD 5%	2.81	2.65	2.70	3.37	3.41	4.97
FYM levels						
F_0 : Control	31.60	31.06	16.93	16.56	48.53	47.62
F_1 : 5 t ha^{-1} FYM	36.27	39.28	19.67	20.49	55.94	59.77
F_2 : 10 t ha^{-1} FYM	41.20	44.91	21.95	23.12	63.15	68.03
SEm ±	0.47	0.66	0.23	0.30	0.53	0.75
CD 5%	1.42	1.98	0.68	0.89	1.58	2.25
Interaction N*F						
SEm±	0.94	1.32	0.45	0.59	1.06	1.50
CD 5%	2.83	3.96	1.36	1.78	3.17	4.50

Fig. 15. N, P and K uptake (kg ha^{-1}) of chickpea as impacted by residual effect of various treatments

Table 34 (a): Combined effect of residual RDF and FYM levels on nitrogen uptake (kg ha^{-1}) by seeds and haulm of chickpea during 2023-24 and 2024-25

Nitrogen uptake by seeds (2023-24)					**Nitrogen uptake by seeds (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	16.95	21.43	25.92	21.44	**N_0**	12.42	16.13	20.57	16.38
N_1	29.16	30.68	32.90	30.91	**N_1**	23.67	35.80	39.84	33.10
N_2	35.86	40.33	49.86	42.02	**N_2**	41.08	45.96	57.64	48.23
N_3	44.43	52.65	56.13	51.07	**N_3**	47.07	59.21	61.57	55.95
Mean	31.60	36.27	41.20		**Mean**	31.06	39.28	44.91	
SEm±	0.94				**SEm±**	1.32			
CD 5%	2.83				**CD 5%**	3.96			

Nitrogen uptake by haulm (2023-24)					**Nitrogen uptake by haulm (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	9.52	12.47	13.51	11.83	**N_0**	6.98	9.50	11.55	9.34
N_1	14.78	16.01	17.65	16.14	**N_1**	12.26	17.46	20.31	16.67
N_2	19.81	21.81	26.95	22.86	**N_2**	21.54	24.18	28.68	24.80
N_3	23.62	28.39	29.68	27.23	**N_3**	25.47	30.81	31.96	29.41
Mean	16.93	19.67	21.95		**Mean**	16.56	20.49	23.12	
SEm±	0.45				**SEm±**	0.59			
CD 5%	1.36				**CD 5%**	1.78			

Overall nitrogen uptake (2023-24)					**Overall nitrogen uptake (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	26.48	33.90	39.43	33.27	**N_0**	19.40	25.63	32.12	25.72
N_1	43.94	46.68	50.54	47.05	**N_1**	35.93	53.26	60.15	49.78
N_2	55.67	62.14	76.81	64.87	**N_2**	62.61	70.15	86.33	73.03
N_3	68.05	81.04	85.81	78.30	**N_3**	72.55	90.03	93.52	85.37
Mean	48.53	55.94	63.15		**Mean**	47.62	59.77	68.03	
SEm±	1.06				**SEm±**	1.50			
CD 5%	3.17				**CD 5%**	4.50			

Table 35: Residual effect of integrated nutrient management on P uptake (kg ha^{-1}) of chickpea during 2023-24 and 2024-25

Treatments	Phosphorus uptake (kg ha^{-1})					
	Seed		Haulm		Total	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	3.21	2.44	2.72	2.16	5.93	4.60
N_1 : 50 % RDF	4.60	4.97	3.57	3.74	8.17	8.71
N_2 : 75 % RDF	6.02	7.10	4.83	5.38	10.85	12.48
N_3 : 100 % RDF	6.86	8.26	5.53	6.14	12.39	14.40
SEm ±	0.08	0.33	0.16	0.21	0.22	0.28
CD 5%	0.28	1.15	0.56	0.73	0.75	0.96
FYM levels						
F_0 : Control	4.61	4.53	3.73	3.57	8.34	8.10
F_1 : 5 t ha^{-1} FYM	5.18	5.86	4.19	4.42	9.37	10.29
F_2 : 10 t ha^{-1} FYM	5.72	6.68	4.56	5.08	10.29	11.76
SEm ±	0.07	0.17	0.05	0.08	0.09	0.14
CD 5%	0.21	0.50	0.14	0.23	0.28	0.43
Interaction N*F						
SEm±	0.14	0.34	0.10	0.16	0.18	0.28
CD 5%	0.42	1.01	0.29	0.47	0.55	0.85

Table 35 (a): Combined effect of residual RDF and FYM levels on phosphorus uptake (kg ha^{-1}) by seeds and haulm of chickpea during 2023-24 and 2024-25

Phosphorus uptake by seeds (2023-24)					Phosphorus uptake by seeds (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	2.53	3.24	3.85	3.21	**N_0**	2.03	2.25	3.04	2.44
N_1	4.32	4.57	4.92	4.60	**N_1**	3.12	5.62	6.16	4.97
N_2	5.32	5.87	6.86	6.02	**N_2**	6.19	6.71	8.41	7.10
N_3	6.29	7.03	7.27	6.86	**N_3**	6.78	8.88	9.12	8.26
Mean	4.61	5.18	5.72		**Mean**	4.53	5.86	6.68	
SEm±	0.14				**SEm±**	0.34			
CD 5%	0.42				**CD 5%**	1.01			

Phosphorus uptake by haulm (2023-24)					Phosphorus uptake by haulm (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	2.27	2.86	3.03	2.72	**N_0**	1.45	2.32	2.71	2.16
N_1	3.31	3.55	3.84	3.57	**N_1**	2.88	3.86	4.47	3.74
N_2	4.35	4.70	5.46	4.83	**N_2**	4.79	5.01	6.34	5.38
N_3	5.00	5.66	5.92	5.53	**N_3**	5.15	6.50	6.77	6.14
Mean	3.73	4.19	4.56		**Mean**	3.57	4.42	5.08	
SEm±	0.10				**SEm±**	0.16			
CD 5%	0.29				**CD 5%**	0.47			

Total P uptake (2023-24)					Total P uptake (2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	4.80	6.10	6.89	5.93	**N_0**	3.48	4.56	5.75	4.60
N_1	7.63	8.12	8.76	8.17	**N_1**	6.01	9.48	10.64	8.71
N_2	9.67	10.57	12.32	10.85	**N_2**	10.98	11.72	14.75	12.48
N_3	11.29	12.69	13.19	12.39	**N_3**	11.93	15.39	15.89	14.40
Mean	8.34	9.37	10.29		**Mean**	8.10	10.29	11.76	
SEm±	0.18				**SEm±**	0.28			
CD 5%	0.55				**CD 5%**	0.85			

Table 36: Residual effect of integrated nutrient management on K uptake (kg ha^{-1}) of chickpea during 2023-24 and 2024-25

Treatments	**Potassium uptake (kg ha^{-1})**					
	Seed		**Haulm**		**Total**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	4.91	3.80	20.44	16.01	25.35	19.81
N_1 : 50 % RDF	7.22	7.91	27.52	28.44	34.74	36.35
N_2 : 75 % RDF	10.08	11.37	35.82	39.10	45.90	50.47
N_3 : 100 % RDF	12.21	13.45	40.69	43.18	52.89	56.64
SEm ±	0.39	0.42	1.17	2.06	1.38	2.37
CD 5%	1.35	1.44	4.03	7.13	4.76	8.20
FYM levels						
F_0 : Control	7.42	7.31	27.70	27.14	35.12	34.46
F_1 : 5 t ha^{-1} FYM	8.64	9.40	31.44	32.29	40.08	41.69
F_2 : 10 t ha^{-1} FYM	9.75	10.68	34.21	35.62	43.96	46.30
SEm ±	0.17	0.14	0.46	0.54	0.49	0.58
CD 5%	0.51	0.43	1.38	1.61	1.47	1.74
Interaction N*F						
SEm±	0.34	0.29	0.92	1.08	0.98	1.16
CD 5%	1.01	0.86	2.76	3.22	2.94	3.48

Table 36 (a): Combined effect of residual RDF and FYM levels on potassium uptake (kg ha^{-1}) by seeds and haulm of chickpea during 2023-24 and 2024-25

Potassium uptake by seeds (2023-24)					Potassium uptake by seeds (2024-25)				
Interaction N*F	F_0	F_1	F_2	Mean	Interaction N*F	F_0	F_1	F_2	Mean
N_0	3.85	4.94	5.94	4.91	N_0	2.78	3.74	4.87	3.80
N_1	6.82	7.10	7.73	7.22	N_1	5.76	8.52	9.45	7.91
N_2	8.45	9.82	11.98	10.08	N_2	9.59	10.93	13.59	11.37
N_3	10.55	12.70	13.36	12.21	N_3	11.13	14.41	14.81	13.45
Mean	7.42	8.64	9.75		Mean	7.31	9.40	10.68	
SEm±	0.34				SEm±	0.29			
CD 5%	1.01				CD 5%	0.86			

Potassium uptake by haulm (2023-24)					Potassium uptake by haulm (2024-25)				
Interaction N*F	F_0	F_1	F_2	Mean	Interaction N*F	F_0	F_1	F_2	Mean
N_0	15.43	22.21	23.67	20.44	N_0	11.74	16.68	19.63	16.01
N_1	25.75	27.41	29.40	27.52	N_1	21.54	30.26	33.51	28.44
N_2	32.78	34.43	40.26	35.82	N_2	36.12	37.42	43.76	39.10
N_3	36.85	41.72	43.50	40.69	N_3	39.17	44.80	45.58	43.18
Mean	27.70	31.44	34.21		Mean	27.14	32.29	35.62	
SEm±	0.92				SEm±	1.08			
CD 5%	2.76				CD 5%	3.22			

Overall potassium uptake (2023-24)					Overall potassium uptake (2024-25)				
Interaction N*F	F_0	F_1	F_2	Mean	Interaction N*F	F_0	F_1	F_2	Mean
N_0	19.28	27.14	29.61	25.35	N_0	14.52	20.41	24.50	19.81
N_1	32.57	34.51	37.13	34.74	N_1	27.30	38.77	42.96	36.35
N_2	41.23	44.25	52.23	45.90	N_2	45.71	48.35	57.35	50.47
N_3	47.40	54.42	56.86	52.89	N_3	50.30	59.22	60.39	56.64
Mean	35.12	40.08	43.96		Mean	34.46	41.69	46.30	
SEm±	0.98				SEm±	1.16			
CD 5%	2.94				CD 5%	3.48			

4.2.3 Soil analysis

4.2.3.1 Physical properties of soil

4.2.3.1.1 Bulk density (g cm^{-3})

The bulk density after harvesting of chickpea recorded under different treatments applied to preceding maize is presented in Table 37.

Residual effect of RDF levels

The bulk density of soil recorded after the harvest of maize was not considerably impacted by the application of RDF across the two years of research.

Residual effect of FYM levels

The application of FYM given to prior corn notably impacted the bulk density of soil across the two years of research. Highest bulk density (1.35 and 1.34 g cm^{-3}) noted in control (F_0), showing parity to of 5 t ha^{-1} FYM (F_1) and 10 t ha^{-1} FYM (F_0) across two years of research. The lowest bulk density noted in 10 t ha^{-1} FYM (F_2) given to preceding maize.

Lower bulk density observed after chickpea harvest in the organic manuring, can be credited to enhanced organic carbon content. This improvement in organic matter helps promote better soil aggregation and creates more macropores, ultimately leading to improved soil structure (Bellaki *et al.,* 1998). This results are similar with Ojha *et al.,* (2014), Nagar *et al.,* (2016), Bhuva and detroja (2018), Prabhavathi *et al.,* (2024) and Chauhan *et al.,* (2024).

Interaction effect

The combined influence of leftover nutrients from different levels of RDF and FYM didn't show any meaningful impact during either year of the study.

4.2.3.1.2 Particle density (g cm^{-3})

The particle density noted under residual effect of varying treatments is shown in Table 37. After chickpea harvest, soil particle density was not notably impacted by the RDF and FYM rates applied to previous maize crop, nor by their interactions, during both years of the study.

4.2.3.1.3 Porosity (%)

The soil porosity registered under varying treatments is shown in Table 37. Porosity of soil after harvesting of chickpea found insignificant in the application of

RDF and FYM levels given to prior crop and their interactions the two years of research.

Table 37: Residual effect of integrated nutrient management on physical properties of soil at harvest of chickpea during 2023-24 and 2024-25

Treatments	**Physical properties of soil**					
	Bulk density (g cm^{-3})		**Particle density (g cm^{-3})**		**Porosity (%)**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels						
N_0 : Control	1.33	1.33	2.61	2.61	49.04	49.17
N_1 : 50 % RDF	1.33	1.33	2.61	2.61	48.89	48.95
N_2 : 75 % RDF	1.34	1.34	2.62	2.62	48.64	48.83
N_3 : 100 % RDF	1.35	1.36	2.62	2.63	48.27	48.11
SEm ±	0.01	0.02	0.02	0.02	0.92	0.51
CD 5%	NS	NS	NS	NS	NS	NS
FYM levels						
F_0 : Control	1.35	1.34	2.62	2.61	48.45	48.65
F_1 : 5 t ha^{-1} FYM	1.34	1.33	2.61	2.60	48.77	48.82
F_2 : 10 t ha^{-1} FYM	1.34	1.32	2.61	2.60	48.91	49.20
SEm ±	0.01	0.01	0.01	0.01	0.17	0.30
CD 5%	0.02	0.03	NS	NS	NS	NS
Interaction N*F						
SEm±	0.01	0.012	0.01	0.02	0.35	0.60
CD 5%	NS	NS	NS	NS	NS	NS
Initial value	**1.35**		**2.62**		**48.47**	

4.2.3.2 Chemical properties of soil

4.2.3.2.1 Soil pH

The soil pH after harvesting of chickpea recorded under different treatments applied to preceding maize is illustrated in Table 38 and figure 16.

Residual effect of RDF levels

The soil pH measured after chickpea harvest remained unaffected by the application of RDF across the two years of research.

Residual effect of FYM levels

Applying FYM to prior maize had a notable impact on soil pH after chickpea harvest across both study years. Lowest soil pH (7.69 and 7.67) was recorded in 10 t ha^{-1} FYM (F_2) to preceding maize. Highest soil pH was recorded in the 10 t ha^{-1} FYM (F_2).

Long-term application of FYM led to a noticeable drop in soil pH compared to its original level. This decline is likely due to the breakdown of organic materials, such as root residues, which release organic acids into the soil, contributing to its acidification (Margal et al., 2021). This finding are similar with Ojha *et al.,* (2014), Nagar *et al.,* (2016), Bhuva and detroja (2018) and Thakur *et al.,* (2023)

Interaction effect

The combined residual effects of different RDF and FYM levels did not show any statistically meaningful influence over the two years of the study.

4.2.3.2.2 Electrical conductivity (dSm^{-1})

Electrical conductivity of soil recorded under different treatments applied to preceding chickpea is illustrated in Table 38 and figure 16.

Residual effect of RDF levels

RDF application had no notable impact on the soil's electrical conductivity after chickpea harvest across the two years of research.

Residual effect of FYM levels

The residual impact of FYM significantly influenced the electrical conductivity of the soil throughout the two years of the study. Highest electrical conductivity (0.20 and 0.22 dSm^{-1}) noted in 10 t FYM ha^{-1} (F_0), showed significant superiority over control (F_0) and 5 t ha^{-1} FYM (F_1) across the two years of research. Lowest electrical conductivity noted in the control (F_0).

The increase in electrical conductivity (EC) following manure application was linked to an increase in soluble salt concentration and the enhanced solubilization of native minerals, resulting from a reduction in soil pH. Acids released during the decomposition of manure react with existing soil salts, converting them into more soluble forms or increasing their solubility (Dhaliwal *et al.*, 2023). Similar results was noted by Ojha *et al.,* (2014) and Chauhan *et al.,* (2024).

Interaction effect

The combined carryover impact of different RDF and FYM on electrical conductivity showing non significance effect across the two years of research.

4.2.3.2.3 Organic carbon (%)

The soil organic carbon after harvesting of chickpea recorded under residual impact of varying treatments is shown in Table 38 and figure 16.

Residual effect of RDF levels

Organic carbon of soil was considerably impacted by RDF levels across the two years of research. The highest organic carbon (0.42 and 0.43 %) found under residual effect of 100% RDF (N_3), showing similarity to control (N_0), 50% (N_1), and 75% RDF (N_2) in the first year. However, it showed similarity to 50% (N_1) and 75% RDF (N_2) in the next season of experimentation. Lowest organic carbon recorded in control (N_0).

The use of fertilizers to maize promoted carbon accumulation primarily by enhancing root biomass production of succeeding crop. Over time, the breakdown of residues contributed to buildup of carbon in the soil, leading to sustained carbon enrichment (Borah *et al.,* 2023). Comparable outcomes registered by Rathore *et al.,* (2014).

Residual effect of FYM levels

Carryover impact of FYM considerably impacted OC of soil after harvesting of chickpea across both study years. The highest organic carbon (0.44 and 0.46 %) noted in the carryover impact of 10 t FYM ha^{-1} (F_0), showed similarity to 5 t ha^{-1} FYM (F_1) across the two years of research. Control (F_0) recorded the lowest organic carbon of soil.

The rise in soil organic carbon with the incorporation of organic matter can be credited to the ongoing addition of decomposable carbon compounds. This increase in carbon content is closely linked to the incorporation of organic matter, which helps build up soil organic carbon stocks (Borah *et al*., 2023). As organic matter breaks down, some of the carbon is released as minerals, while the remaining carbon contributes to the buildup of soil organic carbon, enhancing soil fertility, structure, and microbial activity. Comparable outcomes registered by Ojha *et al.,* (2014), Nagar *et al.,* (2016), Bhuva and detroja (2018), Mandanbhai (2022) and Chauhan *et al.,* (2024).

Interaction effect

The combined effect of residual RDF and FYM levels on organic carbon showing insignificance effect across the two years of research.

4.2.3.2.4 Available nitrogen (kg ha^{-1})

The soil available nitrogen after harvesting of chickpea recorded under residual effect of various treatments and their combinations is presented in Table 38, 38 (a) and figure 16.

Residual effect of RDF levels

Leftover impact of RDF significantly increased the soil available nitrogen after chickpea harvest across the two years of research. Available nitrogen increased with increasing RDF levels applied to preceding maize. The highest available nitrogen (183.35 and 192.07 kg ha^{-1}) recorded in residual effect of 100% RDF (N_3), showing considerable superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. Control (N_0) noted the least available nitrogen.

Increased availability of nitrogen (N) under residual 100 % RDF can be linked to improved growth and greater nitrogen fixation by the legume. Legumes form a symbiotic association with nitrogen-fixing bacteria such as Rhizobium in their root nodules, enabling them to convert atmospheric N_2 into a plant-available form. Enhanced legume growth, encouraged by favourable treatment conditions, promotes more efficient biological nitrogen fixation, thereby contributing to higher available nitrogen (Lokose *et al*., 2017). The present outcomes are similar to Rathore *et al.,* (2014), Lakum *et al.,* (2020), Prajakta *et al.,* (2021) and Thakur *et al.,* (2023).

Residual effect of FYM levels

FYM incorporation to preceding maize notably enhanced the available N of soil throughout the two study years. Available nitrogen increased with carryover effect of increasing FYM levels. Highest available N (180.26 and 187.32 kg ha^{-1}) noted in residual impact of 10 t ha^{-1} FYM (F_2), showed superiority than control (F_0), and 5 t

FYM ha^{-1} (F_1) across the two years of research. The control (N_0) treatment noted the lowest available nitrogen.

The leftover organic matter from applying organic manures helps improve overall soil health. This improvement creates a better soil environment, increasing nutrient availability, promoting beneficial microbes, and aiding in the breakdown of organic materials. As a result, these processes lead to a continuous boost in soil fertility (Lakum *et al.,* 2020). The carryover effect of FYM at 10 t ha^{-1} notably enhanced the soil N after harvesting of preceding crop. This improvement is likely due to the steady release of nitrogen through mineralization and the reduction in leaching losses, leading to a higher residual N in the soil (Chauhan *et al.,* 2024). This findings similar with Nagar *et al.,* (2016), Bhuva and Detroja (2018), Lakum *et al.,* (2020) and Chauhan *et al.,* (2024).

Interaction effect

Combined effect residual of RDF and FYM was notably impactful across the two years of research. The highest available nitrogen (194.47 and 204.46 kg ha^{-1}) noted in residual impact of 100 % RDF + 10 t ha^{-1} FYM (N_3F_2), which was found statistically similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) across the two years of research. The present results are supported by Sinha (2017).

Table 38: Residual effect of integrated nutrient management on chemical properties of soil at harvest of chickpea during 2023-24 and 2024-25

Treatments	Chemical properties of soil											
	pH		**EC (dSm^{-1})**		**Organic carbon (%)**		**Available nitrogen (kg ha^{-1})**		**Available phosphorus (kg ha^{-1})**		**Available potassium (kg ha^{-1})**	
	2023-24	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
Nutrient management levels												
N_0 : Control	7.70	7.70	0.12	0.10	0.40	0.39	139.47	143.24	13.63	12.75	302.91	289.88
N_1 : 50 % RDF	7.70	7.69	0.15	0.16	0.41	0.42	162.89	167.56	16.70	17.31	333.28	337.41
N_2 : 75 % RDF	7.69	7.68	0.19	0.21	0.42	0.42	174.11	180.30	18.56	20.07	349.85	358.09
N_3 : 100 % RDF	7.69	7.68	0.23	0.25	0.42	0.43	183.35	192.07	20.32	22.24	364.69	372.84
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	1.51	3.09	0.43	0.70	2.51	0.60
CD 5%	NS	NS	NS	NS	0.02	0.03	5.21	10.68	1.50	2.41	8.68	2.07
FYM levels												
F_0 : Control	7.70	7.70	0.13	0.12	0.39	0.37	149.83	153.95	16.18	15.98	317.77	310.56
F_1 : 5 t ha^{-1} FYM	7.69	7.68	0.17	0.18	0.42	0.44	164.78	171.10	17.25	18.23	337.20	342.89
F_2 : 10 t ha^{-1} FYM	7.69	7.67	0.20	0.22	0.44	0.46	180.26	187.32	18.47	20.06	358.08	365.22
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	1.59	1.76	0.16	0.24	1.90	1.79
CD 5%	0.03	0.02	0.02	0.02	0.04	0.04	4.78	5.29	0.48	0.73	5.69	5.36
Interaction N*F												
SEm±	0.01	0.01	0.01	0.01	0.03	0.03	3.19	3.53	0.32	0.48	3.80	3.58
CD 5%	NS	NS	NS	NS	NS	NS	9.56	10.58	0.96	1.45	11.38	10.72
Initial value	**7.70**		**0.15**		**0.62**		**175.62**		**19.26**		**360.08**	

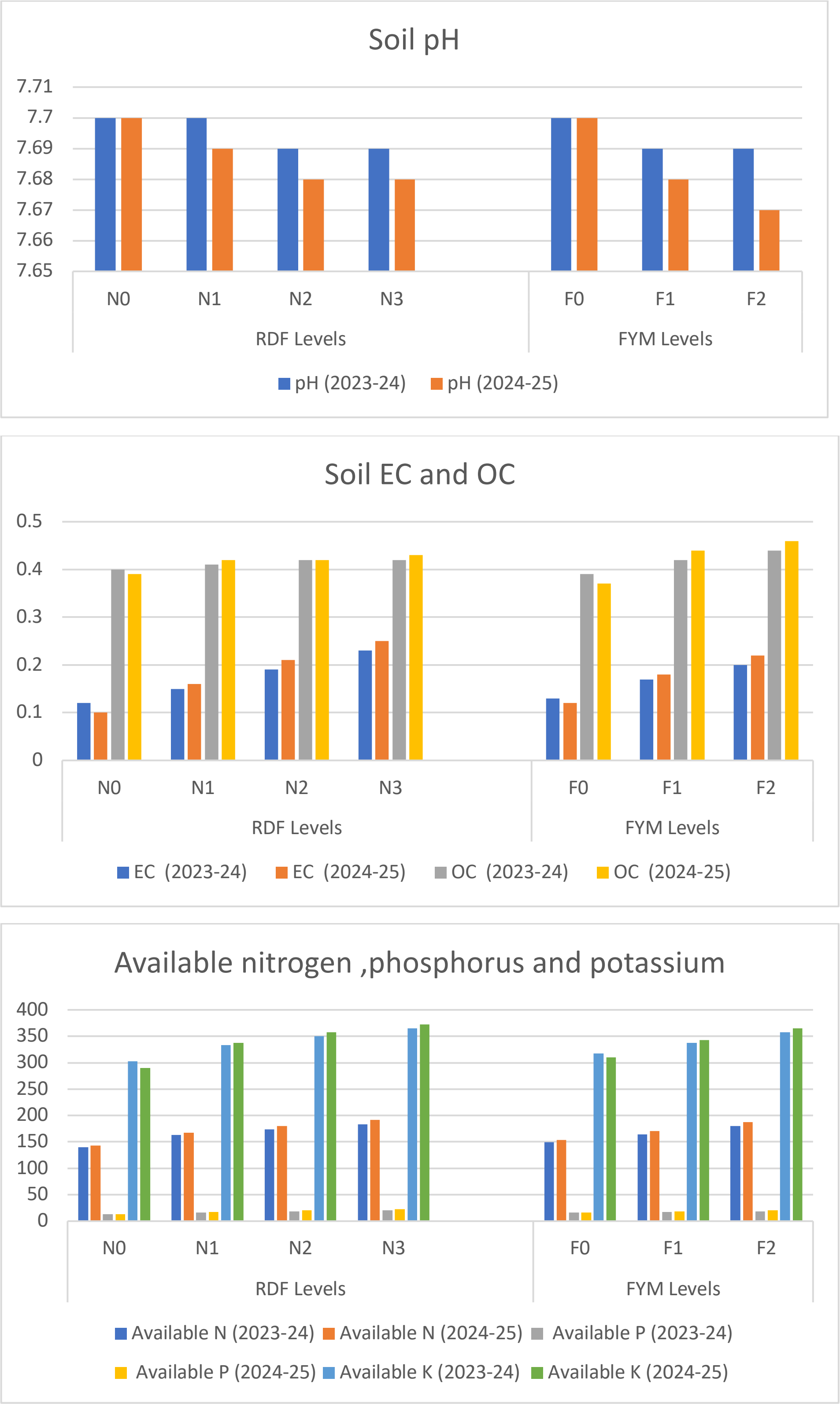


Fig. 16. Chemical properties of soil at harvest of chickpea as impacted by residual effect of varying treatments

Table 38 (a): Combined effect of leftover RDF and FYM on available nitrogen, phosphorus and potassium (kg ha^{-1}) at harvest of chickpea during 2023-24 and 2024-25

Available nitrogen (kg ha^{-1}) (2023-24)					Available nitrogen (kg ha^{-1})(2024-25)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	131.42	135.17	151.82	139.47	**N_0**	134.14	139.20	156.37	143.24
N_1	142.34	162.72	183.61	162.89	**N_1**	145.07	167.38	190.22	167.56
N_2	155.91	175.29	191.14	174.11	**N_2**	159.59	183.08	198.23	180.30
N_3	169.65	185.93	194.47	183.35	**N_3**	177.01	194.75	204.46	192.07
Mean	149.83	164.78	180.26		**Mean**	153.95	171.10	187.32	
SEm±	3.19				**SEm±**	3.53			
CD 5%	9.56				**CD 5%**	10.58			
Available phosphorus (kg ha^{-1}) (2023-24)					**Available phosphorus (kg ha^{-1}) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	13.19	13.51	14.20	13.63	**N_0**	11.24	12.55	14.46	12.75
N_1	15.71	16.22	18.16	16.70	**N_1**	14.55	17.02	20.35	17.31
N_2	16.83	18.70	20.15	18.56	**N_2**	17.47	20.56	22.16	20.07
N_3	18.99	20.59	21.38	20.32	**N_3**	20.68	22.78	23.27	22.24
Mean	16.18	17.25	18.47		**Mean**	15.98	18.23	20.06	
SEm±	0.32				**SEm±**	0.48			
CD 5%	0.96				**CD 5%**	1.45			
Available potassium (kg ha^{-1}) (2023-24)					**Available potassium (kg ha^{-1}) (2024-25)**				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	291.58	297.01	320.15	302.91	**N_0**	266.83	288.76	314.06	289.88
N_1	307.27	334.03	358.55	333.28	**N_1**	296.71	344.05	371.47	337.41
N_2	327.24	348.84	373.47	349.85	**N_2**	330.05	358.76	385.45	358.09
N_3	344.98	368.92	380.16	364.69	**N_3**	348.66	379.97	389.88	372.84
Mean	317.77	337.20	358.08		**Mean**	310.56	342.89	365.22	
SEm±	3.80				**SEm±**	3.58			
CD 5%	11.38				**CD 5%**	10.72			

4.2.3.2.5 Available phosphorus (kg ha^{-1})

Soil available phosphorus after harvesting of chickpea recorded under residual effect of various treatments and their combinations is presented in Table 38, 38 (a) and figure 16.

Residual effect of RDF levels

Application of RDF to prior maize significantly increased the soil available phosphorus after chickpea harvest across the two years of research. The available phosphorus increased with higher RDF levels applied to preceding maize. The highest available phosphorus (20.32 and 22.24 kg ha^{-1}) noted in 100% RDF (N_3), showing superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) in first season and similar to 75 % RDF (N_2) in second season. The lowest available phosphorus was registered in the control (N_0).

Increase in phosphorus (P) levels was observed in treatments receiving higher doses of NPK fertilizers. The plots treated with balanced amounts of inorganic fertilizers were able to sustain a consistent level of available soil available phosphorus. The accumulation of available phosphorus in these plots, despite receiving only synthetic inputs, may be due to the plant uptake is lower than quantity of phosphorus applied externally (Pathak *et al*., 2005). Comparable results was observed by Rathore *et al.,* (2014), Lakum *et al.,* (2020), Prajakta *et al.,* (2021) and Thakur *et al.,* (2023).

Residual effect of FYM levels

FYM incorporation to prior corn markedly enhanced soil available P after chickpea harvest throughout the two study years. Available phosphorus increased with residual effect of raising FYM levels. The highest available P (18.47 and 20.06 kg ha^{-1}) registered in residual effect of 10 t ha^{-1} FYM (F_2), showing statistical superiority over control (F_0), and 5 t FYM ha^{-1} (F_1) across both study years. The lowest available phosphorus registered in the control (N_0).

The significantly higher available P_2O_5 after harvesting of chickpea could be attributed to reduced nutrient losses, as FYM releases nutrients gradually, ensuring their steady availability to plants. Moreover, the production of organic acids during the microbial breakdown of organic manure can improve the native phosphates solubility, which, in turn, boosts the available phosphorus pool in the soil (Chauhan *et al.,* 2024).

These results are similar with Nagar *et al.,* (2016), Bhuva and Detroja (2018) and Chauhan *et al.,* (2024).

Interaction effect

The interaction of leftover impact of various RDF and FYM showed considerable significance across the two years of research. The highest available phosphorus (21.38 and 23.27 kg ha^{-1}) noted in residual effect of 100 % RDF + 10 t ha^{-1} FYM (N_3F_2) across both study years. The N_3F_2 combination is similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) in first season. In the next season, N_3F_2 is similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2). Similar results was registered by Sinha (2017).

4.2.3.2.6 Available potassium (kg ha^{-1})

Soil available potassium after harvesting of chickpea noted in various treatments and their combinations is shown in Table 38, 38 (a) and figure 16.

Residual effect of RDF levels

Application of RDF to prior maize significantly increased soil available potassium after chickpea harvest of chickpea across both study years. Available potassium increased with increasing RDF levels applied to preceding maize. The highest available potassium (364.69 and 372.84 kg ha^{-1}) registered in residual effect of 100% RDF (N_3), showed considerable superiority than control (N_0), 50% (N_1), and 75% RDF (N_2) across the two years of research. Lowest available potassium was registered in the control (N_0).

Lower fertilizer levels in the control, residual 50%, and 75% RDF treatments led to a decline in available potassium (K) compared to the initial soil values. This reduction is likely due to crop uptake not being adequately replenished by fertilizer potassium, resulting in decreased extractable potassium and the mining of less accessible potassium reserves (Sathish *et al*., 2016). However, in the 100% RDF treatment, available K showed an increase, likely due to sufficient potassium application meeting or exceeding crop demand, thereby enhancing soil potassium availability. Similar results was registered by Rathore *et al.,* (2014), Lakum *et al.,* (2020), Prajakta *et al.,* (2021) and Thakur *et al.,* (2023).

Residual effect of FYM levels

Incorporation of FYM to preceding maize significantly increased the soil available K throughout the two study years. Soil available potassium increased with residual effect of higher FYM levels. The highest available potassium (358.08 and 365.22 kg ha^{-1}) noted in residual effect of 10 t ha^{-1} FYM (F_2), showed statistical superiority than control (F_0), and 5 t FYM ha^{-1} (F_1) across both study years. Control (N_0) recorded least available K.

Organic manures incorporation increase in available potassium in the soil, which can be ascribed to the dissolution effect of organic acids released during FYM breakdown and its enhanced ability to retain potassium in an accessible form over longer period (Vidyavathi *et al.,* 2011). Additionally, the incorporation of organic matter releases organic acids during decomposition, which facilitates the mineralization of fixed potassium, thereby enhancing its availability in the soil (Nagar *et al.,* 2016). These findings are comparable with Nagar *et al.,* (2016), Bhuva and Detroja (2018), Lakum *et al.,* (2020) and Chauhan *et al.,* (2024).

Interaction effect

Combination of various doses of RDF and FYM applied to preceding showed notable significance across the two years of research. The highest available potassium (380.16 and 389.88 kg ha^{-1}) noted in residual effect of 100 % RDF + 10 t ha^{-1} FYM (N_3F_2), showing similarity with 100% RDF + 5 t ha^{-1} FYM (N_3F_1), and 75% RDF + 10 t ha^{-1} FYM (N_2F_2) across the two years of research. These findings are similar with Sinha (2017).

4.2.3.3 Microbial properties of soil

4.2.3.3.1 Bacterial count (cfu × 10^6 g^{-1} soil)

The count of bacteria after harvesting of chickpea recorded under various treatments applied to preceding maize and their combinations depicted in Table 39.

Residual effect of RDF levels

The carryover impact of RDF significantly influenced the bacterial population in soil across the two years of research. The bacterial population increased with higher levels of RDF applied to preceding maize. The highest bacterial population (19.09 and 21.53 × 10^6 cfu g^{-1} soil) noted in residual effect of 100% RDF (N_3), showing significant superiority than control (N_0), 50% RDF (N_1), and found similar to 75% RDF (N_2) across the two years of research. The lowest bacterial population in soil was found in the control (N_0).

Legumes can return a portion of the unused nitrate generated during symbiotic nitrogen fixation to the soil. Furthermore, they release a variety of low molecular weight organic compounds via root exudates, which act as a food source for microorganisms. These exudates specifically promote the growth of bacterial populations, leading to a general increase in microbial activity and abundance within the soil (Ananda, 2009). The present investigation aligns with Borah *et al.,* (2023).

Residual effect of FYM levels

FYM incorporation to preceding maize significantly increased the bacterial population throughout the two study years. The bacterial population increased with carryover impact of FYM given to maize. Highest bacterial population (20.07 and 23.52 × 10^6 cfu g^{-1} soil) was noted in 10 t FYM ha^{-1} (F_2), which showed statistical superiority than control (F_0), and 5 t ha^{-1} FYM (F_1) across two seasons of research. Least bacterial population registered in the control (N_0).

The leftover impact of FYM resulted in the maximum bacterial population, probably because the rich organic matter gave soil bacteria plenty of nutrients and a good environment to grow and thrive (Mairan and Dhawan 2016). These findings are consistent with Nagar *et al.,* (2016) and Borah *et al.,* (2023).

Interaction effect

The combination of residual impact of various levels of RDF and FYM showed non significance effect across the two years of research.

4.2.3.3.2 Fungal count (cfu × 10^4 g^{-1} soil)

The fungal count recorded under residual impact of varying treatments and their combinations illustrated in Table 39.

Residual effect of RDF levels

The carryover impact of RDF significantly influenced the fungal count after chickpea harvest across the two years of research. Fungal count increased with increasing levels of RDF applied to preceding maize. The highest fungal count (10.15 and 10.87 × 10^4 cfu g^{-1} soil) noted under residual effect of 100% RDF (N_3), showing superiority than control (N_0), 50% RDF (N_1), 75 % RDF (F_2) in first season and similar to 75% RDF (N_2) in next season. Lowest fungal count in soil was recorded in the control (N_0).

The increase in microbial biomass is often linked to improved plant growth, which enhances rhizodeposition-the discharge of organic compounds from roots into the soil. This increased rhizodeposition plays a crucial role in driving changes within the fungal community structure (Dinca *et al.,* 2022). The present investigation aligns with Borah *et al.,* (2023).

Residual effect of FYM levels

FYM incorporation to preceding corn significantly impacted the fungal count throughout the two study years. The fungal count increased with residual effect of raising FYM levels. The highest fungal count (11.23 and 13.10 × 10^4 cfu g^{-1} soil) was noted in 10 t FYM ha^{-1} (F_2), which was statistically superior than control (F_0), and 5 t ha^{-1} FYM (F_1) across the two years of research. Control (N_0) noted lowest fungal count.

Among the various organic sources, FYM exhibited superior performance in promoting fungal growth. This was mainly because the well-decomposed organic matter in FYM provided an ideal food source for fungi, helping them grow and multiply more effectively (Mairan and Dhawan 2016). The present investigation aligns with Nagar *et al.,* (2016) and Borah *et al.,* (2023).

Interaction effect

The combination of residual effect of various levels of RDF and FYM showed insignificant effect across the two years of research.

4.2.3.3.3 Actinomycetes count (cfu × 10^5 g^{-1} soil)

The count of actinomycetes after harvesting of chickpea recorded under residual effect of various treatments and their combinations depicted in Table 39.

Residual effect of RDF levels

Carryover impact of RDF significantly influenced the actinomycetes count after harvesting of chickpea in soil across both study years. Highest actinomycetes count (12.54 and 13.67 × 10^5 cfu g^{-1} soil) noted in residual effect of 100% RDF (N_3), showed superiority than control (N_0), 50% RDF (N_1) and found at par with 75% RDF (N_2) across the two years of research. The lowest actinomycetes count in soil was found in the control (N_0).

Nitrogen (N) and phosphorus (P) given to preceding corn stimulated growth and reproduction of soil microorganisms. With more nutrients available, plant root activity also increased, leading to greater root growth. This, in turn, provided more surface area in the soil for microorganisms to colonize. Additionally, legumes cultivation supported a higher microbial population than cereals, mainly because legumes help restore soil health and maintain its long-term productivity through nitrogen fixation and better organic matter (Ananda, 2009). The present investigation aligns with Borah *et al.,* (2023).

Residual effect of FYM levels

FYM incorporation to preceding corn significantly increased the actinomycetes count throughout the two study years. Actinomycetes count increased with higher levels of FYM applied to preceding maize. The highest actinomycetes count (14.26 and 16.10 $\times 10^5$ cfu g^{-1} soil) noted in carryover impact of 10 t FYM ha^{-1} (F_2), showing superiority to control (F_0), and 5 t FYM ha^{-1} (F_1) across the two years of research. Lowest actinomycetes count was recorded in the control (N_0).

Organic manures enhance soil structure by improving the distribution of particle sizes and contribute to a more consistent and balanced supply of nutrients. This steady nutrient availability supports a richer and more diverse microbial community. Additionally, incorporation of organic amendments is known to increase microbial activity, raise soil organic matter levels, and enhance physico-chemical soil characteristics (Dinca *et al.,* 2022). The present investigation aligns with Nagar *et al.,* (2016) and Borah *et al.,* (2023).

Interaction effect

The combined influence of different RDF and FYM levels given to preceding maize didn't show any statistically significant impact over the two years of the study

Table 39: Residual effect of integrated nutrient management on microbial properties of soil at chickpea harvest during 2023-24 and 2024-25

Treatments	Microbial properties of soil					
	Bacteria (cfu × 10^6 g^{-1} soil)		Fungi (cfu × 10^4 g^{-1} soil)		Actinomycetes (cfu × 10^5 g^{-1} soil)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Nutrient management levels						
N_0 : Control	16.96	15.82	8.13	8.05	10.63	10.09
N_1 : 50 % RDF	17.31	18.45	8.79	9.51	11.28	11.61
N_2 : 75 % RDF	18.12	20.28	9.32	9.94	11.80	13.05
N_3 : 100 % RDF	19.09	21.53	10.15	10.87	12.54	13.67
SEm ±	0.47	0.61	0.18	0.32	0.25	0.52
CD 5%	1.64	2.10	0.64	1.12	0.86	1.79
FYM levels						
F_0 : Control	15.61	14.35	7.07	6.22	8.58	7.94
F_1 : 5 t ha^{-1} FYM	17.95	19.20	8.99	9.46	11.84	12.27
F_2 : 10 t ha^{-1} FYM	20.07	23.52	11.23	13.10	14.26	16.10
SEm ±	0.41	0.80	0.22	0.31	0.21	0.38
CD 5%	1.23	2.41	0.64	0.92	0.62	1.15
Interaction N*F						
SEm±	0.82	1.61	0.43	0.61	0.42	0.77
CD 5%	NS	NS	NS	NS	NS	NS
Initial value	**18**		**7**		**11**	

4.3 Economics of maize-chickpea cropping system

4.3.1 Cost of cultivation (₹ ha^{-1})

In agriculture or any business, the main goal is usually to reduce input costs in order to increase profit margins. However, not all farming practices can be evaluated solely based on profit. Some cultivation methods may not show immediate financial returns but offer important indirect benefits like improving soil health, sustainability, or crop resilience which can be more valuable in the long term than direct economic gains. The cost of cultivation of maize-chickpea cropping system noted in varying treatments is illustrated in Table 40.

Effect of RDF levels

Lowest cost of cultivation (99599, 103100 and 101350 Rs. ha^{-1} respectively) registered in control (N_0) across the two years of research and on pooled basis. Highest cost of cultivation (108422, 112293 and 110358 ₹ ha^{-1} respectively) was registered with the 100 % RDF (N_3) across two seasons of research and on pooled basis.

An increase in RDF levels led to a gradual escalation in the cost of cultivation. This primarily attributed to the greater quantity of fertilizers required at higher RDF levels, thereby elevating input costs. Fertilizer application constituted a significant share of the total expenditure, directly influencing the overall cost. Thus, managing nutrients through recommended dose of fertilizers (RDF) plays a key role in shaping the overall economic returns from the maize-chickpea cropping system. Above findings are similar with Chauhan (2010) and Dubey *et al.,* (2022).

Effect of FYM levels

Lowest cost of cultivation (94099, 97809 and 95954 ₹ ha^{-1}) registered in control (F_0) across the two years of research and on pooled basis. Highest cost of cultivation (115299, 119009 and 117154 ₹ ha^{-1} respectively) registered in the 10 t ha^{-1} FYM (F_2) across the two years of research and on pooled basis.

Increasing application rate of farmyard manure (FYM) raises cultivation costs, as more FYM is required per hectare, leading to greater input expenditure. Thus, the use of FYM for nutrient management significantly influences the economic investment required in the maize–chickpea cropping system. Similar findings are observed by Chauhan (2010) Rathore *et al.,* (2014) and Rangaswamy *et al.,* (2023).

4.3.2 Gross returns (₹ ha^{-1})

Gross returns generated from maize–chickpea cropping system under various treatments and their combinations is shown in Table 40 and 40 (a).

Effect of RDF levels

The recommended dose of fertilizers (RDF) notably impacted the gross returns of maize-chickpea rotation across two years of research and on pooled basis. Highest gross returns (249971, 277518 and 263745 ₹ ha^{-1} respectively) was registered with the 100 % RDF (N_3), showed marked superiority than control (N_0), 50 % (N_1) and 75% RDF (N_2) across the two years of research and on pooled basis. The lowest gross return of maize-chickpea cropping system (155849, 144628 and 150239 ₹ ha^{-1} respectively) was registered with the control (N_0) across the two years of research and on pooled basis. Similar findings was noted by Nawle *et al.,* (2009), Rajkumara *et al.,* (2012), Jinjala *et al.,* (2016), Hiremath *et al.,* (2016), Iqbal *et al.,* (2020) and Dubey *et al.,* (2022).

Effect of FYM levels

The application of FYM notably influenced the gross return of maize-chickpea cropping system across the two years of research and on pooled basis. The highest gross returns (220750, 240864 and 230807 ₹ ha^{-1}) noted in 10 t FYM ha^{-1} (F_2), showed superiority than control (F_0) and 5 t ha^{-1} FYM (F_1) across the two years of research and on pooled basis. Lowest gross returns of maize-chickpea cropping system (190325, 195096 and 192710 ₹ ha^{-1} respectively) was registered with the control (F_0) across the two years of research and on pooled basis. Similar results were observed by Chauhan (2010), Bhuva and Detroja (2018) and Rangaswamy *et al.,* (2023).

Interaction effect

The interaction of various levels of RDF and FYM was found significant across the two years of research and on pooled basis. Highest gross returns (263020, 291559 and 277289 ₹ ha^{-1}) registered in 100 % RDF + 10 t ha^{-1} FYM (N_3F_2), showed considerable superiority than all the treatment combinations in first year and on pooled basis and similar to 100% RDF + 5 t ha^{-1} FYM (N_3F_1) during second year. The present results are supported by Gudadhe *et al.,* (2011), Rajkumara *et al.,* (2012) and Ravi *et al.,* (2012).

4.3.3 Net returns (₹ ha^{-1})

The net returns from the maize–chickpea cropping system, as impacted by varying treatments and their combinations illustrated in Table 40 and 40 (a).

Effect of RDF levels

The recommended dose of fertilizers (RDF) notably impacted the net returns of maize-chickpea cropping system across the two years of research and on pooled basis. The maximum net returns (141550, 165225 and 153387 ₹ ha^{-1} respectively) registered with the 100 % RDF (N_3), showing considerable superiority than control (N_0), 50 % (N_1) and 75% RDF (N_2) across the two years of research and on pooled basis. The lowest net returns of maize-chickpea cropping system (56250, 41528 and 48889 ₹ ha^{-1} respectively) was registered with the control (N_0) across the two years of research and on pooled basis. Similar results noted by Nawle *et al.,* (2009), Rajkumara *et al.,* (2012), Jinjala *et al.,* (2016), Hiremath *et al.,* (2016), Jat and Praharaj (2018) and Dubey *et al.,* (2022).

Effect of FYM levels

The FYM incorporation markedly influenced the net returns of maize-chickpea cropping system across the two years of research and on pooled basis. Highest net returns (105451, 121856 and 113653 ₹ ha^{-1}) noted in 10 t FYM ha^{-1} (F_2), showed notable superiority than control (F_0) and 5 t ha^{-1} FYM (F_1) across two study years and on pooled basis. Least net returns of maize-chickpea cropping system (96226, 97287 and 96757 ₹ ha^{-1} respectively) was registered with the control (F_0) across the two years of research and pooled basis. The present results are supported by Chauhan (2010), Bana *et al.,* (2016), Bhuva and Detroja (2018), Jat and Praharaj (2018), Singh *et al.,* (2019) and Rangaswamy *et al.,* (2023).

Interaction effect

Combination of various levels of RDF and FYM showed considerable effect across the two years of research and on pooled basis. Highest net returns (145777, 172721 and 159249 ₹ ha^{-1}) recorded in the 100 % RDF + 5 t ha^{-1} FYM (N_3F_1), showing similarity to 100% RDF + 10 t ha^{-1} FYM (N_3F_2) across the two years of research and on pooled basis. These findings are supported by Kumar *et al.,* (2005), Gudadhe *et al.,* (2011), Ravi *et al.,* (2012), Senthilvalavan and Ravichandran (2016) and Sonboir *et al.,* (2020).

4.3.4 Benefit : cost ratio

The B:C ratio of maize-chickpea rotation recorded in varying treatments is shown in Table 40.

Effect of RDF levels

The RDF increased B:C ratio of maize-chickpea rotation across two years of research and on pooled basis. Highest B:C ratio (2.31, 2.47 and 2.39) noted in 100 % RDF (N_3) across the two years of research of investigation and on pooled basis. Control (N_0) noted lowest B:C ratio across both study years.

The improvement can be attributed to the balanced nutrient supply provided by 100% RDF, which increases yield of maize- chickpea cropping system. The consistent increase in the B:C ratio over two years demonstrates the economic efficiency of applying 100% RDF, as it maximized returns relative to costs. Lower levels of RDF may have resulted in suboptimal nutrient availability, thereby reducing yields and economic benefits. Similar results found by Nawle *et al.,* (2009), Rajkumara *et al.,* (2012), Jinjala *et al.,* (2016), Hiremath *et al.,* (2016), Jat and Praharaj (2018), Iqbal *et al.,* (2020) and Dubey *et al.,* (2022).

Effect of FYM levels

Highest B:C ratio (2.02 and 2.01) noted in control (F_0) during first year and on pooled basis and in second year highest B:C ratio (2.04) registered in 5 t FYM ha^{-1} (F_1). Least B:C ratio recorded in 10 t ha^{-1} FYM (F_2) in first year and under the control (F_0) in second year.

The higher economic returns under the control in the first year may be attributed to the lower input cost, as the cost of FYM application was avoided. Additionally, the benefits of FYM are generally realized over the long term, and its effect on crop productivity may not be immediate. In contrast, the improved performance of 5 t FYM ha^{-1} in second year suggests a residual or cumulative effect of organic matter on soil health and crop response. Lowest B:C ratio noted in 10 t FYM ha^{-1} (F_2) in the first year, likely due to higher input costs not offset by proportional yield gains. In the second year, however, lowest B:C ratio was recorded under the control, indicating the positive influence of FYM over time in enhancing economic returns. The present results are supported by Bhuva and Detroja (2018) and Jat and Praharaj (2018).

Table 40: Effect of integrated nutrient management on economics of maize-chickpea cropping system during 2023-24 and 2024-25

Treatments	Cost of Cultivation (₹ ha^{-1})			Gross returns (₹ ha^{-1})			Net returns (₹ ha^{-1})			B:C		
	2023-24	**2024-25**	**Pooled**	**2023-24**	**2024-25**	**Pooled**	**2023-24**	**2024-25**	**Pooled**	**2023-24**	**2024-25**	**Pooled**
Nutrient management levels												
N_0 : Control	99599	103100	101350	155849	144628	150239	56250	41528	48889	1.56	1.40	1.48
N_1 : 50 % RDF	104911	108597	106754	192978	203831	198405	88068	95234	91651	1.84	1.88	1.86
N_2 : 75 % RDF	106665	110444	108554	223980	251262	237621	117316	140819	129067	2.10	2.28	2.19
N_3 : 100 % RDF	108422	112293	110358	249971	277518	263745	141550	165225	153387	2.31	2.47	2.39
SEm ±	-	-	-	1791	3760	2082	1791	3760	2082	-	-	-
CD 5%	-	-	-	6199	13011	6416	6199	13011	6416	-	-	-
FYM levels												
F_0 : Control	94099	97809	95954	190325	195096	192710	96226	97287	96757	2.02	1.99	2.01
F_1 : 5 t ha^{-1} FYM	105299	109009	107154	206009	221970	213990	100710	112962	106836	1.96	2.04	2.00
F_2 : 10 t ha^{-1} FYM	115299	119009	117154	220750	240864	230807	105451	121856	113653	1.91	2.02	1.97
SEm ±	-	-	-	1120	1732	1031	1120	1732	1031	-	-	-
CD 5%	-	-	-	3357	5193	2971	3357	5193	2971	-	-	-
Interaction N*F												
SEm±	-	-	-	2239	3464	2063	2239	3464	2063	-	-	-
CD 5%	-	-	-	6713	10386	5942	6713	10386	5942	-	-	-

Table 40 (a): Combined impact of RDF and FYM on gross return and net returns of maize-chickpea cropping system during 2023-24 and 2024-25

Gross returns (₹ ha^{-1}) (2023-24)					Gross returns (₹. ha^{-1}) (2024-25)					Gross returns (₹ ha^{-1}) (Pooled)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	139335	157594	170617	155849	**N_0**	125922	146695	161268	144628	**N_0**	132629	152145	165943	150239
N_1	185559	191052	202324	192978	**N_1**	173073	208552	229869	203831	**N_1**	179316	199802	216096	198405
N_2	204112	220791	247038	223980	**N_2**	225806	247220	280761	251262	**N_2**	214959	234005	263900	237621
N_3	232295	254599	263020	249971	**N_3**	255582	285414	291559	277518	**N_3**	243938	270006	277289	263745
Mean	190325	206009	220750		**Mean**	195096	221970	240864		**Mean**	19271	213990	230807	
SEm±	2239				**SEm±**	3464				**SEm±**	2063			
CD 5%	6713				**CD 5%**	10386				**CD 5%**	5942			

Net returns (₹ ha^{-1}) (2023-24)					Net returns (₹ ha^{-1}) (2024-25)					Net returns (₹ ha^{-1}) (Pooled)				
Interaction N*F	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**	**Interaction N*F**	**F_0**	**F_1**	**F_2**	**Mean**
N_0	50536	57595	60618	56250	**N_0**	33622	43195	47767	41528	**N_0**	42079	50395	54193	48889
N_1	91448	85742	87013	88068	**N_1**	75276	99555	110872	95234	**N_1**	83362	92648	98943	91651
N_2	108247	113726	129974	117316	**N_2**	126162	136376	159918	140819	**N_2**	117205	125051	144946	129067
N_3	134673	145777	144198	141550	**N_3**	154088	172721	168865	165225	**N_3**	144381	159249	156532	153387
Mean	96226	100710	105451		**Mean**	97287	112962	121856		**Mean**	96757	106836	113653	
SEm±	2239				**SEm±**	3464				**SEm±**	2063			
CD 5%	6713				**CD 5%**	10386				**CD 5%**	5942			

CHAPTER V

SUMMARY AND CONCLUSION

The current field study was performed at Agronomy Research Farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab (India), during the *kharif* and *rabi* 2023-24 and 2024-25 to evaluate the "Response of maize to integrated nutrient management and its residual effect on the succeeding chickpea in maize-chickpea cropping system in central plain zone of Punjab". The study aimed to assess the growth and yield performance of maize and its residual effects on the subsequent chickpea crop. The soil at the testing site had a sandy loam composition, was deficient in available N, moderate in P content, and exceptionally rich in K, with a pH slightly on the alkaline side.

The trial was arranged using a split-plot design and replicated three times. The main plots contain four levels of nutrient management viz., N_0- Control, N_1- 50 % RDF, N_2- 75% RDF and N_3- 100% RDF and the sub-plots consisted of three levels of farmyard manure (FYM) viz., F_0- Control, F_1- 5 t ha^{-1} FYM and F_2- 10 t ha^{-1} FYM applied to *kharif* maize resulting in total twelve treatment combinations. To check the residual impact of INM, a chickpea was sown subsequently in all plots, receiving 50% RDF. The trial was conducted at the same experimental site, maintaining identical randomization and treatment allocation across both years.

Data were collected on morphology, yield traits, yield, nutrient composition and its intake, and soil properties for maize. In the case of chickpea, observations mainly focused on yield attributes, productivity, nutrient absorption, and soil status after harvest. In addition, quality attributes were recorded only for maize. The cropping sequence of maize-chickpea was also evaluated using monetary returns, and benefit-cost ratio. The principal findings from this investigation are summarized as follows.

5.1 Performance of *kharif* maize

5.1.1 Effect of RDF levels on *kharif* maize

Plant count at establishment and harvest of maize not notably affected by the RDF levels across both study years.

Morphological traits, including height, leaf count, stem girth, leaf area, LAI, DMA, and chlorophyll index, was considerably impacted by the varying treatments of RDF. The 100% RDF resulted in the highest values for all growth parameters across all growth stages. Specifically, the highest height, LA, LAI, and DMA noted in 100% RDF, showing superiority to varying treatments over both years. Maximum leaf count was observed under 100% RDF across both years at all growth stages, showing superiority over other RDF levels at 60 and 90 DAS in the second year, and being comparable with 75% RDF at 90 DAS in the first year. Similarly, maximum stem girth was observed under 100% RDF during both years across all growth stages. It was comparable with 75% RDF at 60 DAS across two study years and superior than other RDF levels at 90 DAS in the first year, while being comparable with 75% RDF at 90 DAS in the second year. Maximum chlorophyll index noted in 100% RDF, showing similarity to 75% RDF at 60 DAS during both years, but superior to all other RDF levels at 90 DAS in the first year, and comparable with 75% RDF at 90 DAS in next season.

The application of RDF notably impacted various yield-attributing traits in maize across both years. These traits included cobs count, cob weight (g/plant) and length (cm), grain rows, grains per row, total grains, and 100-grain weight (g). The application of 100% RDF resulted in the highest cobs count, cob weight (g/plant), grains per row, and total grains per cob was found to be statistically superior to the other RDF levels during both years. The highest length of cob (cm), grain rows per cob and seed index was recorded under 100% RDF and found statistically better over other RDF levels during first year and it was comparable with 75 %RDF during second year.

Overall, 100% RDF noted the highest grain, stover, biological output, and HI across both study years and in the pooled analysis. Grain and biological output notably higher under 100% RDF and were superior to other RDF levels. Stover output and HI were also markedly superior under 100% RDF in the first season and in the pooled findings; however, they similar to 75% RDF in the second season. Shelling percentage was found highest under 100 % RDF and it was superior to other RDF levels during first year and shows similarity with 75 % RDF during second year.

The application of 100% RDF resulted in significantly highest protein percentage in maize grain (%), crude protein output (kg ha^{-1}), moisture content (%), and ash percentage (%) across both study years. Highest protein percentage (%) in 100% RDF was statistically superior to all other RDF levels in the first year, while it showed similarity with 75% RDF in the second year. Crude protein yield was also maximized under 100% RDF and showing superiority to varying RDF levels across two study years. Similarly, the highest moisture content in grains was noted in 100% RDF, showing similarity to 75% RDF in both years. Ash content in grains was also highest under 100% RDF, being significantly superior to other RDF levels in first year and statistically similar with 75% RDF in second year.

The nitrogen, phosphorus, and potassium content in grains and stover (%) was considerably impacted by the RDF doses. The application of 100% RDF noted the highest nitrogen percent in grains, showing better performance than other RDF levels in the first year and statistically at par with 75% RDF in the second year. The nitrogen content in stover was also maximized under 100% RDF and remained markedly greater to all other RDF levels across both study years. Similarly, phosphorus and potassium content in both grains and stover were considerably higher under 100% RDF, showing consistent superiority over other RDF levels across both study years.

The highest intake of N, P, and K (grains, stover, and total) was also noted under 100% RDF. Nitrogen and phosphorus uptake under this treatment was considerably higher than other RDF levels across both years. P intake by grains and overall uptake were markedly greater to other RDF levels, while potassium uptake by stover was significantly higher under 100% RDF during the first year and statistically similar to 75% RDF during the next season.

The soil physical properties not markedly affected by the RDF levels across both study years. However, soil pH, EC, OC, and available N, P, and K were notably impacted by applied RDF levels. Lowest soil pH and the highest EC and OC were observed under 100% RDF in both years. Additionally, the 100% RDF noted the highest available N, P, and K at maize harvest, exhibiting significant superiority than varying RDF rates across both study years. The microbial properties viz., actinomycetes, bacterial and fungal count of soil was significantly impacted by application of RDF levels. Highest actinomycetes count was found in 100% RDF, which shows considerable superiority over other RDF levels during first season and similar to 75% RDF during next season. Similarly, highest bacterial and fungal count was recorded under 100% RDF across both study years and similar to 75% RDF.

5.1.2 Effect of FYM levels on *kharif* maize

Plant count at establishment and harvest of maize showed insignificance by varying FYM scales across both study years.

The morphological traits such as plant height (cm), number of leaves, stem girth, leaf area (cm^2), leaf area index, dry matter accumulation (g), and chlorophyll index were significantly affected by the varying FYM doses. 10 t ha^{-1} FYM consistently noted the maximum values for all these traits at varying morphometric phases and was found superior to the other FYM levels across both years.

The application of FYM notably enhanced major yield-contributing traits of maize during both years. Parameters such as cobs count and its weight, length, grains count per row, total grains, and seed index were all positively influenced. Greater results for these features registered in 10 t ha^{-1} FYM, which was statistically superior to other FYM levels in both years. Specifically, the maximum grain rows was observed under 10 t FYM, showing considerable improvement over other FYM levels in the first year, and similar to 5 t FYM in the next season.

Incorporation of 10 t ha^{-1} FYM noted highest grain, stover, biological output, and HI across both study years also in the pooled evaluation. Grain, stover, and biological output under 10 t FYM were especially greater to varying FYM levels. Harvest index was also notably higher under 10 t ha^{-1} FYM at first season, while in next season and pooled analysis, it remained statistically similar with 5 t FYM. Additionally, greater shelling efficiency noted with 10 t FYM, showing clear dominance to other FYM levels.

Incorporation of 10 t FYM resulted in markedly highest protein percentage in grains, crude protein yield, moisture and ash percentage across both study years. Highest protein percentage in grains and crude protein yield under 100% RDF showed statistical superiority to all other FYM levels in the first and second year. Similarly, the highest moisture content in grains noted with 10 t FYM, showing statistical similarity with 5 t FYM in both years. Ash content in grains was also highest under 10 t ha^{-1} FYM, being markedly better over different FYM levels in the first year and statistically at par with 5 t ha^{-1} FYM in the second year.

The N, P, and K content in grains and stover (%) impacted by the incorporation of FYM doses. 10 t ha^{-1} FYM recorded the highest N, P and K content in seed and straw, which markedly better than other FYM levels across both study years. Highest intake of N, P, and K (grains, stover, and total) was also noted in 10 t ha^{-1} FYM. N, P and K intake under this input was markedly better over other FYM levels across both years.

The BD markedly impacted by the FYM inputs in across two study years, whereas particle density and porosity were not significantly affected. The bulk density recorded lowest under 10 t FYM across two study years. However, soil pH, EC, OC, and available N, P, and K was notably impacted by applied FYM levels. Lowest soil pH and the highest EC and OC were observed under 10 t ha^{-1} FYM across two study years. Additionally, incorporation of 10 t ha^{-1} FYM noted the highest available N, P, and K at harvest, exhibiting significant superiority over varying FYM inputs across two study years. The microbial properties viz., actinomycetes, bacterial and fungal count was markedly influenced by incorporating FYM. Highest actinomycetes, bacterial and fungal count noted in 10 t ha^{-1} FYM across two study years, showing significant superiority over other FYM levels.

5.1.3 Combined impact of RDF and FYM on *kharif* maize

The interaction between varying levels of RDF and FYM on morphometric traits such as height, leaf numbers, LA, LAI, DMA, and chlorophyll index was statistically insignificant at 30 DAS but became significant at 60 and 90 DAS across two study years. Similarly, the combined impact on stem girth was insignificant at 60 DAS in first season and showed a notable response in the next season. However, at 90 DAS, stem girth was not markedly influenced by interaction in either year.

The combined effect of different RDF and FYM levels considerably affected yield traits like cobs count, total grains count, and seed index at harvest in both years. On the other hand, traits like cob length, grain rows, and grains per row were not considerably affected by interaction during either year. Cob weight was not significantly affected by the interaction during the first season; however, a significant response was observed in the next season.

Grain, stover, and biological yield markedly influenced by interaction between RDF and FYM levels across two years of study also in combined evaluation. The harvest index, however, was not notably influenced by interaction in either year or in the pooled data. In contrast, shelling percentage exhibited a significant response to the interaction across two study years.

The combined impact RDF and FYM had a statistically impacted the N, P, and K percent and intake by maize across both study years.

The combination between RDF and FYM levels not markedly effects the soil physical properties. Similarly, chemical properties such as soil pH, EC and OC showed insignificance by the mutual application of RDF and FYM. However, the interaction showed significance on soil available N, P, and K. In addition, microbial properties, including actinomycetes, bacterial, and fungal populations, were significantly affected by the interaction between RDF and FYM levels.

5.2 Performance of *Rabi* chickpea

5.2.1 Residual effect of RDF levels

The residual effect of the RDF given to prior maize significantly enhanced yield-attributing traits in chickpea, including the pods count and its weight and seed index (g). The carryover impact of 100% RDF resulted in maximum pods count and its weight, showing significant superiority over other RDF levels during both years. The highest seed index was also recorded under leftover impact of 100% RDF, which similar to 75% RDF in both years.

Seed, haulm, biological yield, and HI was significantly impacted by the leftover impact of RDF. The highest seed yield was recorded under residual effect of 100% RDF, which was notably better over other residual RDF levels during first year and on pooed basis and found at par with residual effect of 75% RDF during the second year. Highest haulm yield was noted by the residual effect of 100% RDF, which was comparable with residual effect of 75% RDF during both years and it shows significant superiority over all residual RDF treatments on pooled basis. Similarly, the biological yield was found maximum under residual effect of 100% RDF, which was superior over other residual RDF levels. The maximum harvest index was also found under residual effect of 100% RDF and it was at par with residual effect of 50%, and 75% RDF across two study years and on combined basis.

The N, P, and K percent in chickpea seed and haulm notably affected by RDF doses given to prior crop. The residual impact of 100% RDF noted the highest nitrogen content, demonstrating significant superiority over the other residual RDF levels during the first year, and showed similarity to leftover impact of 75% RDF in the second year. Likewise, the P percent in seed and haulm was maximized under residual effect of

100% RDF and remained statistically comparable to residual 75% RDF across both years. Similarly, potassium percent in seed and haulm significantly elevated in the residual impact of 100% RDF, consistently outperforming other residual RDF levels in seed potassium content across both years, while being statistically similar to 75% RDF in haulm potassium content during both years.

Highest intake of N, P and K (seed, haulm, and overall) noted under residual effect of 100% RDF. Nitrogen and phosphorus uptake under this treatment was notably better than other residual RDF levels across both years. Potassium uptake by seed were significantly superior to other residual RDF levels, while potassium uptake by haulm and overall intake showing highest results under residual effect of 100% RDF during first year and statistically at par with residual effect of 75% RDF in the following season.

The physical properties of soil not markedly affected by the residual RDF doses across two study years. However, chemical properties such as pH, EC was found non significant across both study years. In contrast, OC, available N, P, and K was considerably impacted by RDF levels applied to preceding maize. The highest OC were observed under residual effect of 100% RDF in both years. Additionally, the application of 100% RDF to preceding maize crop noted maximum available N, P, and K at chickpea harvest, exhibiting significant superiority than other residual RDF levels for available N and K across both years. The available P was highest under residual effect of 100 % RDF during first year and showed similarity to carryover impact of 75 % RDF during second year. The microbial properties of soil such as actinomycetes, bacterial and fungal count was notably impacted by the residual RDF doses. Highest actinomycetes and bacterial count was recorded under leftover impact of 100% RDF, which was comparable to residual 75% RDF during first and second year. Similarly, highest fungal count was recorded under residual effect of 100% RDF across both study seasons; it showing superiority to other residual RDF levels during first year and statistically similar to 75% RDF in next season.

5.2.2 Residual effect of FYM levels

The FYM incorporation to the preceding crop significantly enhanced the yield-attributing traits of chickpea in both years. Traits such as the pods count and its weight, and seed index showed notable improvements. The leftover impact of 10 t ha^{-1} FYM noted the highest pods count and its weight, exhibiting significant superiority over the other FYM levels applied to the previous maize crop across both years. Furthermore, the maximum seed index was noted in residual influence of 10 t ha^{-1} FYM and similar to 5 t ha^{-1} FYM across two study years.

Incorporation of 10 t ha^{-1} FYM to prior crop noted the maximum seed, haulm, biological yield, and HI across two study years and in the pooled evaluation. Seed yield, haulm yield, and biological yield under residual effect of 10 t ha^{-1} FYM were considerably greater to varying residual FYM levels. The harvest index was also notably higher under residual impact of 10 t ha^{-1} FYM, and showed similarity to leftover impact of 5 t ha^{-1} FYM across both study years, while in pooled analysis, it remained statistically superior over other residual FYM levels.

The nitrogen, phosphorus, and potassium content in the seed and haulm of chickpea notably affected by FYM incorporation to the prior maize. The carryover impact of 10 t FYM resulted in the greater nitrogen percent in the seed, which showed superiority to varying residual FYM rates in the first year, but it showed similarity to residual effect of 5 t ha^{-1} FYM in second season. Nitrogen percent in haulm was also highest under leftover impact of 10 t ha^{-1} FYM, showing significant improvement over other residual FYM levels in both years. Maximum phosphorus percent in the seed was noted in residual impact of 10 t ha^{-1} FYM, which was comparable to residual 5 t FYM in both years. In the case of haulm, phosphorus percent was maximized under 10 t FYM given to preceding maize and showed superiority to all other FYM levels. Similarly, the potassium percent in the seed was highest under residual effect of 10 t ha^{-1} FYM, showing marked dominance over varying treatments across two study years. Potassium percent in the haulm was also highest under residual 10 t FYM, exhibiting significant superiority in first season and remaining similar to 5 t ha^{-1} FYM in next season.

Maximum intake of N, P, and K (in seed, haulm, and total) noted under the residual impact of 10 t ha^{-1} FYM. The uptake of these nutrients under this treatment showed superiority to varying residual FYM rates across two study years.

BD markedly impacted by the residual FYM rates across two study years, whereas particle density and porosity were not significantly affected. The bulk density recorded lowest under residual effect of 10 t FYM across two study years. However, chemical properties such as pH, EC, OC, and available N, P, and K markedly influenced by applied FYM levels to preceding maize. The lowest soil pH and the highest EC and OC were observed under leftover impact of 10 t FYM across two study years. Furthermore, carryover impact of 10 t FYM led to highest levels of available N, P, and K at the time of harvesting of chickpea, showing significant superiority over the other residual FYM treatments in both years. The microbial properties viz., actinomycetes, bacterial and fungal count of soil markedly impacted by application of FYM to prior crop. Highest actinomycetes, bacterial and fungal count was recorded under residual effect of 10 t FYM across two study years, showing significant superiority over other FYM levels.

5.2.3 Interaction effect of residual RDF and FYM levels on *rabi* chickpea

The interaction between leftover impact of RDF and FYM levels showed considerable results on yield attributes, including pods per count in both years and pod weight in second year at harvest. In contrast, seed index remained unaffected by the interaction across two study years.

The combination between residual impact of RDF and FYM rates exerted a notable influence on seed, haulm, and biological yield of chickpea across two study years and in combined analysis. In contrast, harvest index remained unaffected by the interaction across both seasons and in the combined analysis.

The combination of the carryover effects of RDF and FYM levels was found to be non-significant with respect to nitrogen, phosphorus, and potassium content in chickpea. However, the intake of N, P, and K was notably impacted across both study seasons.

The combination between residual RDF and FYM levels not markedly affected the physical properties of the soil after chickpea harvest. Similarly, chemical properties like soil pH, EC, and OC was not considerably impacted by carryover impact of RDF and FYM. However, the interaction had a notable impact on soil available N, P, and K after harvesting of chickpea. Furthermore, microbial properties, including populations of actinomycetes, bacteria, and fungi, were not considerably impacted by the interaction of residual RDF and FYM levels.

5.3 Economic performance of maize-chickpea cropping system

The highest gross return, net return and B:C ratio of maize-chickpea rotation was found under 100% RDF. The highest gross return and net return was noted under 100% RDF and showed superiority over other RDF levels.

The maximum GR, and NR noted under the 10 t ha^{-1} FYM treatment. Additionally, the GR and NR were also highest in this treatment, showing a significant improvement than varying FYM rates. In first year, the B:C ratio obtained highest in the control, while in the second year, it was highest under the 5 t ha^{-1} FYM treatment.

The combination between RDF and FYM rates markedly impact the gross return and net return across both study years. Highest GR was achieved in 100% RDF + 10 t ha^{-1} FYM in both years. However, this treatment showed superiority to varying combinations in first season, while in second season, it was comparable to 100% RDF + 5 t ha^{-1} FYM. Maximum net return noted with 100% RDF + 5 t ha^{-1} FYM, and showing similarity to 100% RDF + 10 t ha^{-1} FYM across two study years.

5.4 Conclusion

According to the findings of the two-year field experiment, it is evident that increasing rates of RDF and FYM applied to maize markedly enhanced yield, quality, nutrient content, and uptake in both maize and the succeeding chickpea crop. The supply of 100% RDF + 5 t ha^{-1} FYM (N_3F_1) to maize, combined with 50% RDF to chickpea, proved to be the most beneficial practice in terms of profitability, productivity, and the sustainability of soil fertility in maize–chickpea cropping system. This integrated nutrient management approach was found to be promising strategy for improving system performance while maintaining long-term soil health.

Future scope of work

Future research should aim to strengthen nutrient management recommendations for cereal-legume cropping systems through multi-location trials, as the present study was confined to a single site. Additional nutrient sources such as vermicompost, green manures, oil cakes, and industrial by-products may be evaluated alone or with inorganic fertilizers. Alternative crops like lentil, rajmash, and field pea in sequence with maize, and crops such as sorghum, pearl millet, forage maize preceding chickpea, should also be explored for their soil-renovating potential.

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Appendix-I: Price details utilized for estimating the cost of cultivation (₹ ha^{-1}) of *kharif* maize

Sr. No.	Particulars	Amount (₹ ha^{-1})	
		2023-24	**2024-25**
A	**Common cost (₹ ha^{-1})**		
1	Field Preparation		
1.1	Ploughing	2750	3000
1.2	Harrowing	3750	4000
2	Levelling & layout	1800	1800
3	Pre-emergence herbicide + labour charges	-	975
4	Seed	4375	4625
5	Seed treatment	200	200
6	Sowing (Labour charges)	2400	2400
7	Irrigation charges	4500	4500
8	Irrigation charges (Labour charges)	1800	1800
9	Gap filling and thinning	900	900
10	Plant protection	9000	9000
11	Plant protection labour	3600	3600
12	Weeding	7200	7200
13	Harvesting and threshing	6000	6000
14	Miscellaneous costs (Transportation cost etc.)	2500	2700
	Total Cost	50775	52700
B	**Treatment cost**		
1	N0 F0- (0 % RDF + 0 t ha^{-1} FYM)	0	0
2	N0 F1- (0 % RDF + 5 t ha^{-1} FYM)	11200	11200
3	N0 F2- (0 % RDF + 10 t ha^{-1} FYM)	21200	21200
4	N1 F0- (50 % RDF + 0 t ha^{-1} FYM)	5311	5497
5	N1 F1- (50 % RDF + 5 t ha^{-1} FYM)	16511	16697
6	N1 F2- (50 % RDF + 10 t ha^{-1} FYM)	26511	26697
7	N2 F0- (75 % RDF + 0 t ha^{-1} FYM)	7065	7343
8	N2 F1- (75 % RDF + 5 t ha^{-1} FYM)	18265	18543
9	N2 F2- (75 % RDF + 10 t ha^{-1} FYM)	28265	28543
10	N3 F0- (100 % RDF + 0 t ha^{-1} FYM)	8822	9193
11	N3 F1- (100 % RDF + 5 t ha^{-1} FYM)	20022	20393
12	N3 F2- (100 % RDF + 10 t ha^{-1} FYM)	30022	30393

Appendix-II: Price details utilized for estimating the cost of cultivation (₹ ha^{-1}) of *rabi* chickpea

Sr. No.	**Particulars**	**Amount (₹ ha^{-1})**	
		2023-24	**2024-25**
A	**Common cost (₹ ha^{-1})**		
1	Field Preparation (Manual ploughing)	3400	3800
2	Levelling & layout	2100	2100
3	Seed	7200	8400
4	Seed treatment	170	220
5	Sowing (labour charges)	2400	2400
6	Irrigation charges	4500	4500
7	Irrigation charges (labour charges)	1800	1800
8	Gap filling and thinning	600	600
9	Weeding	7200	7200
10	Harvesting and threshing	4800	4800
11	Miscellaneous costs (Transportation cost etc.)	2000	1800
	Total Cost	36170	37620
B	**Treatment cost**		
1	50 % RDF	1854	1980

Appendix-III: Cost details for fertilizers, organic manures, and produce sale

Sr. No.	**Particulars**	**Amount (₹ ha^{-1})**	
		2023-24	**2024-25**
A	**Inputs**		
1	Urea (₹ kg^{-1})	5.38	6
2	SSP (₹ kg^{-1})	9.1	10
3	MOP (₹ kg^{-1})	32.92	31
4	FYM (₹ kg^{-1})	2	2
B	**Selling rate of produce**		
1	Maize grain (₹ q^{-1})	2090	2225
2	Maize stover (₹ q^{-1})	200	200
3	Chickpea seed (₹ q^{-1})	5440	5650
4	Chickpea haulm (₹ q^{-1})	150	150