EFFECT OF INTEGRATED NUTRIENT MANAGEMENT AND AGRONOMIC Zn FORTIFICATION ON GROWTH, YIELD AND QUALITY OF WHEAT (*Triticum aestivum* L.)

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2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled **"Effect of Integrated Nutrient Management and Agronomic Zn fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.)"** in fulfillment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr. Vandna Chhabra (UID 21027), Department of Agronomy, School of Agriculture of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgments have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE I

This is to certify that the work reported in the Ph. D. thesis entitled "**Effect of Integrated Nutrient Management and Agronomic Zn fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.)**" submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Agronomy, School of agriculture, is a research work carried out by Sreethu S, Registration No. 12021113, is bonafide record of her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABSTRACT

The growth and productivity of crops are enhanced by zinc, one of the most important micronutrients. However, the majority of Indian soils lack zinc, and various factors like soil organic matter content, pH, high carbonate and phosphate concentrations, etc., exacerbate this deficiency. Wheat grains grown on severely zinc-deficient soils like Punjab usually have poor grain zinc concentration, and the adoption of different agronomic zinc fortification approaches can improve these levels. Because of its high carbonate content and alkaline nature, the soil limits the amount of available zinc. With the help of agronomic zinc bio fortification technique, the naturally occurring zinc status of the edible part of plants can be enhanced by applying a zinc solution to the crop or zinc to the soil at the right time and dose. The use of chemical fertilizers has increased due to intensive agricultural practices brought on by population growth, which has decreased soil fertility. Global agricultural production has reached incredible heights, but there are still many difficult problems that need to be solved to guarantee both environmental sustainability and food security. The main objectives adopted for the study were to reduce production costs, optimize fertilization, and improve the quality of crop. Keeping this in mind, a two-year field experiment entitled **"Effect of Integrated Nutrient Management and Agronomic Zn fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.)"** was executed during the *rabi* seasons of 2021-22 and 2022-23 at the Agricultural Research Farm of Lovely Professional University, Phagwara, Punjab. A split-plot design was used to conduct the experiment, where the treatments were replicated thrice. There were 21 treatment combinations with three zinc application methods, i.e., soil (Z1), foliar (Z2) and soil along with foliar application (Z3) were considered in main plots and seven INM practices viz, N1: 50% recommended dose of fertilizer (RDF) + 5 t/ha Farm yard manure (FYM) + Azotobacter, N2: 75% RDF + 2.5 t/ha FYM + Azotobacter, N3: 50% RDF + 5 t/ha FYM + Phosphate solubilizing bacteria (PSB), N4: 75% RDF + 2.5 t/ha FYM + PSB, N5: 50% RDF + 5 t/ha FYM + Zinc Solubilizing Bacteria (ZSB), N6: 75% RDF + 2.5 t/ha FYM + ZSB and N7: 100% RDF (120:60:40 N-P-K kg/ha) as subplot factors were evaluated to determine the effect of agronomic zinc fortification and integrated nutrient management on crop growth, development, yield and nutrient quality of wheat crop. The results revealed that agronomic zinc application methods and integrated nutrient management strategies brought significant increments in crop growth, productivity, quality and profitability over the course of both study years. Among different agronomic zinc fortification methods, combined soil and foliar application of zinc produced maximum growth attributes like plant height, dry matter accumulation, LAI and root parameters. Significant improvements in grain yield, spike length, grain count per spike, and test weight were also obtained using the same foliar zinc application. Considerable improvement in quality aspects like grain protein content, total nutrient uptake (nitrogen, phosphorus, potassium and zinc), sedimentation volume, grain appearance score was obtained with combined soil + foliar zinc application. Highest improvement in zinc uptake were also recorded when soil along with foliar zinc was applied at tillering, milking and anthesis stage. When zinc was applied foliarly at various stages, the grain zinc content was higher than when zinc was used solely to the soil. Agronomic zinc application techniques had no discernible effect on the concentration of major macronutrients such as potassium, phosphorus, or nitrogen following wheat crop harvest, even though it significantly influenced soil zinc concentration. Of the various integrated nutrient management approaches, applying 75% RDF + 2.5 t/ha FYM + ZSB was superior in improving the growth (LAI, plant height and accumulation of dry matter). However, treatments 75% RDF + 2.5 t/ha FYM + ZSB and 75% RDF + 2.5 t/ha FYM + PSB were at par for root length and root dry weight during both years. Significantly higher yield, yield attributes and quality aspects were obtained by applying 75% RDF + 2.5 t/ha FYM + ZSB. Adopting various integrated nutrient management strategies substantially impacted the final soil fertility status, including factors such as bulk density and nutrient content. Maximum reduction in bulk density was obtained with treatments receiving 5t/ha FYM as compared to 2 t/ha FYM. The various integrated nutrient management strategies utilized in both years, as well as the aggregated data, had a significant impact on the available nutrient status following crop harvest. It was observed that applying 50% RDF through chemical fertilizers + 5 t/ha FYM + Azotobacter would yield the highest levels of nitrogen, phosphorus, and potassium. All of the integrated nutrient management strategies, except for the control (100% RDF), enhanced the soil fertility. A significant interaction was found between different zinc application methods and integrated nutrient management practices regarding dry matter accumulation, grain yield and yield contributing factors like spike length and number of grains per spike. Substantial enhancement in the protein content of grains, hectolitre value, sedimentation volume and total nutrient uptake were also obtained. Total nitrogen, phosphorus and zinc uptake were significantly influenced when agronomic zinc fortification methods interacted with different integrated nutrient management practices. Overall, the application of 75% RDF through chemical fertilizers + 2.5 t/ha FYM +ZSB along with basal application of zinc at 25kg/ha +foliar application of zinc (0.5%) at tillering, milking and anthesis stage was found to be more promising for obtaining higher growth, productivity, profitability and nutritional quality in wheat. Integrating zinc administration through both foliar and soil methods with the application of 75% RDF + 2.5 t/ha FYM + ZSB yielded maximum values for gross return and return and a higher benefit cost ratio, making it more economically feasible.

Key words: Bio fortification, Integrated nutrient management, Wheat, Yield, Zinc

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LIST OF ABBREVIATIONS

₹	Rupee
%	Per cent
@	At the rate of
^{0}C	Degree Celsius
ANOVA	Analysis of variance
AAS	Atomic Absorption Spectro photometer
B:C	Benefit : Cost
C	Carbon
cc	Cubic centimeters
CD	Critical difference
cm	Centimetre
DAP	Di ammonium phosphate
DAS	Days after sowing
dSm^{-1}	Deci Siemens per meter
DTPA	Diethylene triamine Penta acetic Acid
EC	Electrical conductivity
et al.	Co- worker
Fig	Figure
FYM	Farm yard manure
g	Gram
g/cc	Gram per cubic centimetre
g/kg	Gram per kilogram
ha	Hectare
HI	Harvest index
hl	Hectolitre
i.e.	That is
INM	Integrated nutrient management
K	Potassium
K_2O	Potassium oxide

kg	Kilo gram
kg/ha	Kilo gram per hectare
km/hr	Kilometer per hour
LAI	Leaf area index
MSL	Mean sea level
m	metre
mg	Milligram
mg/g	Milligram per gram
MOP	Muriate of potash
N	Nitrogen
No.	Number
OC	Organic carbon
P	Phosphorus
ppm	Parts per million
pH	Potential of hydrogen
PSB	Phosphorus solubilising bacteria
P_2O_5	Phosphorus Pentoxide
RDF	Recommended dose of fertilizer
Zn	Zinc
ZSB	Zinc solubilising bacteria
$ZnSO_4.7H_2O$	Zinc sulphate hepta hydrate
t	Tonne
t/ha	Tonne per hectare

CHAPTER - 1

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the king of cereals and a vital strategic crop for the world's population. Wheat is an essential staple grain for about two billion people (35%) worldwide. After rice, it is considered India's second most significant crop in terms of acreage and productivity. Internationally and within a country, wheat is cultivated on 215.5 and 29.6 million hectares of land, producing 731.4 and 112.2 million metric tons, respectively. The average yield per hectare is 3390 and 3371 kg. Punjab, India's primary wheat-producing state, is facing difficulties, as indicated by the continuous decrease in the compound annual growth rate of wheat production. Punjab cultivates 35.3 lakh hectares of wheat, yielding a yearly grain production of 149 lakh tonnes (MoA & FW, 2021; Sreethu *et al.,* 2024). India comes in second place among wheat-growing nations in terms of area and production after China.

The decline in wheat production and productivity in Punjab has been attributed to a number of factors, one of which is a shortage of micro nutrients, specifically zinc. Intensive mineral extraction from crops has led to a greater loss of soil micro nutrient reserves, which has resulted in micro nutrient deficits. Zinc deficiency affects roughly 10.82 percent of Punjab soil, with 12.2 percent of the district of Kapurthala affected. Hidden hunger, decreased yields, crop failures, poor trace element accumulation into edible plant parts and grains, and inadequate human nutrition are all results of these deficiencies. Studies demonstrate that the application of micronutrient fertilization can help to identify the extent of zinc deficiency in the soil and help to decrease this deficiency (Suganya *et al.,* 2020).

Of the various micro nutrient deficiencies, zinc deficiency is the most serious worldwide health problem, impacting over one-third of the global population.The most common deficiencies among them are those in zinc and iron. In India, 44% of children under five suffer from zinc deficiency. The human body requires zinc as a co-factor for over 200 enzymatic reactions critical for immune system function, growth, development, and infection resistance (Islam *et al.,* 2023). In Punjab, wheat is considered as the means for daily calorie intake. However, the bioavailability of micronutrients is extremely low in wheat. Wheat grains grown on severely zinc-deficient soils like Punjab may have a zinc concentration of only 10 mg/kg, while human needs are 40–60 mg/kg and global Zn concentrations are currently between 10 and 30 mg/kg. Maximizing the timing and concentration of foliar zinc applications could further raise wheat zinc concentration (Cakmak *et al.,* 2010).

The rapidly growing global population also presents a substantial obstacle to ensuring adequate food security for humanity. The Green Revolution facilitated a surge in food production through high-yielding crop types, intensified use of chemical inputs such as fertilizers, guaranteed access to irrigation, and the application of insecticides, pesticides, and herbicides. Chemical fertilizers enhance food production (Rakesh *et al.,* 2020; Sarkar & Rakshit, 2021); however, excessive use leads to significant challenges and negatively impacts productivity. A crucial element in this situation is the judicious utilization of chemical fertilizers. As the population grows quickly, there must be a corresponding rise in food grain production. This expansion requires large amounts of chemical fertilizers, leading to environmental deterioration and making farming too expensive for farmers.

Using chemical fertilizers has led to a decline in soil agricultural production during the past two decades. The obstacles above prompted a reconsideration of seeking an alternative, which resulted in the concept of integrated nutrient management. The combination of organic, inorganic, and bio fertilizers has a crucial function in maintaining soil fertility and enhancing crop productivity by supplying essential macro and micronutrients consistently (Bayu *et al.,* 2006; Chahal *et al.,* 2019; Dubey *et al.,* 2022). Farmers have long utilized farm yard manure (FYM) as a vital nitrogen source in agriculture. Biological fertilizers are microorganisms that enhance plant growth by transforming inaccessible nutrients into a usable form, hence enhancing crop productivity without causing harm to the environment (Shewry 2009). The integrated application of nutrients from various sources, such as inorganic, organic, and through the employment of microorganisms in the form of biofertilizers, serves as a suitable alternative to reduce reliance on agrochemicals without compromising agricultural production.

Optimal utilization of nitrogen, phosphorus, potassium, and zinc is necessary to achieve the desired wheat yield. However, the presence of deficiencies, namely zinc deficiency, has a negative impact on crop production (Hotz & Brown, 2004). The insufficient zinc levels in wheat are partially attributed to over 40% of the global wheat production taking place on zinc-deficient soils. Zinc is a vital micronutrient that significantly impacts auxin formation, enzyme activation, protein synthesis, respiration, glucose metabolism, and metabolism. Inadequate zinc consumption creates zinc deficiency symptoms in humans, and it impairs growth, metabolism and the immune system. Zinc deficiency has been identified as a leading cause of infant mortality worldwide. Zinc deficiency affects not only plants but also human beings. Its deficiency in man can cause complications such as growth retardation, mental problems and also immunity disturbance, particularly among children and pregnant women (Gibson, 2006; Farias *et al.,* 2020). A concerning circumstance is that zinc deficiency affects over 25% of the world's population. (Maret & Sandstead 2006; Chasapis *et al.,* 2012). There are many factors that limit the availability of zinc in soil like parent rock material low in zinc content, high soil pH, alkaline soil having high calcite content, low organic matter, low soil temperature and soil moisture (Alloway, 2009), high concentration of phosphates and bicarbonates of sodium, calcium and magnesium are some of the determining factors that limits zinc availability in plants (Rashid & Ryan 2008; Abbas *et al.,* 2010). Studies revealed that zinc deficiency in wheat-growing areas paves the way to its low concentration in grain. (Hotz & Brown, 2004). Increasing grain zinc concentrate in staple food crops such as wheat and rice is the only strategy to solve the problem of Zn deficiency in human beings (Aref, 2011). The Zn concentration in wheat is rather low, often ranging from 20 to 35 mg/kg in whole grain. The adoption of zinc bio-fortification methods can effectively achieve this.

Bio-fortification is how the concentration of specific nutrients can be increased in the edible portion of the crop plant (Welch, 2005). This technique of improving the grain zinc concentration was developed primarily to address malnutrition in nations where the population's diet is based mainly on low-quality food. It serves as a simple, sustainable, and cost-effective strategy. Using agronomic zinc fortification techniques, hidden hunger brought on by a zinc deficit can be restored. Agronomic bio-fortification holds great promise for mitigating global hidden hunger as it entails physically integrating fertilizers and other agronomic techniques into agricultural systems (Bhatt *et al.,* 2020; Szerement *et al.,* 2022). In general, it refers to nutrients that have been "pulled" from the soil; it refers to "pushing and providing" them in their accessible forms to the economically significant edible portions of plants (Kumar *et al.,* 2019). Agronomic bio-fortification involves pre-harvest agronomic practices, and improves the nutritional value of food. Agronomic bio fortification is a fertilizer-based strategy that uses a variety of application techniques, such as soil application, soil less cultivation, seed priming, and the sprinkling of an optimal fertilizer solution on leaves at different stages of growth. It also encompasses the use of chemical, manure, and bio fertilizers (Sheoran *et al.,* 2022; Shivay *et al.,* 2016). A sufficient quantity of the micro-nutrient zinc needs to be present in the soil or in the vegetative organs during the reproductive stages to boost the success rate of bio fortification (Cakmak & Kutman, 2018).

When it comes to boosting grain enrichment of micro elements, the timing of foliar spraying micro nutrients is a significant determinant of its effectiveness. For instance, foliar Zn fertilisers applied to wheat at a late growth stage are likely to produce notable increases in zinc concentration in the grain. (Slamet-Loedin *et al.,* 2015). There hasn't been enough research on the agronomic bio-fortification of wheat in Punjab with zinc using various integrated nutrient management techniques to increase yield and quality.

The primary goal of the study is to find whether INM, along with Zinc fortification, is an effective solution to help the farmers in an eco-friendly way and also to remove malnutrition in emerging populations. In view of the importance of INM and zinc fortification in wheat the present experiment, “Effect of Integrated Nutrient Management (INM) and Zinc fortification on growth, yield and quality of wheat”, was conducted with the below-mentioned objectives:

Objectives

1. To find the effect of INM and agronomic Zn fortification on growth, yield and quality of wheat,
2. to study the efficacy of INM and agronomic Zn fortification on nutrient contents and their uptake and
3. to evaluate the economic feasibility of different treatments.

CHAPTER - 2

REVIEW OF LITERATURE

A review of relevant literature on key points related to the current study entitled "**Effect of Integrated Nutrient Management and Agronomic Zn fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.)**" is mentioned here. In addition to these aspects, pertinent research on related crops has also been examined when deemed necessary. This chapter aims to provide a succinct overview of the research undertaken at various sites in India and elsewhere in relation to the subject under investigation.

An overview of the pertinent work that has been carried out over year are presented here.

2.1 Effect of INM

Inorganic fertilizers are used to boost crop yield and quality, but if applied carelessly, they can reduce crop productivity and disturb the natural ecosystem (Bisht & Chauhan, 2020). According to Al-Suhaibani *et al.,* 2020, integrated nutrient management (INM) strategies aim to reduce soil degradation, enhance crop productivity, and safeguard the environment by partially replacing chemical fertilizers with organic compost that is safer for the environment and more sustainable. Multiple studies confirm the positive impacts of combining chemical fertilizers with organic manure, which holds significant potential for maintaining higher crop output and enhancing agricultural production stability. Substitution of organic manure for a portion of chemical fertilizers using a straightforward method that combines certain microorganisms with a minimum effective dose of adequate and balanced amounts of both organic and inorganic fertilizers proved to be an effective strategy. INM is a tool that can provide plants with the necessary amount of nutrients at a reasonable cost, as well as lower overall expenses, improve the physio-chemical conditions of the soil, create a healthy environment, remove obstacles, protect the soil's nutrient balance, and identify safe disposal techniques for agricultural waste (Selim, 2020).

2.1.1 Growth attributes

Integrated nutrient management can enhance crop growth and development by replacing a portion of inorganic fertilizer with organic sources like farm yard manure and biofertilizers. Different components of INM helps in increasing the growth promoting substances in plants like auxin which improved the division and enlargement of cells and thereby enhanced plant height in wheat (Pandey *et al.,* 2004). In order to know the influence of various INM techniques on wheat, Kalia *&* Mankotia experimented in the year 2005 at Palampur. They found that applying Azotobacter or FYM in conjunction with the 75% recommended nutrient dose improved height of plant, shoot number per square metre, and the production of dry matter. This was related with findings of Egamberdieva *et al.* (2008) and Patel, (1969) who suggested that inoculation of nitrogen promotes metabolic and auxin activities of plant which directly helps in improving the height of plant. As per the study conducted by Ram & Mir (2006), wheat crop under 10 t/ha of FYM application along with 120 kg/ha N superiorly improved the growth parameters like height of crop and tiller count over control during the study years. They also confirm that the use of bio-fertilizer like azotobactor and azospirillum accelerated the growth and development of crop. The rise in plant height linked to FYM's nutritive effect in rice crops is consistent with findings of Abro & Mahar (2007), Shah *et al.* (2007) and Haque *et al.* (2015). FYM application (10 t/ha) and a higher fertilizer dose, i.e., 120% RDF treatment, according to Borse *et al.* (2019), resulted enhancement in growth aspects of plant, such as height of plant at 60 DAS (47.2 and 47.3 cm), at harvest (87.3 and 87.4 cm), in wheat crop. Mahato & Kafle, (2018) observed higher growth attributes like plant height, leaf length, leaf number and root length with the use of *Azotobacter* along with chemical fertilizer and FYM. Shekhar *et al.* (2021) found that different INM practices positively impacted wheat growth parameters. Inoculation of Azotobacter aids in improving growth characteristics like height and shoot number in plants through increased biological nitrogen fixation and increased nutrient availability through solubilization, which may have increased cell elongation, cell number, and cell division (Sumbul *et al.,* 2020). In addition, Zulfiqar *et al.* (2023) observed that applying organic and inorganic nutrient sources together improved wheat growth attributes compared to control.

Several factors have an impact, either direct or indirect, on the growth and development of crops. Studies on the distribution and growth of soil roots are crucial for understanding the root-water and nutrient-uptake dynamics in soil-plant systems. In this regard, Meena *et al.,* in 2013, experimented to evaluate the effect on root phenology in wheat under the influence of different nutrient management and planting system in New Delhi. They found that, in comparison to the control and treatment RDF alone, wheat roots treated with a combination of RDF or 75% RDF plus FYM, biofertilizer, and zinc during both years of the field study displayed significantly higher root growth parameters. This was related to the findings of Raghuvamshi and Singh in the wheat crops in 2020.

2.1.2 Yield and yield attributes

Various INM strategies result in improvement in different yield and yield contributing attributes. Enhanced fertilizer use efficiency and consistent yield are guaranteed by integrated nutrient management (Caravaca *et al.,* 2002). Considering this aspect, Khaliq *et al.* (2006) conducted an experiment and suggested that the maximum yield in wheat and cotton was achieved by utilizing a balanced combination of NPK, organic manure, and beneficial microbes rather than relying solely on synthetic fertilizer. Garg & Bahl, (2008) suggested that this increase was brought about by enhanced yield component yields and enhanced residual soil phosphorus bio-availability.

As organic matter can enhance soil health and increase nutrient availability, inorganic fertilizers perform better when combined with organic manures like FYM (Asai *et al.,* 2009). According to Singh (2019), using integrated nutrient management (INM) had a positive effect on the yield attributes of rice and wheat. The highest values for all yield attributes were observed in the treatment that received 100% NPK fertilizer along with 5 tons of farmyard manure (FYM) per hectare, followed by the treatment with 75% NPK fertilizer and 5 tons of FYM per hectare, compared to using only 100% NPK fertilizer.

Dhaliwal *et al.* (2015) conducted an experiment to examine how nutrient management techniques affected the quality of the wheat grains in a basmati rice and wheat system. The findings showed that integrated nutrient management and suggested fertilizer treatments maximized wheat grain yield. While the recommended fertilizer treatment produced the maximum protein content, the treatments receiving organic sources achieved the maximum value of quality parameters, including hectoliter weight, test weight, grain appearance score, grain hardness and sedimentation rate. In the unfertilized plot, or control, the minimum value of these quality attributes was attained.

The addition of RDF in conjunction with 5 t/ha of FYM, 20 kg/ha of $ZnSO_4$, and Azotobacter produced superior value in yield attributes and yield as compared to the application of RDF through chemical fertilisers, as demonstrated by Kumar *et al.* in an experiment conducted in 2016 to evaluate the impact of INM in wheat crop. Maurya *et al.* (2019) experimented to know the influence of INM approaches on the performance of wheat (*Triticum aestivum* L.). They found that the yield contributing characters were associated highly with 125% RDF + 25% through vermicompost. The application of the same recorded significantly higher grain and straw yield. The harvest index was slightly improving with increasing the rate of RDF but did not reach the level of par; it was recorded as highest under 100 per cent RDF application + 25 per cent FYM.

Tejalben *et al.* (2017) experimented on wheat with different INM approaches. They found an increase in grain and straw yields under 75% RDF + 10 t FYM per ha was 24.74 and 42.29 per cent over control and registered maximum value for number of effective tillers (82.77) and weight of 1000 grains (33.30 g). In a study on the impact of various INM on wheat yield attributes and yield, Mohan *et al.* (2018) concluded that grain and straw yields rose as nutrient levels (NPK) increased, up to 100 per cent of the recommended dose of fertilizers applied either alone or in conjunction with organic sources.

According to Sharma *et al.* (2019), INM treatment has a favourable impact on grain yield compared to inorganic chemicals and organic manures. The yield increase brought about by the INM treatment suggests combining organic and inorganic fertilisers could be a workable alternative for managing nutrients. They also said that a complete switch to organic farming is not a practical solution to ensure humankind's food security. As per Zulfiqar *et al.* (2023) application of a 50-50 ratio of organic and inorganic sources application recorded significantly higher effective tillers (284.4), biological yield (14.82 t/ha), test weight (44.48g) and radiation use efficiency (2.15 g MJ^{-1}) in wheat crop. They also recorded that the highest value for grain yield (4.54 t ha^{-1}) was attained with 50% organic manure with 50% inorganic NPK treatment, followed by 100% inorganic (NPK) (4.14 t/ha) and 75% FYM + 25% inorganic NPK (3.77 t/ha).

Abid *et al.* (2020) found that the combined use of chemicals and organics as nutrient sources accelerated the productivity of crops and improved the use efficiency of fertilizers in maize when compared to treatments amended with the sole application of mineral fertilizers and organic manure. Paramesh *et al.* (2020) concluded that 50% phosphorus through phospho-enriched compost + 50% phosphorus through inorganic source recorded higher yield attributes as compared to sole chemical application.

2.1.3 Economic feasibility

In a field experiment conducted in Jodhpur in 2003–04 and 2004–05, Singh *et al.* (2008) discovered that the wheat-based cropping sequence with the integrated use of farm yard manure at 7.5 t/ha, 50 per cent RDF, and biofertilizer (*Azotobacter* + PSB) produced noticeably higher net returns and a lower cost-benefit ratio than the control. According to Ghosh *et al.* (2014), the maximum benefit-cost ratio was determined for the combined FYM application (5 t/ha) along with chemical fertilizers that are advised based on IPNS, making this treatment more cost-effective than other options. According to research by Kaur *et al.* (2018), applying 75% NPK + organic manure @ 2.5 t/ha along with the use of symbiotic nitrogen-fixing bacteria, viz., Azotobacter, resulted in the maximum value of net returns and fetched the highest benefit.

2.1.4 Nutrient uptake

Bonde *et al.,* (2017), recorded an improvement in nutrient uptake by soybean crops with the application of 75% NP through chemical sources + 4 t FYM + 25 kg sulphur per ha or 5 kg zinc per ha. Ghosh *et al.* (2020) found that combining organic and inorganic nutrients enhanced soil physical structure and increased microbial enzymatic activity. This, in turn, resulted in higher levels of accessible nutrients in the soil. The application of 50% of the necessary nitrogen dose from organic sources in the integrated nutrient management strategy resulted in a considerable increase in the crop's uptake of nitrogen, phosphorous, and potassium. Midya *et al.,* 2021 also demonstrated that the total nutrient content of primary macronutrients was found to be higher with the application of integrated plant nutrition compared to the sole application of chemical fertilizers.

2.1.5 Soil health

When organic manure, like FYM, is added to the soil, the amount of soil OM increases, enhancing the productivity and health of the soil. It also improves the soil's physical, chemical, and biological properties.

It also increases soils' ability to supply nutrients and hold water (Kamboj *et al.,* 2022).

Sharma & Banik, (2012) found that applying FYM in addition to RDF boosts overall land productivity more than applying inorganic fertilizer alone and enhances soil fertility status. Sandhu *et al.* (2020), found that the prolonged and combined use of balanced nutrients through inorganic sources and organic manures enhances the physio-chemical properties of soil and promotes soil carbon sequestration, hence potentially enhancing soil sustainability.

They found that the highest carbon sequestration occurred when 50% of the recommended dose of NPK was applied through fertilizers + 50% through FYM in Kharif, and 100% NPK was supplied through fertilisers in Rabi.

Dhaliwal *et al.* (2021) suggested that increasing the availability of phosphorus in the soil was achieved by adding nutrients to the wheat crop through the simultaneous application of inorganic nutrient sources and organic FYM. This treatment exhibited a much larger accumulation of P content (31.4 kg/ha) compared to all other treatments, making it more favourable. The soil's potassium (K) content increased with the addition of FYM and chemical fertilizers, surpassing the starting level. Shah *et al.* (2022), found that the addition of manures, either solely or in conjunction with synthetic fertilizers, reduced soil pH.

They also recorded a maximum pH decrement with the application of 40 kg P + PSB + Rhizobium + FYM, which was found to be 3.30 per cent less than the control treatment, and maximum soil microbial biomass with the application of an integrated module comprising phosphorus, molybdenum, and farm yard manure. According to

Jamal *et al.* (2023), the availability of phosphorus in soil was enhanced by the addition of chemical fertilizers in addition to FYM.

2.2 Effect of Zn

Zinc concentrations in plants typically range from 25 to 150 mg/kg. Zinc toxicity happens when the zinc concentration in leaf surpasses 400 mg/kg. Plant roots absorb zinc as Zn^{2+} ions, which are a part of both natural and artificial complexes. Moreover, Zinc complexes may enter the plant system through the leaves (White *et al.,* 2002; Broadley *et al.,* 2007). Multiple data suggest that the mean zinc concentration in whole wheat grains varies from 20 to 35 mg/kg across different countries (Cakmak, 2004). The reported concentrations of zinc are insufficient to fulfil the daily needs of humans. To produce a noticeable impact on human health, whole wheat grains must contain at least an additional 10 mg/kg of zinc (Pfiffer *et al.,* 2007).

Obtaining the ideal amount of zinc is crucial for raising crop quality and yield. According to Sreethu *et al.* (2022), Indian soils are zinc deficient, meaning crops grown in these soils will not receive enough of this nutrient. This will hinder crop growth and cause low zinc accumulation in grain. Lack of zinc hinders healthy plant growth, resulting in inter-node stunting, increased susceptibility to pathogens and interveinal leaf chlorosis, smaller leaves, delayed maturity, necrotic tissue, and, in extreme situations, plant death (Sreethu *et al.,* 2023).

2.2.1 Growth attributes

Hussain *et al.* 2012, concluded from a study in Pakistan that zinc when applied in soil along with foliar spraying at the developmental stage of grain, improved grain zinc by 95 per cent and bio-availability by 74%. Zou *et al.* (2012) investigated the process of enhancing the zinc content in wheat through bio-fortification. They found that applying zinc to the leaves of the plants, either alone or in conjunction with applying it to the soil, increased zinc concentrations in the grains. This improvement was observed in all locations and with all local wheat varieties used in those countries. On average, the grain zinc concentrations increased from 27.4 mg/kg to 48.0 mg/kg by applying zinc to the leaves.

In contrast to applying the total recommended dose of nitrogen, a study by Arif *et al.* (2019) showed that using 125% RDN, 25 kg/ha of $ZnSO_4$ as soil application, and 0.5% $ZnSO_4$ as foliar spray increased growth aspects like height by 10.35%, accumulation of dry matter by 26.56%, and LAI by 34.06% in wheat.

2.2.2 Yield and yield attributes

Results from the field experiment carried out at the IARI in New Delhi by Shivay *et al.* (2008) showed a significant increment in yield attributes, yield, zinc concentrations in the grain and straw, and zinc uptake upon application of zinc in the form of 0.5 to 2% zinc enriched urea. They also concluded from their results that the application of 0.5 to 1% zinc enrichment of urea with $ZnSO_4$ or 1% zinc enrichment with ZnO can be advised. Mosanna & Behrozyar (2015) conducted study which found that the application of zinc nano-chelate through the soil, along with the foliar technique in maize led to increased pigment levels and a larger percentage of biological yield. Keeping this aspect in mind, Esfandiari *et al.* (2016) experimented on wheat crop and suggested that zinc, when applied foliar during late stages, produced the highest biological yield (686 g/m^2), while the control group made the lowest biological yield (461 g/m^2). According to Arif *et al.* (2019), enhancement in grain (5681 kg/ha) and straw (8265 kg/ha) yields happened when treatment 125 per cent RDN + $ZnSO_4$ 25 kg/ha as soil application + $ZnSO_4$ 0.5 per cent as the foliar spray was applied.

The effects of INM and agronomic approach for of zinc fortification on quantitative and qualitative aspects of wheat were investigated by Paramesh *et al.* (2020). They discovered that the application of P50-phospho enriched compost + P50-through fertilizer, combined with soil application + foliar spray of zinc, resulted in significantly higher yield attributes, including spikes m^2, test weight, spike length, and spikelets spike^{-1}. This was comparable to applying 25 kg of zinc in the soil. Similarly, Kumar *et al.* (2020) found that using zinc as a foliar spray at 0.5% $ZnSO_4$ during the pre-flowering and milking stages, combined with a 50 kg ha^{-1} soil application, yielding the highest grain and straw.

2.2.3 Uptake of nutrients and quality

Studies conducted in Turkey and Anatolia by Yilmaz *et al.* (1997) proved that grain zinc concentration increased by applying zinc fertilizers to wheat planted in fields. Applying zinc topically can enhance the amount of zinc that is transported from leaves into seeds, especially in situations where there is environmental stress (such as drought) or in soils that may be potentially zinc deficient. The effects of combined foliar and soil application of zinc fertilizers on improving the grain zinc and iron content were reported by Ranjbar & Bahmaniar, (2007). Peck *et al.* (2008) examined the impact of zinc nutrition on the protein composition of bread wheat flour in Australia. Applying zinc topically was found to increase the concentration of zinc in grains twofold, decrease the amount of SDS-unextractable polymeric protein and gliadin, and increase the amount of SDS-extractable polymeric protein.

The findings showed that protein composition can be changed by zinc supplementation in relation to grain filling temperature. Cakmak (2004) reported from Turkey that the best way to increase the amount of zinc in grain was to apply soil and foliar zinc, which led to a 3.5-fold increase in the concentration of zinc in grain.

In this regard, Hussain *et al.* (2012) experimented in Pakistan by applying soil zinc in conjunction with foliar spraying during the grain development stage and observed an increase in grain zinc concentration and bio-availability by 74%. Keeping this in mind, Bharti *et al.* (2014) conducted an experiment using different wheat genotypes and suggested that zinc-applied foliar in conjunction with soil was best suited for promoting wheat genotype growth, suggesting that wheat leaves have the ability to absorb zinc sulphate solution and effectively translocate it to other wheat tissues and organs. With zinc applied both topically and, in the soil, they also saw improvements in the amount of chlorophyll in wheat as well as an increase in photosynthetic activity.

Das *et al.* (2020) found that the application rate of zinc significantly affected the concentration of nitrogen in wheat grains. The maximum grain N concentration (1.77%) was found in the $Zn_{6:0}$ treatment, which was statistically different from that observed in all other treatments, except $Zn_{4:5}$. Zinc had a significant impact on grain Zn concentration, with $Zn_{4:5}$ having the highest Zn concentration (39.7 μg/g) and the lowest with the control.

According to Arif *et al.* (2019), applying 125 per cent of the suggested dose of nitrogen along with 25 kg/ha of $ZnSO_4$ soil application and 0.5 per cent of $ZnSO_4$ as a foliar spray resulted in noticeably higher levels of primary nutrients as well as micro-nutrient zinc uptake in the grain and straw. Similarly, Paramesh *et al.* (2020) observed that the increase in crude protein percentage in grain with the application of P50-phospho enriched compost + P50- through synthetic fertilizers was 15% over control. The level of amino acids and crude protein in grain were significantly impacted by zinc application. The amount of crude protein, lysine, methionine, and tryptophan in grain was significantly higher after adding 25 kg of zinc to the soil compared. Kumar *et al.* (2020) discovered that the application of $ZnSO_4$ @ 50 kg/ha and two foliar sprays @ 0.5% $ZnSO_4$ during the pre-flowering and milking stages resulted in the highest nutrient content and uptake of all the primary macronutrient and also zinc. Ji and co-workers 2022 and Lv and co-workers 2022 suggested that zinc application in rice crops improved the translocation and uptake of nitrogen by the crop.

2.2.4 Economic feasibility

Harris *et al.* (2008) argued that the expenses associated with applying zinc fertilizer are minimal compared to the financial gains from higher crop yields and the positive impact on public health. Arif *et al.* (2019), also observed an improvement in net return to the tune of Rs 83230/ha in wheat crops with the use of 125 % of the recommended dose of nitrogen + soil and foliar applied zinc.

Palai *et al.* (2018) opined that that soil zinc application (6 kg/ha) in baby corn, when used with one foliar spray at a rate of 0.05% zinc at 25 DAS, produced the highest net return (165442 Rs/ha). They also found an improvement in the B: C ratio to the tune of 4.46 with the application of the same. Similar studies on agronomic zinc bio-fortification on baby corn were carried out by Amutham *et al.* in 2021 and found that the use of $ZnSO_4$ in soil at 37.5 kg/ha along with foliar application at 1.0 % during initial days resulted in maximum cultivation costs (78612 Rs/ha) and higher gross returns (417732 Rs/ha) and additionally a 5.31 benefit-to-cost ratio.

2.2.5 Soil health

Zinc application through different means has a significant impact on influencing the soil properties. The application of zinc in wheat crops affected the residual level of primary macronutrients and zinc, as shown by Mathew *et al.* (2006). They suggested that maximum residual primary nutrients were obtained with the use of 150 % RDF, bio-fertilizers and $ZnSO_4$ @ 25 kg/ha. However, the treatment receiving the recommended dose of fertilizer, bio-fertilizers, and $ZnSO_4$ had the highest residual zinc levels. Krupashree *et al.* (2020) found that the application of zinc and iron incorporated compost equivalent to 100 per cent of required nitrogen + foliar spray of 3 per cent panchagavya recorded a significantly higher microbial population i.e., bacterial, fungal, actinomycetes, nitrogen fixers and phosphorous solubilizing bacteria after harvest as OM addition through different methods might have encouraged soil microorganisms' growth and activity.

The results from the study conducted by Shalini *et al.* (2020) in wheat crop revealed that the application of zinc-coated urea along with foliar zinc application at 2 and 0.2 percent through zinc sulphate helped in improving the bioaccessibility of nitrogen , phosphorus, potassium and zinc by 414.19, 20.80, 2227.67 kg/ha and 0.67 ppm in soil. An increment pf zinc in soil to the tune of 55 % was registered with the same treatment when compared to control. Despite the generally accepted low efficiency of zinc fertilizers in providing zinc to plants, Recena *et al.* (2021) suggested that their contribution to zinc nutrition depended on the initial availability of zinc in the soil, with zinc deficiencies having a very significant effect.

CHAPTER - 3

MATERIALS AND METHODS

This chapter offers a comprehensive description of the supplies, methods, procedures, and tactics used in the current experiment.

3.1 Experimental site

In order to know the impact of various INM and Agronomic Zinc fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.), a field experiment was executed during *rabi* season of 2021-2022 and 2022-23 in the agricultural field of Lovely Professional University, Phagwara Punjab (India). Experimental area chosen for the study is shown in fig 3.1.

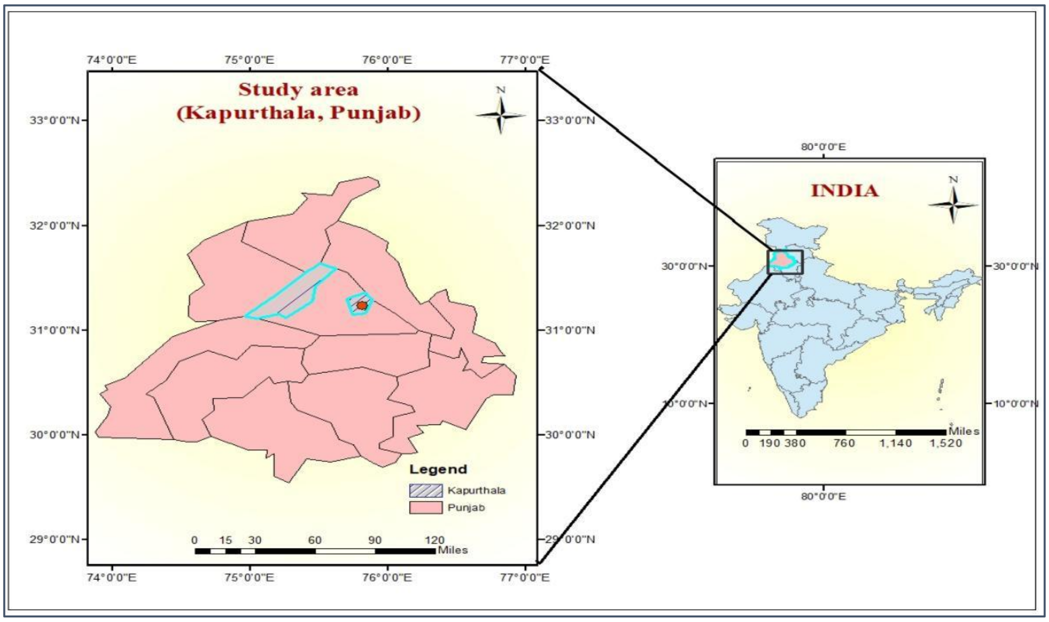


Fig 3.1: Experimental site location

3.2 Location and climate

The site of the experiment is in the Central Plain zone of Punjab and is situated at 31° 13' 26.4" N and 75° 46' 14.9" E, at an elevation (234 m above MSL).

3.3 Characteristics of soil

The experimental soil had a moderate level of fertility with sandy loam in texture. Samples of soil were collected from randomly chosen places at depths ranging from 0-15 centimetres with the aid of a soil auger. During the soil sampling procedure, all possible technical precautions were taken. Samples were dried, crushed, sieved through 2 mm mesh in the laboratory. Several chemical analyses of the resultant soil samples were performed in order to evaluate the chemical characteristics of the soil.

The methodology and findings are detailed below.

Table 3.1: Chemical properties of soil before sowing

Particulars	**Values obtained**		**Method employed**	**References**
	2021	**2022**		
Organic carbon (%)	0.40	0.42	Walkley and Black method	Piper, 1966
pH (1:2.5 soil: water)	7.7	7.5	Glass electrodes pH meter	Jackson, 1973
EC (1:2.5 soil: water) (dSm^{-1} at 25^0C)	0.56	0.57	Conductivity bridge	Jackson, 1973
Available N (kg/ha)	248.7	261.2	Alkaline permanganate method	Subbiah & Asija, 1956
Available P_2O_5 (kg/ha)	44.5	46.7	Olsen's method	Olsen *et al.*, 1954
Available K_2O (kg/ha)	159.8	172.0	Flame photometer method	Jackson, 1973
DTPA Zinc (mg/g)	0.50	0.60	AAS	Lindsay & Norvell, 1978

The scale provided in Table 3.2 was used to classify the soil of the experimental plot.

Table 3.2: Soil test value rating chart

Parameters	Rating of Soil		
	Low	Medium	High
*OC (%)	<0.50	0.51-0.75	>0.75
Av.N (kg/ha)	<280	281-560	>560
Av.P_2O_5 (kg/ha)	<11	11-22	>22
Av.K_2O (kg/ha)	<140	141-336	>336
Av.Zn (mg/kg)	<0.6	0.6-1.2	>1.2

*OC -Organic carbon,

Av.=Available

From the above rating chart, experimental soil was rated in Table 3.3

Table 3.3: Fertility level of the study area

Sl.No	Particulars	Interpretation
1.	OC (%)	Low
2.	Av.N (kg/ha)	Low
3.	Av. P_2O_5 (kg/ha)	High
4.	Av. K_2O (kg/ha)	Medium
5.	DTPA Zinc (mg/kg)	Low

3.4 Weather conditions during the crop growing period

Meteorological parameters showed substantial fluctuations during 2021-22 and 2022-23. Weather variables like atmospheric temperature (maximum & minimum), rainfall, relative humidity and wind speed were recorded from the agrometeorological observatory Lovely Professional University and are shown in Appendix I and are shown in fig 3.2, 3.3, 3.4 and 3.5.

3.4.1 Temperature

The average maximum (Max.) and minimum (Min.) temperature of the study site were 38.6 ^{0}C and 9.0 ^{0}C during the years 2021-22 (Fig 3.2) and ranged from 33.1 ^{0}C to 7.1 ^{0}C during 2022-23 (Fig 3.3).

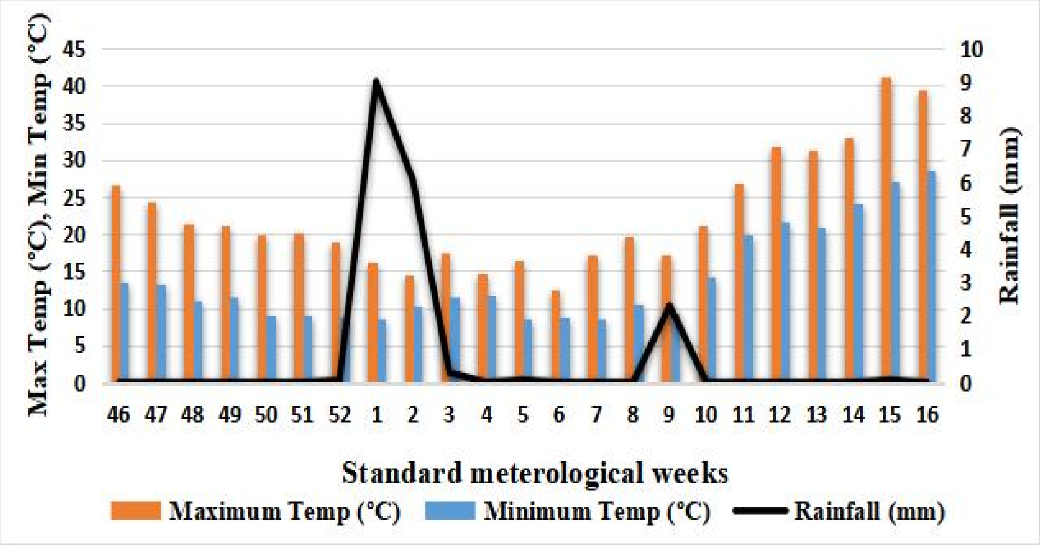


Fig 3.2: Standard meteorological weekly mean Max. and Min. temperatures (^{0}C) and average rainfall (mm) during the crop season during 2021-22

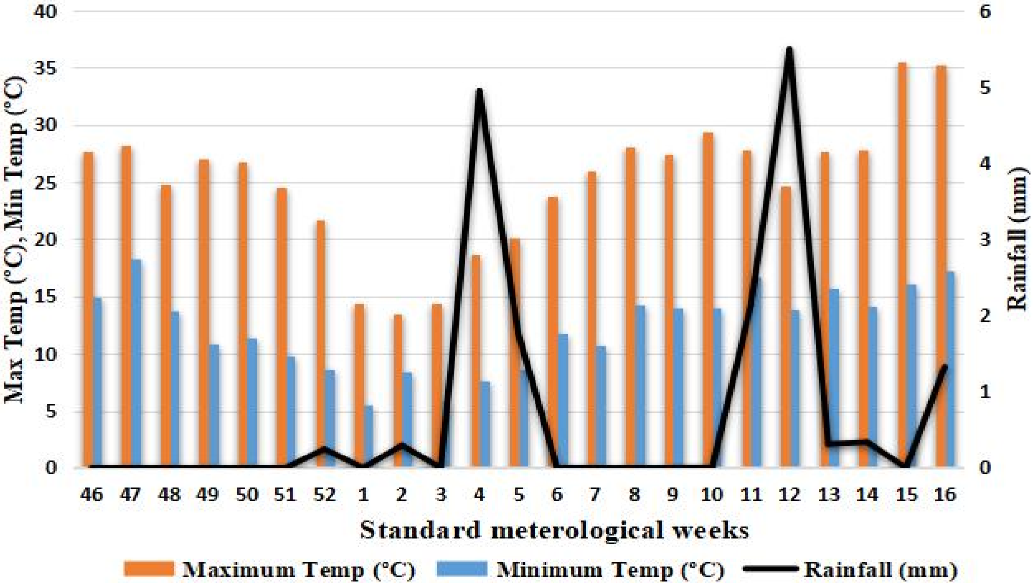


Fig 3.3: Standard meteorological weekly mean Max. and Min. temperatures (^{0}C) and average rainfall (mm) during the crop season during 2022-23

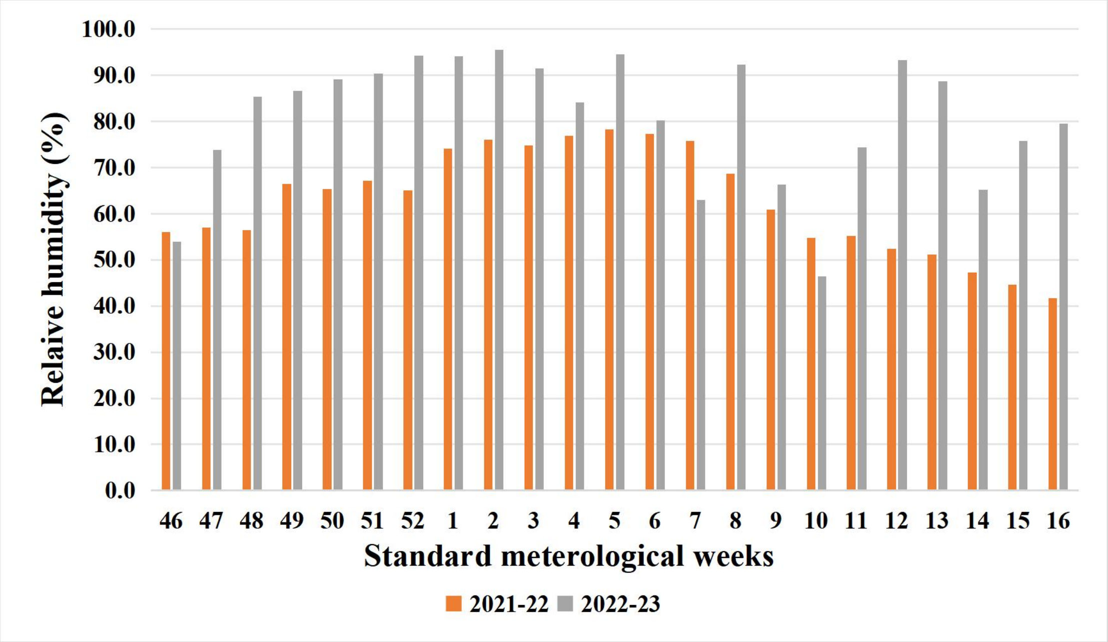


Fig 3.4: Standard meteorological weekly mean relative humidity (%) during the crop season 2021-22 and 2022-23

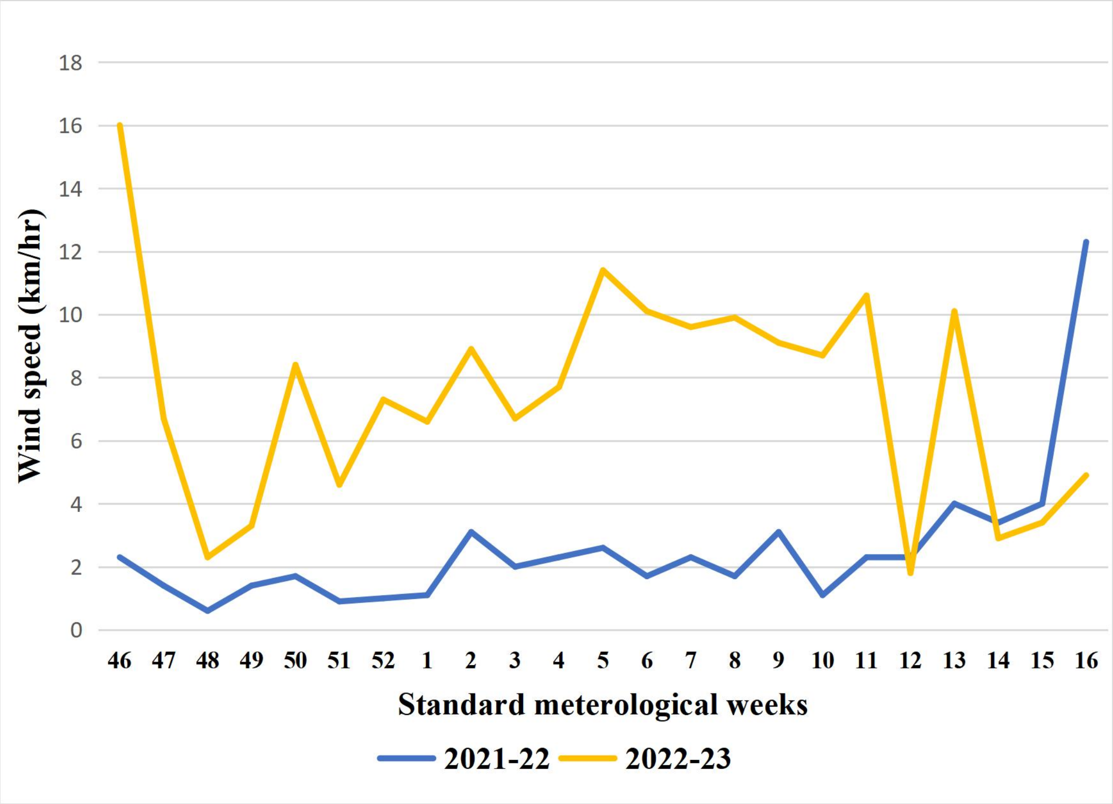


Fig 3.5: Standard meteorological weekly average wind speed (km/hr) during the crop season 2021-22 and 2022-23

3.4.2 Relative humidity (%)

In 2021–22, the weekly mean relative humidity varied between 41.7 and 78.3%; however, in 2022–2023, it varied between 46.4 and 95.6%. The relative humidity showed significant change throughout the growth season in both years (Fig 3.4).

3.4.3 Wind speed (km/hr)

In the first year, the average weekly wind speed varied between 0.6 and 12.3 km/hr; in the second year, it varied between 1.8 and 16 km/hr (Fig 3.5).

3.5 Cropping history

Represented in the table below:

Table 3.4: History of cropping patterns followed in the study area

Year	***Kharif***	***Rabi***
2018-19	Maize	Mustard
2019-20	Green gram	Wheat
2020-21	Maize	Mustard
2021-22	Maize	Wheat
2022-23	Soybean	Wheat

3.6 Experimental details

A field experiment on the wheat crop (var. PBW 803) was administered during the rabi season 2021-22 and 2022-23 in the same plot with the same treatment combinations.

3.6.1 Design and Layout

Three replicates of the experiment were conducted using a split-plot design. The agronomic zinc bio-fortification approaches were assigned to main plots, whereas the different integrated nutrient management practices were in sub-plots within each main plot. The treatments in the main and subplots were allocated randomly. There were twenty-one treatment combinations in each replication.

Design : Split – plot

Year of experiment : 2021-22 and 2022-23

Crop : Wheat

Variety : PBW-803

Treatments : 21

Replication : 3

Total no. of plots : 21 x 3 = 63

Gross Plot size : 5 x 3 m^2

Net plot size : 4 x 2 m^2

Path : 1.0 m

Irrigation channel : 1.5 m

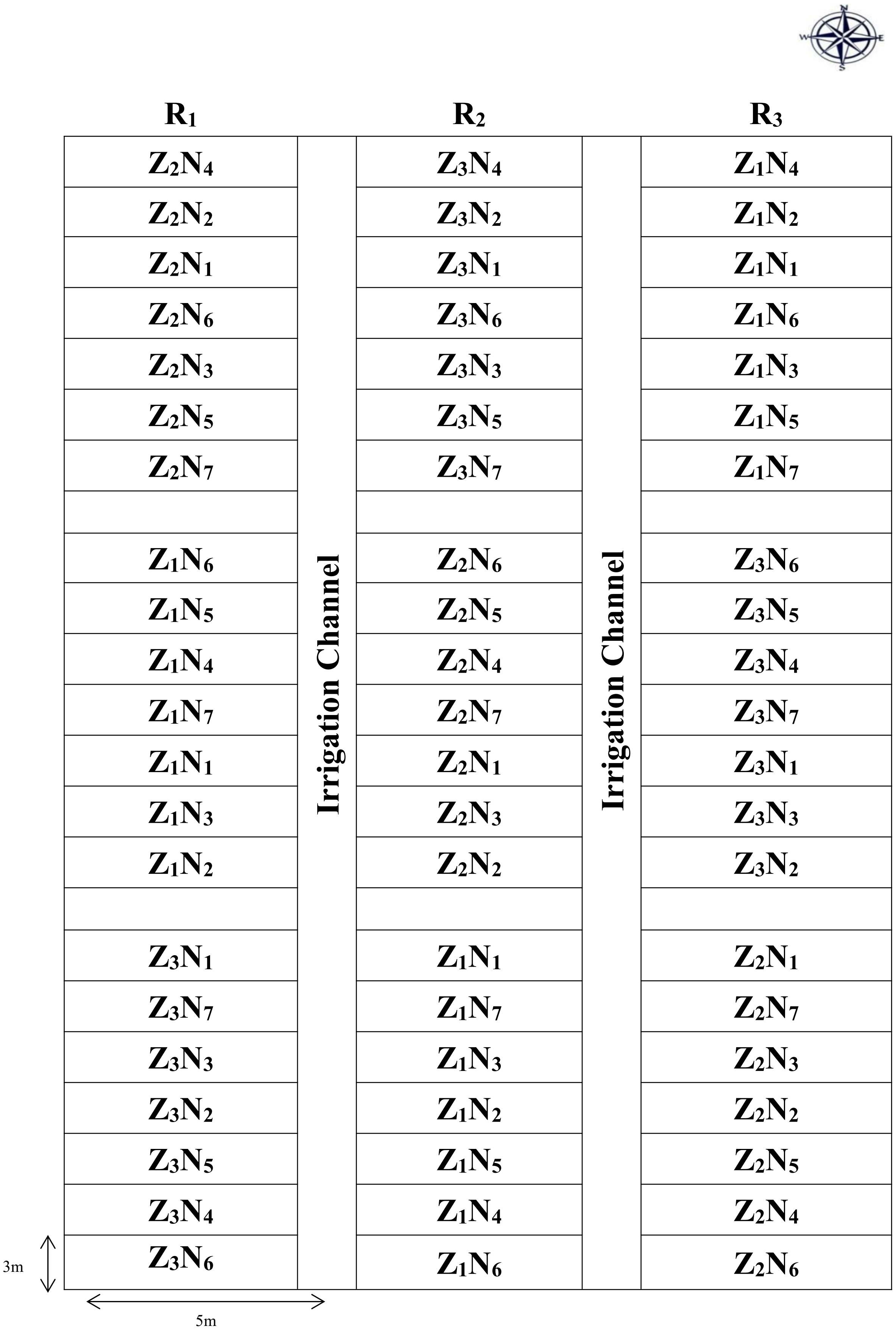
Spacing (Row) : 22.5 cm

3.6.2 Treatment details

Table 3.5: Treatment details and symbols used

Treatments	Symbol
A. Main plots treatments (Agronomic Zinc fortification)	
Soil application of Zn	Z1
*Foliar application of Zn	Z2
Soil and foliar application of Zn	Z3
B. Sub-plot treatments (INM)	
50% RDF + 5 t/ha FYM + Azotobacter	N1
75% RDF + 2.5 t/ha FYM + Azotobacter	N2
50% RDF + 5 t/ha FYM + PSB	N3
75% RDF + 2.5 t/ha FYM + PSB	N4
50% RDF + 5 t/ha FYM + ZSB	N5
75% RDF + 2.5 t/ha FYM + ZSB	N6
100% RDF (120:60:40 N-P-K kg/ha)	N7

* Foliar application of zinc (0.5%) was done at tillering, milking and dough stage



R_1	R_2	R_3
Z_2N_4	Z_3N_4	Z_1N_4
Z_2N_2	Z_3N_2	Z_1N_2
Z_2N_1	Z_3N_1	Z_1N_1
Z_2N_6	Z_3N_6	Z_1N_6
Z_2N_3	Z_3N_3	Z_1N_3
Z_2N_5	Z_3N_5	Z_1N_5
Z_2N_7	Z_3N_7	Z_1N_7
Z_1N_6	Z_2N_6	Z_3N_6
Z_1N_5	Z_2N_5	Z_3N_5
Z_1N_4	Z_2N_4	Z_3N_4
Z_1N_7	Z_2N_7	Z_3N_7
Z_1N_1	Z_2N_1	Z_3N_1
Z_1N_3	Z_2N_3	Z_3N_3
Z_1N_2	Z_2N_2	Z_3N_2
Z_3N_1	Z_1N_1	Z_2N_1
Z_3N_7	Z_1N_7	Z_2N_7
Z_3N_3	Z_1N_3	Z_2N_3
Z_3N_2	Z_1N_2	Z_2N_2
Z_3N_5	Z_1N_5	Z_2N_5
Z_3N_4	Z_1N_4	Z_2N_4
Z_3N_6	Z_1N_6	Z_2N_6

Field Layout during experimentation

3.7 Agronomic zinc fortification

Agronomic bio fortification, involves physical incorporation of fertilizers and other agronomic methods into agricultural system. Agronomic bio fortification is a fertilizer-based strategy which encompasses the use of chemical fertilizers, manure, bio fertilizers though different application methods like seed priming, soil less cultivation, soil application and sprinkling optimized fertilizer solution on leaf. Compared to soil fertilization, foliar fertilization with micro nutrients usually increases nutrient absorption and efficient allocation in the edible plant portions. In contrast to foliar feeding, which quickly corrects zinc deficiency in plants, soil treatment is typically done to increase the delivery of nutrients needed in large quantities. Agronomic bio-fortification typically relies on techniques for applying fertilizer, solubilizing mineral elements, and mobilizing nutrients from source to sink. In the experimental study agronomic zinc fortification was carried out by soil, foliar and soil + foliar application of zinc. The zinc source used was $ZnSO4.7H_2O$, which has a zinc content of 21%. Soil application of zinc at 25 kg/ha and foliar application of $ZnSO_4.7H_2O$ at 0.5% was carried out.

3.8 Cultural practices

This section provides a comprehensive description of the many cultural operations conducted during the experimentation:

Table 3.6: Scheduling of cultural operation starting from field preparation to harvest

S.No	Operations	Date	
		2021-22	2022-23
1	Field preparation	11-11-2021	05-11-2022
2	Layout preparation	12-11-2021	06-11-2022
3	FYM application in the field	12-11-2021	07-11-2022
4	Seed treatment	19-11-2021	14-11-2022
5	Fertilizer application and sowing	20-11-2021	15-11-2022
6	First irrigation	10-12-2021	04-12-2022
7	Hand weeding using a hand hoe	14-12-2021	09-12-2022

8	1/3 rd urea application (1st split)	16-12-2021	10-12-2022
9	First foliar spray of Zinc	24-12-2021	15-12-2022
10	Second irrigation	30-12-2021	21-12-2022
11	Third irrigation	25-01-2022	20-01-2023
12	1/3 rd urea application (2nd split)	28-01-2022	27-01-2023
13	Fourth irrigation	15-02-2022	10-02-2023
14	Herbicide application	22-02-2022	01-02-2023
15	Second foliar spray of Zinc	28-02-2022	21-02-2023
16	Third foliar spray of Zinc	07-02-2022	29-02-2023
17	Fifth irrigation	10-03-2022	05-03-2023
18	Harvest	12-04-2022	06-04-2023
19	Weighing and threshing	13-04-2022	08-04-2023
20	Cleaning, winnowing, threshing	14-04-2022	08-04-2023

3.8.1 Field preparation

Tractor-mounted tools were used to prepare the experimental field. Land was prepared by one deep ploughing with disc harrow, cross ploughing with cultivator (twice), and planking. Uniform pre-sowing irrigation was provided to ensure favourable conditions for seed emergence.

3.8.2 Sowing

A manual line-sowing procedure was used to sow the wheat seeds at a depth of 5 cm, considering a seed rate of 100 kg/ha. Soon after the seeds were sown, the furrows were covered with soil.

Plate 3.1: Land preparation before sowing

3.8.3 Fertilizer application

Nitrogen, phosphorus, and potassium were applied according to the treatments. Primary macro nutrients used were urea (46% N), DAP (18% N, 46% P_2O_5), and MOP (60% K_2O), respectively. One-third of the nitrogen was administered as an initial dose. At the same time, the remaining two-thirds were divided equally and applied in two separate doses throughout the tillering and booting periods.

Plate 3.2: (a) FYM application (b) Fertilizer application (c) Manual sowing

Zinc application

Soil zinc was applied as basal as per the treatments. Zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) was sprayed at 0.5% at tillering, milking, and dough stages. Foliar spraying of zinc at 0.5% was prepared by mixing 5 g of ZnSO4.7H2O and 2.5g of slaked lime in one litre of water. Slaked lime was applied to avoid the scorching effect on leaves.

Plate 3.3: Foliar application of zinc

Farm yard manure (FYM) application

FYM was collected from a local farmer and analyzed chemically to determine its nutrient composition. A week prior to seeding, FYM was applied according to the treatment and fully integrated into the corresponding plots. The nutrient composition of FYM obtained during both years is represented in Table 3.6.

Bio-fertilizer application

Various types of biofertilizers, such as Azotobacter, Phosphate solubilizing bacteria (PSB), and Zinc solubilizing bacteria (ZSB), were utilized in the study based on the specific treatment needs. The PSB and ZSB were administered at a dosage of 500 ml per 3 liters of water for 60 kg of seeds, while the Azotobacter was administered at a dosage of 250 ml per 3 liters of water for 60 kg of seeds.

Table 3.7: Nutrient composition in FYM used for the study

Particulars	2021-22	2022-23	Method employed	References
Total nitrogen (%)	0.53	0.55	Kjeldahl's digestion method	Jackson,1973
Total Phosphorus (%)	0.23	0.24	Vandomolybdo phosphoric acid yellow colour method	Jackson,1973
Total Potassium (%)	0.59	0.61	Flame photometry	Jackson, 1973
DTPA Zinc (mg/kg)	62	62	Atomic absorption spectroscopy	Lindsay & Norvell, 1978
Organic carbon (%)	10.7	11	Walkley and Black method	Jackson, 1973

3.8.4 Irrigation

Depending on the amount of rainfall, a total of 5 irrigation were given. In both years, the first irrigation was applied when the crop reached the CRI stage. Subsequent irrigation were given as per the need.

3.8.5 Weeding

2-4 D, a post-emergence herbicide, was used to suppress the late weed flush at a rate of 400 ml per hectare. Weeds were manually controlled throughout the latter growing season. The required quantity of herbicide stock solution was prepared separately in a container by dissolving it in half a litre of water. Then, water was added to make the necessary spray solution.

3.8.6 Harvesting

After 145–150 days, harvesting was carried out manually with the use of sickles. After harvesting, each net plot was sun-dried for two days. After sun drying, manual threshing was carried out separately, and harvested produce obtained from individual plots was weighed and collected in labeled bags. Once the grains were cleaned and winnowed, the yield was recorded independently. Following the deduction of the grain's weight from the bundle weight, the size of the net plot was used to compute the yield of straw and convert it into tonnes per hectare.

Plate 3.4: Harvesting and threshing operation in wheat crop

3.9 Sampling procedure

Proper sampling procedures were adopted to decrease the sampling error and increase the accuracy rate. Sample plants were tagged properly for field observation in situ. The analysis of plant samples is done in the laboratory after the materials are cleaned and dried properly, as needed.

3.10 Plant sampling

Plant samples were collected at periodical intervals, with a gap of 30 days. Five plants were randomly selected from each individual plot. The collected plants were cleaned, washed, and dried thoroughly in the laboratory and stored in poly bags for analysis.

3.11 Growth parameters

3.11.1 Plant height (cm)

Using a metre scale, the plant height of five initially tagged plants was measured at 30, 60, 90, and 120 DAS and at harvest from each plot. Before heading, height of the plant was taken in centimetres (cm) from the base till apex of leaf. Following heading, its taken between the spike's base and ground level. A mean height estimate was derived from the average height of the plants.

Plate 3.5: Recording plant height (cm) using measuring scale

3.11.2 Number of tillers per square meter

From five initially tagged plants in each plot, the number of tillers per plant was visually counted and then converted into a per metre square at 30, 60, 90 and 120 DAS (effective tillers).

3.11.2 Dry matter production (g/m^2)

At every 30-day interval, five plants were pulled from each plot and carefully cleaned. Following air drying, the entire plant samples were oven-dried for 48 hours at 70 degrees Celsius until a persistent weight was reached. The final dry weight was then determined and represented in grams per square metre.

3.11.3 Leaf Area Index

The LAI was evaluated at regular intervals of 30 days. Two sample leaves from each size category were selected, and the areas of each were independently measured using an automated leaf area metre. The average leaf area value was then multiplied by the total leaf number in each category, and the results were added up to estimate the sample's total leaf area. The leaf area index is a unit-less parameter.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Unit land area}}$$

Plate 3.6 Recording of leaf area using leaf area meter

3.11.4 Root length (cm)

The length of the longest root of 5 plants that were chosen randomly was measured at 30-day intervals. The average length was then calculated and reported in centimeters.

Plate 3.7: Recording root length using measuring scale

3.11.5 Root dry weight (g/plant)

The samples were taken at 30-day intervals. The roots of five distinct plants were randomly extracted from each plot using an auger and subsequently underwent meticulous cleaning. After that, the roots were first allowed to air dry before being oven dried for 48 hours at 70 degrees Celsius until a constant weight was reached. The root dry weight was recorded using an electronic balance.

3.12 Yield attributing characters

3.12.1 Number of spikes meter^{-2}

The number of spikes per square metre was counted from the net plot area.

3.12.2 Number of grains per spike

The average number of grains per spike was determined when the spikes from the tagged plants were harvested individually and the grains were counted separately.

3.12.3 Spike length (cm)

Spikes from five initially tagged plants were selected and harvested separately. After measuring the spike length in centimeters from base to apex, the average length was computed and noted.

3.12.4 Test weight (g)

The test weight was determined by randomly counting the weight of a thousand seeds from each plot.

3.12.5 Grain yield (t/ha)

Crops were harvested from net plot area after achieving physiological maturity. The grain yield thus received from net plot area is converted into tonnes per hectare (t/ha).

3.12.6 Straw yield (t/ha)

After the net plot area's plants were threshed, the straw was dried in the sun and weighed. The weight of straw, thus obtained, was converted into tonnes per hectare.

3.12.7 Harvest Index (%)

The economic yield ratio is determined as a percentage by dividing the grain yield by the total yield of grain and straw. The calculation can be done using the formula shown below.

$$\text{Harvest index (\%)} = \frac{\text{Economical yield (grain yield)}}{\text{Biological yield (grain + straw yield)}} \times 100$$

3.12.8 Grain: straw ratio

The grain: straw ratio for each treatment was recorded separately after the grain and straw yields from the respective plots were obtained. The formula was derived by dividing the grain yield from the same treatment by the straw yield.

3.13 Soil studies

Soil samples were collected from a research plot using a soil auger at 0 to 15 cm depth. After proper labelling, the soil samples were appropriately preserved.

3.13.1 Soil pH and electrical conductivity (EC)

Samples of dried soil weighing 20 g were taken and put into a 100 ml capacity beaker. 40 millilitres of distilled water (soil: water in a 1:2 ratio) were added, thoroughly mixed with a glass rod, and left undisturbed for an hour. The pH meter was calibrated using three buffer solutions (4, 7, and 9.2 pH). The pH of the soil suspension was measured using a pH meter. EC was also recorded from the prepared suspension using a conductivity meter (Jackson, 1973).

3.13.2 Organic carbon (%)

The soil OC was determined by Walkley and Black's rapid titration method as reported by Jackson (1973).

Plate 3.8: Recording pH using pH meter

3.13.3 Available Nitrogen (kg/ha)

The soil's available nitrogen was measured using the alkaline permanganate method, as suggested by Subbiah & Asija (1956).

Procedure

20 grams of soil were weighed and added to Kjeldahl's distillation assembly's flask. Once this flask was assembled, 100 milli litres of 0.32% $KMnO_4$ solution was added. Two drops of methyl red indicator were added to a 250 ml conical flask with 25 ml of N/50 H_2SO_4 pipetted. Make sure the delivery tube of the distillation apparatus is positioned beneath this conical flask so that it dips deeply into the flask's contents. Make sure the delivery tube of the distillation apparatus is positioned beneath this conical flask so that it dips deeply into the flask's contents. Distillation was then initiated, and roughly 150 ml of the distillate was collected. This was followed by a wet litmus paper test to confirm that ammonia was not coming out from the delivery tube. The quantity of accessible nitrogen (N) in the designated soil was subsequently ascertained by titrating the materials of the conical flask with an N/50 sodium hydroxide (NaOH) solution and determining the amount of NaOH required to reach the endpoint.

3.13.4 Available P_2O_5 (kg/ha)

Using Jackson's (1973) description of Olsen's method, the amount of available phosphorus in the soil was calculated.

Procedure of extraction

50 milli liters of Olsen's extract are added to a 250 millilitre flask or shaking bottle containing 2.5 grams of soil and 0.5 grams of phosphorus-free activated charcoal. Whatman filter paper No. 1 is used to filter the contents after they have been shaken for 30 minutes on a mechanical shaker. A blank was also run side by side.

Procedure

In a 50 ml volumetric flask, 10 ml of extract is taken, and 1-2 drops of 2, 4 dinitrophenol indicator are added. 5 N H_2SO_4 is then added to bring the pH down to 3.5. The end point should be colourless. Following pH correction, 8 ml of ascorbic acid solution is added, and 50 ml of distilled water is added to complete the volume. With the aid of a colorimeter and a 660 nm wavelength or red filter, the intensity of the colour was measured after 30 minutes and before two hours of colour development. The instrument was first adjusted to zero reading using a blank. The phosphorus content of the extract is determined by comparing the reading to the phosphorus standard curve.

3.13.5 Available K_2O (kg/ha)

Soil extraction using a neutral normal ammonium acetate solution, the amount of potassium that was available in the soil was ascertained. The potassium in the titrate and the extractant ratio of 1: 5 were calculated using a flame photometer in accordance with Jackson's (1973) protocol.

Procedure

5 g soil and 1 N ammonium acetate (25 ml) were taken in a shaking bottle on a horizontal shaker and shake for 5 minutes. Then the solution is filtered through Whatman filter paper No. 1. The flame photometer's K content is ascertained following the required calibration and standardization of the devices using 10, 20, and 30 ppm K solution.

3.13.6 Available Zinc (mg/g)

DTPA extractable soil Zn was obtained by extracting 10 g soil with 20 ml DTPA solution as per the standard procedure given by Lindsay & Norvell, 1978). Following two hours of continuous agitation at room temperature, the soil suspension underwent centrifugation and filtration. The Zn content in the extract was estimated by using an Atomic Absorption Spectrometer (AAS).

3.13.7 Bulk density (g/cc)

The core sampler method, as recommended by Singh *et al.* (1980), was used to determine the soil bulk density (ρb).

$$\text{Bulk density } (\rho b) = \frac{\text{Oven dry weight of soil}}{\text{Volume of soil}}$$

3.14 Quality parameters

3.14.1 Total nutrient content (%) and nutrient uptake (kg/ha) by the crop

Samples were ground with the aid of a mortar and pestle. The method as described by Jackson in 1973 was followed to determine the total nutrient concentration in samples.

Plant samples were analysed using an Atomic Absorption Spectro photometer (AAS) to determine their zinc content. Samples after oven drying were ground with the help of a mortar and pestle. 10ml of concentrated nitric acid was added to 0.5g of the sample and kept overnight for pre-digestion. Ultimately, digestion was carried out on a hot plate using an 8 ml di-acid digestion mixture that contained nitric acid and perchloric acid in a 9:4 ratio. After digestion, the digest was allowed to cool, diluted, and filtered using Whatman No. 1 filter paper. The samples were examined using an AAS device to determine the zinc concentration in each sample.

The following formula was used to determine uptake of nutrient by crop.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Grain/Straw dry weight (kg/ha) x Nutrient concentration (\%)}}{100}$$

In case of zinc, uptake was expressed in g/ha, and concentration was expressed in mg/kg.

Plate 3.9 : Digestion and estimation of plant samples

3.14.2 Chlorophyll content

Fully expanded leaf from each representative samples were taken at respective stages for estimation of total chlorophyll content. Using Arnon's (1949) colorometric method, 80 percent acetone was used to extract the chlorophyll. Total chlorophyll content was estimated using the formula given below

$$\text{Total Chlorophyll Content (mg. g}^{-1}\text{)} = \left(\frac{20.2\,A_{645}+8.02\,A_{663}}{a\,X\,1000\,X\,W}\right)X\,v$$

Where, A = Absorbance

W = fresh weight of sample in g

V = Extract volume (ml)

Plate 3.10: Grinding of plant sample for chlorophyll estimation

3.14.3 Protein content (%)

Sample weighing 1 g was combined with buffer solution (5 ml) and was centrifuged at 10000 g for 20 minutes at 4^0C. Standard curve was prepared and graph was plotted. A volume of 1 ml of the aliquot was combined with 5 ml of Bradford dye and allowed to incubate for 30 minutes. A wavelength of 595 nm was used for estimation. The protein content of the supernatant was estimated using the Bradford (1976) method, with bovine serum albumin (BSA) serving as a reference standard.

3.14.4 Hectolitre value (kg/hl)

The samples were transferred into a stainless-steel measuring cylinder with a capacity of 100 ml to determine their hectolitre weights. Using a round stroker, the excess wheat was levelled off, and the hectolitre value was calculated by weighing the wheat grains inside the cylinder.

3.14.5 Sedimentation volume(cc)

The Axford *et al.* (1979) technique was used to assess the sodium dodecyl sulphate sedimentation value of wheat samples. In this method, 5-gram flour were treated with 50 ml of distilled water and which was then followed by addition of 50 ml of sodium dodecyl sulfate -lactic acid reagent. Following a half-hour rest period for the mixture, the volume of settled particles was measured.

3.14.6 Grain appearance score

This was assigned based on the lustre, colour size and shape of grain. It received a subjective evaluation with a maximum score of 10.

3.15 Economic analysis

The economic analysis of different treatments was evaluated by considering the current market pricing of inputs and outputs, specifically straw and grain. The purchase and selling costs were utilized for each treatment to determine the benefit: cost ratio, net return, and gross return.

Gross return (₹/ha) = Selling price of grain (₹/t) × grain yield (t/ha) + selling price of straw (₹/t) x straw yield (t/ha).

Net return (₹/ha) = Gross return – total cost of cultivation

$$\text{Benefit: cost ratio} = \frac{\text{Net return}}{\text{Cost of cultivaiton}}$$

3.16 Statistical analysis

The "F" test was employed to ascertain the significance of the treatment effect. Standard errors of differences between various treatment groups and their interactions were computed at a 5-percent probability where 'F' was significant. The treatment means calculated from the original value are also shown with the converted values in parentheses.

The data collected from the different characters under investigation were analyzed using Gomez's (1984) variance analysis method. For every character, an analysis of variance (ANOVA) table was created, as listed below.

To compare the mean value of treatments, the standard error and critical difference values were computed.

(a) Emergence stage

(b) CRI stage

(c)Tillering stage

(d) Jointing stage

(e)Booting stage

(f) Anthesis stage

(g) Milking stage (h) At maturity

Plate 3.11: Different growth stages in wheat crop

Plate 3.12: Experimental field at maturity

CHAPTER - 4

RESULTS AND DISCUSSIONS

Experimental findings and their interpretations on the topic "**Effect of Integrated Nutrient Management and Agronomic Zn fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.)**" are given in this chapter with respect to main and interaction effects. The results showing the impact of various INM practices and agronomic zinc fortification methods on various growth, yield and yield attributes, quality aspects and economics have been discussed in this chapter. Furthermore, a deliberate effort has been made to apply pertinent scientific arguments gleaned from the corpus of literature to show how the experimental results correspond to the associated causes and effects.

4.1. Effect of INM and agronomic Zn fortification on growth, yield and quality of wheat

The agronomic zinc application methods and integrated nutrient management methods are termed as Z1 for soil Zn application, Z2 for foliar zinc application, Z3 for combined soil and foliar application of Zinc, N1, N2, N3, N4, N5, N6 and N7 for different integrated nutrient management methods like 50% RDF + 5 t/ha FYM + Azotobacter, 75% RDF + 2.5 t/ha FYM + Azotobacter, 50% RDF + 5 t/ha FYM + PSB, 75% RDF + 2.5 t/ha FYM + PSB, 50% RDF + 5 t/ha FYM + ZSB, 75% RDF + 2.5 t/ha FYM + ZSB and 100% RDF (120:60:40 N-P-K kg/ha).

4.1.1 Growth parameters

Plant height (cm)

The height of the plant is a crucial indicator of the growth of a plant. It is an essential physiological component for the crop's growth. Table 4.1 displays the plant height data collected at periodic intervals during both years. As crop age increased in both years, a discernible gradual rise in plant height was noticed. A notable increase in plant height was documented during the grand growth stage, which lasts from 60 to 120 DAS. In addition, the pace of plant height growth decreased from 120 DAS until maturity.

During both years, 2021-22 and 2021-22, plant height was significantly affected by the application of different agronomic zinc fortification approaches and integrated nutrient management at later growth stages, whereas at 60 DAS, plant height was significantly influenced by INM approaches. However, the effect on plant height due to agronomic zinc fortification was non-significant. Although the plant increased in height gradually from 30 to 120 days, the greatest rate of development occurred between 60 and 90 days.

Plant height at 30 DAS was not significantly impacted by integrated nutrient management, agronomic zinc fortification techniques, or interaction during the two study years. In 2021–2022, there was a noticeable variation in plant height from the grand growth stage when the agronomic zinc fortification method was applied. Maximum plant height to the tune of 38.1, 81.4, 100.4 and 103.5 cm was observed at 60, 90, and 120 DAS and harvest with the combined application of soil and foliar application of Zn as compared to sole soil and foliar application of Zn. This depicts that the combined application of zinc as soil + foliar helps in providing proper nourishment to the crop and helps in improving the activity of meristematic cells, thereby resulting in improved cell elongation. The findings were consistent with the research conducted by Suresh *et al.* (2016) and Nazir *et al.*(2021).

Within the realm of INM strategies, at 60 DAS, a significant maximum increment in the height of the plant to the tune of 38.54 cm was observed with 75% RDF + 2.5 t/ha FYM + *Azotobacter* (N2). Significantly greater plant heights of 82.3, 102.4, and 103.9 cm were obtained at 90,120 DAS and harvest, and these results were found to be statistically comparable to those of N6 and N7. Plant height was unaffected by the interaction effect of the two study components, agronomic zinc fortification techniques and integrated nutrient management from the beginning to the end of crop growth.

It was discovered that plant height in the second year (2022–2023) was marginally greater than in the first. The probable reason for this might be the occurrence of favourable weather which accelerated the plant's vegetative growth. The combined soil and foliar application of zinc, or Z3 (44.07 cm), produced a significantly higher plant height at 60 DAS among the various agronomic zinc fortification techniques. In comparison, the soil application of zinc produced the lowest plant height (40.05 cm). A comparable pattern was observed at 90 and 120 days after sowing (DAS), as well as at the time of harvest.

Plant height was noted to have a significant impact due to several integrated nutrient management practices at every growth stage, except 30 DAS. Within the various INM approaches, the application of 75% RDF + 2.5 t/ha FYM + Azotobacter (N2) superseded the height of the plant from 60 DAS till harvest, from 44.5 to 107.6 cm, respectively. Interaction between the two aspects of the study was found to have a non-significant effect on plant height during all the growth stages.

The study of plant height data from both years revealed a substantial impact of the agronomic zinc fortification strategy on all growth phases except at 30DAS. Markedly increased plant heights of 41.1, 82.6, 102.3, and 105.1 cm were obtained with the soil + foliar application of zinc (Z3), whereas the minimum values of 38.1, 80.1, 98.8, and 100.7 cm were obtained with the soil application of zinc (Z1).

At 30 days after sowing (DAS), there was no substantial influence in plant height due to the various INM approaches. Albeit, plant height was significantly affected at later stages of growth, i.e., at 60, 90, 120 and harvest with 75% RDF + 2.5 t/ha FYM + ZSB (Z6) treatment with values of 42.7, 85.2, 105.9 and 106.5 cm respectively. It was observed in the pooled data that there was a non-significant interaction between agronomic zinc fortification methods and integrated nutrient management practices.

One possible explanation for the present experimental finding may be because consistent zinc provision to the plant during its growth phases facilitates an abundant supply of these at ideal concentrations, leading to enhanced cell division and elongation, which in turn improves plant height. These observations closely matched the conclusions made by Prajapati *et al.* (2022). Zinc improved plant height in tomato crops by lengthening inter-node spacing (Kaya & Higgs, 2002). As a co-factor, zinc stimulates several hormones, including auxin, necessary for plant growth and development. Thus, leaf deformation and inter-node shortening are caused by zinc deficiency (Begum *et al.,* 2016). Applying zinc, therefore, has a significant impact on increasing plant height. Due to its significance as a component of all six classes of enzymes needed to promote crop growth, zinc is a crucial micronutrient (Imran *et al.,* 2015). Because of several soil constraints such as high pH, low OM, and quick absorption in alkaline calcareous soil, limited mobility of the zinc added to the soil limits its availability to the plant (Alloway, 2008). A plant can only get a limited amount of nutrients through foliar treatment; therefore, it cannot cover all of its needs. Additionally, foliar spray should only be used as a complement to soil treatment rather than as a replacement (Arshad & Ali, 2016; Patil & Chetan, 2018). According to Pooniya *et al.* (2012) and Haslett *et al.* (2001), applying zinc topically and sub-surface was a successful way to increase plant mobility of zinc and lessen the adverse effects of zinc shortage.

An appropriate combination of nutrient sources improves soil characteristics and creates an atmosphere conducive to crop development. Azotobacter, provided along with 75 per cent of RDF and FYM (2.5 t/ha), helps in stimulating plant growth by producing phytohormones like IAA, cytokinin and giberreline (Hindersah *et al.,* 2020). *Azotobacter* increases the availability of nitrogen, which encourages the synthesis of auxin and ultimately leads to a rise in plant height. The benefits of synthetic fertilisers, biofertilizer inoculation, and organic FYM include improved soil physical properties, increased fertility, and increased availability of various nutrients for plant uptake, all of which promote the growth of wheat plants (Mahato & Kafle, 2018). The research outcomes were in line with the research observations of Egamberdieva *et al. (*2008) and Patel, (1969), who suggested that injection of nitrogen promotes metabolic and auxin activities of plants which directly helps in improving the height of the plant

Table 4.1: Effect of different treatments on plant height (cm) of wheat

Treatments	30 DAS			60 DAS			90 DAS			120 DAS			At harvest		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification															
Z1: Soil application of Zn	15.2	15.7	15.4	36.1	40.1	38.1	79.0	81.3	80.1	97.9	99.7	98.8	100.0	101.4	100.7
Z2: *Foliar application of Zn	14.3	15.1	14.7	36.8	41.4	39.1	79.3	83.0	81.1	98.8	101.0	99.9	100.8	102.9	101.8
Z3: Soil and foliar application of Zn	15.1	15.8	15.4	38.1	44.1	41.1	81.4	83.8	82.6	100.4	104.1	102.3	103.5	106.7	105.1
SEm(±)	**0.1**	**0.2**	**0.1**	**0.4**	**0.6**	**0.3**	**0.5**	**0.4**	**0.4**	**0.4**	**0.7**	**0.5**	**0.6**	**0.8**	**0.6**
CD at 5%	**NS**	**NS**	**NS**	**NS**	**2.3**	**1.4**	**1.9**	**1.7**	**1.4**	**1.5**	**2.9**	**2.0**	**2.4**	**3.3**	**2.5**
Integrated Nutrient Management															
N1: 50% RDF + 5 t/ha FYM + Azotobacter	14.7	14.8	14.7	36.7	41.0	38.8	79.8	82.2	81.0	98.1	101.1	99.6	100.7	102.8	101.8
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	15.1	15.8	15.4	38.5	44.5	41.5	82.3	85.3	83.8	102.4	105.7	104.0	103.9	107.6	105.7
N3: 50% RDF + 5 t/ha FYM + PSB	14.0	14.8	14.3	34.7	38.3	36.5	77.5	79.2	78.4	93.8	95.5	94.6	98.5	98.6	98.6
N4: 75% RDF + 2.5 t/ha FYM + PSB	14.9	15.1	15.0	36.0	40.5	38.3	78.7	81.6	80.2	98.4	100.9	99.7	100.9	103.4	102.1
N5: 50% RDF + 5 t/ha FYM + ZSB	14.9	16.0	15.4	36.9	42.5	39.7	79.5	82.3	80.9	99.5	101.4	100.5	101.3	103.6	102.4
N6:75% RDF + 2.5 t/ha FYM + ZSB	15.1	15.9	15.5	37.8	43.3	40.5	80.7	84.7	82.7	100.9	103.2	102.0	102.5	105.5	104.0
N7: 100% RDF (120:60:40 N-P-K kg/ha)	15.5	16.1	15.8	38.3	42.6	40.5	80.7	83.4	82.1	100.4	103.4	101.9	102.2	104.3	103.3
SEm(±)	**0.3**	**0.4**	**0.3**	**0.6**	**0.8**	**0.5**	**0.7**	**0.9**	**0.5**	**0.8**	**1.3**	**0.8**	**0.9**	**1.1**	**0.7**
CD at 5%	**NS**	**1.1**	**0.7**	**1.7**	**2.3**	**1.6**	**2.1**	**2.6**	**1.5**	**2.3**	**3.9**	**2.3**	**2.7**	**3.3**	**1.9**
Zn X INM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Number of tillers/m^2

Tiller density is a crucial crop development characteristic that has a direct effect on grain yield. Table 4.2 presents data on the number of tillers/m^2 at various growth phases. Number of tillers increased from 30 to 60 days, peaked at 60 days, and then started to decline, possibly due to death of tillers. The primary cause of tiller death is competition between and among tillers for environmental resources (Hunt & Pararajasingham, 1995).

During the first year of the study (2021-22), tiller count was found to significantly affect 30, 60, and 90 DAS and effective tillers/m2 with agronomic zinc fortification approaches, integrated nutrient management, and interaction. The combination treatment of soil and foliar zinc resulted in a significantly greater tiller number per square meter.

Considering the second aspect of the study, it was observed that at 30 DAS, a significantly higher number of tillers/m^2 (235.1) was obtained with the application of 100% RDF (120:60:40 N-P-K kg/ha (N7) compared to other treatments. The maximum number of tillers (433.2) during the crop growth was attained at 60 DAS with N6 application. With N6 treatment, a significantly higher number of tillers, 421.6 and 389.8, was obtained at 90 and 120 DAS, and it was discovered to be similar with 50% RDF + 5 t/ha FYM + ZSB (N5). The application of 50 per cent RDF combined with 5 tons per hectare of FYM and PSB resulted in the lowest tiller count per square meter (N3).

Tiller count was found to be significantly impacted at all growth stages by the interaction between agronomic zinc fortification and various integrated nutrient management practices. Z3N6 obtained the highest increment in effective tiller count per m2, which was found to be at par with Z3N7, Z3N5, Z3N4, Z3N2, Z2N6, and Z2N5 during 2021-22.

The tiller number was noticed to be significant with agronomic zinc fortification, integrated nutrient management and interactions during the second year of study (2022-23). Zinc (Z3) applied foliar in the soil resulted in a noticeably increased tiller number per square metre at 60, 90 and 120 DAS (451.1, 430.5 and 387.9). A maximum number of effective tillers/m^2 was achieved with soil + foliar application of zinc (Z3 - 387.9), which was then followed by foliar application (Z2 - 359.9) and soil application of Zn (Z1- 340.9).

With respect to integrated nutrient management, at 30 DAS similar number of tillers/m^2 (235.7) was recorded with Z6 and Z7 application. At 60 days after sowing (DAS), the use of 75per per cent RDF along with 2.5 tons per hectare of farmyard manure (FYM) and zinc sulfate (ZSB) resulted in a considerably greater number of tillers per square meter (459.3). Superior tiller count/m^2 was achieved with 75% RDF + 2.5 t/ha FYM + ZSB (N6) (434.5) at 90 DAS which was found to be at par with 50% RDF + 5 t/ha FYM + ZSB (N5) (418.5). The trend followed in obtaining effective tillers/m^2 was similar to that followed in 60DAS.

Interaction due to agronomic zinc fortification and different integrated nutrient management practices was found to significantly impact tiller count at all the growth stages (Table 4.3, Fig 4.1). Maximum enhancement in effective tillers/m2 was obtained with Z3N6, which was found to be at par with Z3N7, Z3N5, Z3N4, Z3N2, Z2N6, and Z2N5.

The impact of agronomic zinc fortification techniques on the tiller count per square meter was determined to be significant at 30, 60, and 90 DAS based on pooled data. Tiller count from the grand growth stage till harvest was noticed to be substantially higher with the Z3 method of zinc application to the tune of 440.4, 421.8 and 386.3, respectively, which was then followed by foliar zinc application and soil application of zinc. It was also clear from the findings that the maximum no. of effective tillers/m2 achieved with combined soil and foliar application of zinc, i.e., Z3 was 14.22 % higher than soil application of zinc (Z1).

A number of tillers/m^2 was found to have a significant influence on different integrated nutrient management practices. At 30 DAS, N7 (235.4) recorded a significantly higher tiller count per square metre than 75% RDF + 2.5 t/ha FYM + ZSB (N6) (231.5). The highest number of tillers per square meter was achieved at 60, 90, as well as 120 days after sowing (DAS) while using a combination of 75 per cent RDF, 2.5 tons per hectare of farmyard manure (FYM), and ZSB. This was closely followed by a combination of 50% RDF, 5 tons per hectare of FYM, and ZSB (N5). The least tiller count m^{-2} was registered with N3 treatment. The interaction due to both aspects of the study was found to have a significant effect where the maximum count for productive tillers m^{-2} was achieved with Z3N6 and was followed by Z3N2, Z3N7, Z3N5, Z2N6 and Z2N5 (Table 4.3).

Combined application of zinc as soil and foliar helps in a continuous steady supply of nutrients to the plant and improves the tiller count as zinc plays an irreplaceable role in many physiological processes (Dawar *et al.,* 2022). The primary factor influencing auxin (IAA) and cytokinin (CTK) production is zinc. Zn shortage causes a reduction in IAA production and transport as well as an acceleration of IAA breakdown, which inhibits proper tiller development (Liu *et al.,* 2022).

The soil-dwelling zinc solubilizing microbiota solubilizes an inaccessible form of 'zinc', a special micronutrient required for plant growth (Kamran *et al.,* 2017). Increasing tiller number per plant is facilitated by zinc (Liu *et al.,* 2022). A sufficient amount of zinc encourages cell proliferation and elongation because the appropriate growth of tillers in meristem tissue requires 10 times the zinc of mature leaf blades (Fongfon *et al.,* 2021). FYM plays a direct and indirect role in contributing to plant nutrition. The release of micronutrients and increased availability of macronutrients resulting from FYM treatment might have contributed to the improvement of wheat production quality. Given that FYM contains a variety of primary, secondary, and micronutrients, applying FYM together with inorganic and biofertilizers functions as a slow-release nutritional supply (Sreethu *et al.,* 2024). When combined with chemical and organic sources, a sufficient amount of zinc has promoted cell division and growth (Sharma & Banik, 2012). FYM binds to the metal cations in the soil to produce various complexes that limit their loss from the system. Mathan *et al.,* 1996 and Balyan *et al.,* 2002 have similarly demonstrated positive effects of FYM on urd bean growth metrics. The findings are corroborated by the conducted studies done by Rehman *et al.,* 2018, Patel *et al.,* 2022, and Tuiwong *et al.,* 2022.

Table 4.2: Effect of different treatments on number of tillers/m^2 of wheat

Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**Effective tillers**		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification												
Z1:Soil application of Zn	212.9	214.66	213.8	381.1	387.4	384.3	359.9	374.3	367.1	335.5	340.9	338.2
Z2:*Foliar application of Zn	206.2	210.45	208.3	398.1	402.6	400.3	376.3	387.2	381.7	355.8	359.9	357.8
Z3: Soil and foliar application of Zn	211.7	215.74	213.7	429.7	451.1	440.4	413.0	430.5	421.8	384.6	387.9	386.3
SEm(±)	**1.2**	**1.0**	**0.9**	**3.2**	**5.3**	**3.1**	**4.8**	**5.2**	**3.6**	**3.4**	**4.3**	**2.0**
CD at 5%	**5.0**	**4.0**	**3.6**	**12.5**	**20.8**	**12.3**	**19.1**	**20.6**	**14.3**	**13.7**	**17.1**	**8.2**
Integrated Nutrient Management												
N1: 50% RDF + 5 t/ha FYM + Azotobacter	206.1	204.1	205.1	387.6	394.1	390.8	366.1	379.1	372.6	346.2	349.5	347.9
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	207.4	212.8	210.1	408.4	421.0	414.7	386.4	401.9	394.1	363.7	364.2	364.0
N3: 50% RDF + 5 t/ha FYM + PSB	183.7	185.6	184.7	360.5	362.1	361.3	342.4	349.3	345.9	314.3	323.4	318.9
N4: 75% RDF + 2.5 t/ha FYM + PSB	210.2	217.1	213.6	400.0	406.1	403.0	376.5	390.8	383.7	356.7	362.3	359.5
N5: 50% RDF + 5 t/ha FYM + ZSB	202.1	204.2	203.2	423.0	433.0	428.0	404.0	418.5	411.2	373.4	377.9	375.7
N6:75% RDF + 2.5 t/ha FYM + ZSB	227.2	235.7	231.5	433.2	459.3	446.2	421.6	434.5	428.1	389.8	394.3	392.1
N7: 100% RDF (120:60:40 N-P-K kg/ha)	235.1	235.7	235.4	408.2	420.2	414.2	384.5	407.2	395.9	366.1	368.7	367.4
SEm(±)	**1.8**	**1.6**	**1.2**	**4.8**	**5.8**	**3.4**	**6.6**	**6.1**	**4.9**	**4.7**	**4.4**	**3.1**
CD at 5%	**5.0**	**4.5**	**3.4**	**13.8**	**16.9**	**9.8**	**19.0**	**17.6**	**14.2**	**13.7**	**12.9**	**9.1**
Zn X INM	**8.7**	**7.9**	**5.9**	**23.8**	**29.2**	**16.9**	**33.0**	**30.5**	**24.6**	**23.7**	**22.3**	**15.8**

Table 4.3: Interaction effect of agronomic zinc fortification methods with integrated nutrient management on effective tillers per square meter

Treatments	2021-2022				2022-2023				Pooled			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	356.9	319.9	361.9	346.2	357.0	324.2	367.4	349.5	356.9	322.1	364.6	347.9
N2	325.2	361.6	404.2	363.7	325.4	362.0	405.3	364.2	325.3	361.8	404.8	364.0
N3	308.2	307.9	326.9	314.3	323.5	316.5	330.2	323.4	315.9	312.2	328.5	318.9
N4	316.9	361.9	391.2	356.7	324.2	364.1	398.5	362.3	320.6	363.0	394.8	359.5
N5	327.6	392.9	399.9	373.4	333.1	399.1	401.4	377.9	330.3	396.0	400.7	375.7
N6	366.2	397.2	405.9	389.8	373.9	400.8	408.3	394.3	370.0	399.0	407.1	392.1
N7	347.2	348.89	402.2	366.1	349.2	352.4	404.4	368.7	348.2	350.6	403.3	367.4
Mean	335.5	355.8	384.6		340.9	359.9	387.9		338.2	357.8	386.3	
Z×N (CD at 5 %)	**23.7**				**22.3**				**15.8**			

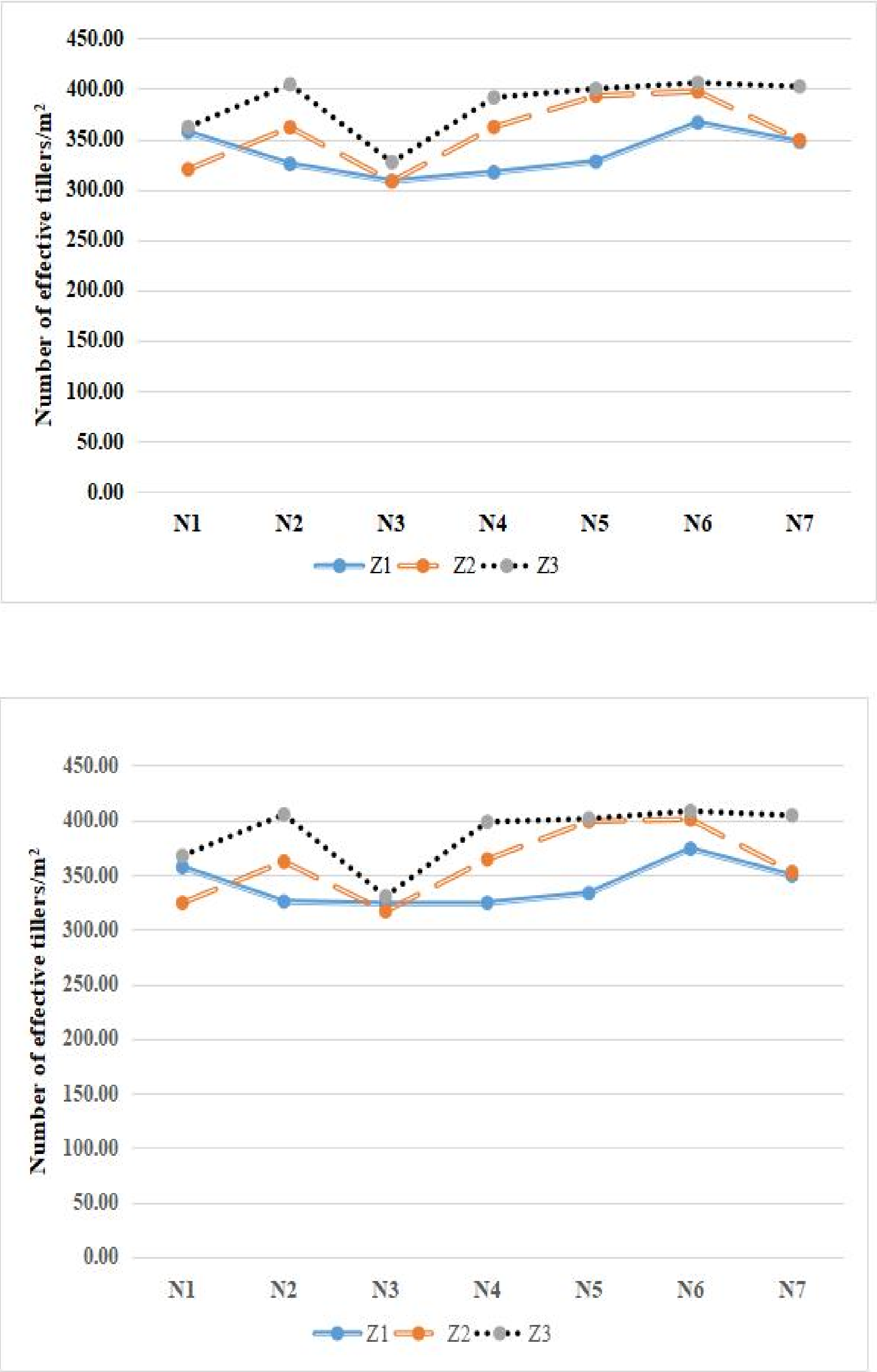


Fig 4.1: Representing the effect of interaction on effective tillers/m^2 of wheat at harvest during 2021-22 and 2022-23

Dry matter accumulation (g/m^2)

Table 4.4 shows data on DMA at various stages of the wheat crop. Throughout the two study years, it was discovered that the accumulation of dry matter occurred quickly between 60 and 90 DAS.

Throughout 2021–2022, the crop's dry matter accumulation varied greatly throughout all growth stages when agronomic zinc fortification techniques were used. At 60 DAS, maximum dry matter accumulation (154.8 g/m^2) was obtained with the combined soil and foliar application of zinc (Z3), which was followed by foliar application of zinc alone (Z2) (143.0 g/m^2) and soil application of zinc alone (Z1) (138.5 g/m^2). A similar trend was followed at all subsequent growth phases. Considering the next aspect of the study, there was a notable effect at all growth stages due to integrated nutrient management approaches. At 60 DAS, a significantly higher (155.8g/m^2) value on dry matter accumulation was acquired using the N6 method and was determined to be statistically equivalent to N5 (150.5 g/m^2). Significantly higher than all other treatments, 75% RDF + 2.5 t/ha FYM + ZSB (N6) showed superior dry matter accumulation (577.2 g/m^2) at 90 DAS. From 120 DAS till physiological maturity, there was a noticeable increase in dry matter accumulation, with values of 792.4 and 870.1 g/m^2, respectively, following a consistent pattern. and the least value (731.0 and 805.7 g/m^2) was noted with 50% RDF + 5 t/ha FYM + PSB (N3). The combined influence of both research aspects was observed to substantially impact the formation of dry matter.

At harvest, maximum dry matter accumulation was obtained with Z3N6, which was found to be statistically at par with Z3N5, Z3N7, Z3N2, Z2N6, and Z2N5. The least accumulation of dry matter was noticed with the Z2N3 combination (Table 4.5).

The second year of study, 2022-23, also followed the same trend as that of the first year. The maximum accumulation of dry matter from 60 DAS till harvest was found to be recorded with the Z3 method of zinc application, and the most negligible value for the same was registered with Z1. Significantly higher dry matter accumulation (49.3, 165.0, 582.6, 800.2 and 873.3 g/m$^{2)}$ was acquired with N6. The interaction due to both aspects of the study was found to have a significant effect on DMA. The highest DMA at harvest was obtained with combined soil +foliar application along with 75% RDF + 2.5 t/ha FYM + ZSB (Table 4.5, Fig 4.2).

The effect of agronomic zinc fortification was found to be significant at 30 DAS, despite the fact that almost similar values were obtained with soil application alone (46.7 g/m^2) and with combined soil + foliar application of zinc (46.8 g/m^2). There was a significant effect on the accumulation of dry matter with the application of agronomic zinc fortification methods, where the maximum value at all the stages was received with the Z3 method. When soil+foliar zinc was applied at harvest, there was a 4.24 per cent increase in DMA compared to soil zinc application alone.

The observation clearly indicated that the dry matter buildup was considerably influenced by various INM approaches. The application of 75 per cent of RDF with 2.5 t/ha FYM and ZSB (N6) resulted in a significantly higher dry matter accumulation (48.4 g/m^2) at 30 DAS, while 50% RDF + 5 t/ha FYM + PSB (N3) produced the least amount of dry matter accumulation (42.0 g/m^2). During harvest, the dry matter accumulation value varied between 809.2 and 871.7 g/m^2. N6 treatment resulted in a significantly superior dry matter accumulation of 871.7 g/m^2. The combined influence of both elements of the investigation was observed to have a substantial impact on the formation of dry matter. From the aforementioned results, it can be concluded that adding organic sources to inorganic and biofertilizers was more advantageous in enhancing the accumulation of dry matter. This was in support of the research outcomes of Dash *et al.* (2011) in rice crops.

Zinc may be used foliar and in the soil to help with dry matter buildup, which is crucial for achieving greater yields. According to Narwal *et al.* (2010), increasing grain production is more dependent on soil application than micro-nutrient concentration. One possible explanation for the rise in dry weight after zinc delivery could be an augmentation in photosynthesis. Zinc is crucial in the process of photosynthesis since it serves as a vital component of carbonic anhydrase, an enzyme necessary for the proper functioning of Rubisco. Rubisco is responsible for accepting carbon dioxide in C3 plants (Supuran, 2008).

Table 4.4: Effect of different treatments on dry matter accumulation (g/m^2) of wheat

Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**			**At harvest**		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification															
Z1:Soil application of Zn	46.2	47.2	46.7	138.5	139.9	139.2	522.5	525.5	524.0	754.4	759.3	756.9	830.4	833.3	831.9
Z2:*Foliar application of Zn	42.6	42.9	42.8	143.0	148.1	145.6	535.5	539.6	537.6	763.6	767.7	765.6	840.4	841.6	841.0
Z3:Soil and foliar application of Zn	46.4	47.2	46.8	154.8	163.1	158.9	568.1	577.7	572.9	787.7	798.7	793.2	862.5	871.9	867.2
SEm(±)	**0.3**	**0.4**	**0.3**	**1.7**	**1.4**	**0.9**	**4.9**	**8.3**	**5.7**	**4.9**	**4.5**	**3.7**	**4.2**	**6.1**	**3.8**
CD at 5%	**1.2**	**1.6**	**1.1**	**6.9**	**5.7**	**3.5**	**19.3**	**32.7**	**22.5**	**19.4**	**17.7**	**14.7**	**16.4**	**24.1**	**14.8**
Integrated Nutrient Management															
N1: 50% RDF + 5 t/ha FYM + Azotobacter	44.2	44.4	44.3	140.5	145.7	143.1	530.4	533.1	531.8	759.2	762.9	761.1	835.2	837.5	836.3
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	45.8	46.4	46.1	146.8	155.0	150.9	545.0	551.0	548.0	776.5	780.3	778.4	852.8	855.7	854.2
N3: 50% RDF + 5 t/ha FYM + PSB	41.8	42.3	42.0	132.9	132.7	132.8	508.5	520.6	514.5	731.0	739.0	735.0	805.7	812.7	809.2
N4: 75% RDF + 2.5 t/ha FYM + PSB	44.5	45.1	44.8	143.0	147.8	145.4	538.0	543.1	540.6	762.8	771.0	766.9	837.9	845.1	841.5
N5: 50% RDF + 5 t/ha FYM + ZSB	46.2	46.8	46.5	150.5	154.0	152.2	555.5	558.9	557.2	778.8	789.3	784.0	854.3	861.9	858.1
N6:75% RDF + 2.5 t/ha FYM + ZSB	47.4	49.3	48.4	155.8	165.0	160.4	577.2	582.6	579.9	792.4	800.2	796.3	870.1	873.3	871.7
N7: 100% RDF (120:60:40 N-P-K kg/ha)	45.6	46.1	45.9	148.6	152.7	150.6	539.5	543.8	541.6	779.5	783.7	781.6	854.9	856.4	855.7
SEm(±)	**0.4**	**0.5**	**0.4**	**2.2**	**1.8**	**1.4**	**6.6**	**6.5**	**4.9**	**6.0**	**7.0**	**4.5**	**5.7**	**6.9**	**5.6**
CD at 5%	**1.3**	**1.5**	**1.0**	**6.3**	**5.1**	**4.0**	**19.0**	**18.7**	**14.1**	**17.2**	**20.1**	**12.9**	**16.5**	**19.8**	**16.0**
Zn X INM	**2.3**	**2.5**	**1.8**	**10.9**	**8.9**	**7.0**	**32.9**	**32.4**	**24.4**	**29.8**	**34.9**	**22.3**	**28.5**	**34.4**	**27.7**

Table 4.5: Interaction effect of agronomic zinc fortification methods with integrated nutrient management on DMA (g/m^2) at harvest

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	845.9	812.8	846.8	835.2	849.1	802.6	860.9	837.5	847.5	807.7	853.8	836.4
N2	828.4	849.5	880.7	852.8	831.7	844.3	890.9	855.7	830.1	846.9	885.8	854.2
N3	802.9	787.6	826.7	805.7	809.1	788.1	840.8	812.7	806.0	787.8	833.7	809.2
N4	809.0	847.8	857.0	837.9	812.1	856.4	866.7	845.1	810.5	852.1	861.8	841.5
N5	828.5	867.0	867.3	854.3	837.5	870.8	877.5	861.9	833.0	868.9	872.4	858.1
N6	853.9	869.1	887.4	870.1	846.2	878.5	895.2	873.3	850.1	873.8	891.3	871.7
N7	844.3	849.2	871.3	854.9	847.3	850.4	871.6	856.4	845.8	849.8	871.4	855.7
Mean	830.4	840.4	862.4		833.3	841.6	871.9		831.9	841.0	867.2	
Z×N (CD at 5 %)	**28.5**				**34.4**				**27.7**			

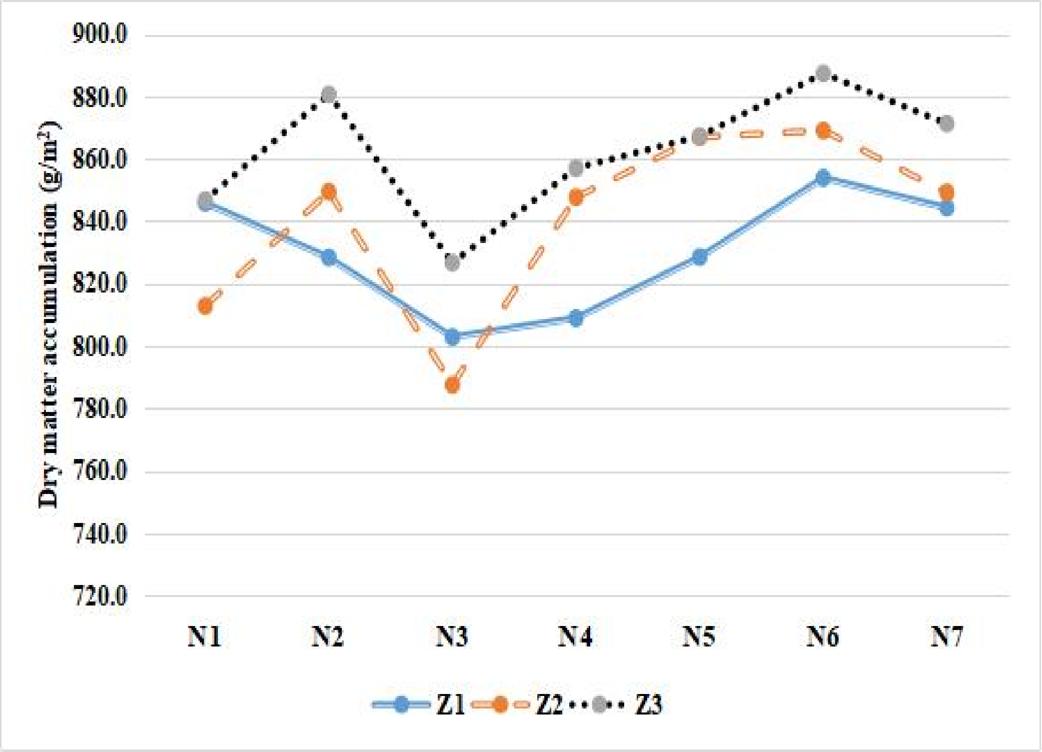


Fig 4.2: Representing the effect of interaction on dry matter accumulation (g/m^2) of wheat at harvest during 2021-22 and 2022-23

Leaf Area Index (LAI)

The LAI is an important factor in controlling crop yield, thus determining the active photosynthetic area. A strong correlation exists between the LAI and the quantity of photo-synthetically active radiation intercepted. A higher LAI results in more PAR intercepted, promoting better crop growth and higher yield.

A perusal of the data related to LAI from Table 4.6 revealed that the agronomic zinc fortification approaches at all stages except at 30 DAS had a significant effect on LAI during the year 2021-22. Maximum values to the tune of 3.04, 3.94 and 3.36 were obtained at 60, 90 and 120 DAS in combined soil + foliar treated plots and were discovered to be considerably greater than those of the other two treatments. Different INM approaches also showed a notable effect on improving LAI at all stages other than 30 days after sowing. Among the second aspect of the study, N6 acquired a higher LAI than all the rest of the treatments at 60 (3.20), 90 (4.13) and 120 DAS (3.44). At 120 DAS, the application N6 recorded 30.79 % more improvement in LAI than the lowest treatment i.e. N3. It was found that, except for the 30 DAS growth stage, every interaction had a notable effect on the leaf area index.

In the 2022-23 period, the results from Table 4.6 indicated that agronomic zinc fortification did not have a significant impact on LAI at 30 DAS (days after sowing). However, it was found to have a substantial effect on LAI during all other phases of the wheat crop. Applying zinc (Z3), both foliar and in the soil at 60, 90, and 120 DAS, produced a significantly higher value on LAI; this was followed by applying zinc (Z2) familiarly and in the soil. A similar trend in the use of INM, as in the case of the first year, was followed in the second year of study. The application of N6 was recorded to obtain maximum LAI (3.05) at 60 DAS, whereas N2 and N5 were found to be similar to each other. At 90 and 120 DAS, the leaf area index (LAI) showed a considerable increase, following the same pattern as observed at 60 DAS, with values of 4.46 and 3.95, respectively.

The adoption of N6 treatment resulted in a 27% increment in LAI compared to 50% RDF + 5 t/ha FYM + PSB (N3) at 120 DAS. The combined influence of both factors was observed to have a substantial impact on LAI and exhibited a consistent pattern similar to that of the initial year (Fig 4.12).

The trend in the pooled mean analysis was consistent with the two years' findings. All growth stages, with the exception of 30 DAS, were found to be significantly impacted by the agronomic zinc fortification (Fig 4.15). Superior LAI was obtained at all the stages with the combined soil and foliar application of zinc (Z3) (3.00, 4.15 and 3.62). LAI was found to be minimum with the sole soil application of zinc. The effect of LAI was shown to be considerable for many integrated management strategies, except at 30 DAS. The N6 treatment was noted to have a significantly higher value than all the rest of the treatments at 60, 90 and 120 DAS. The interaction owing to both the elements was found to have a substantial effect on LAI and the maximum LAI was obtained with Z3N6 application (Fig 4.3).

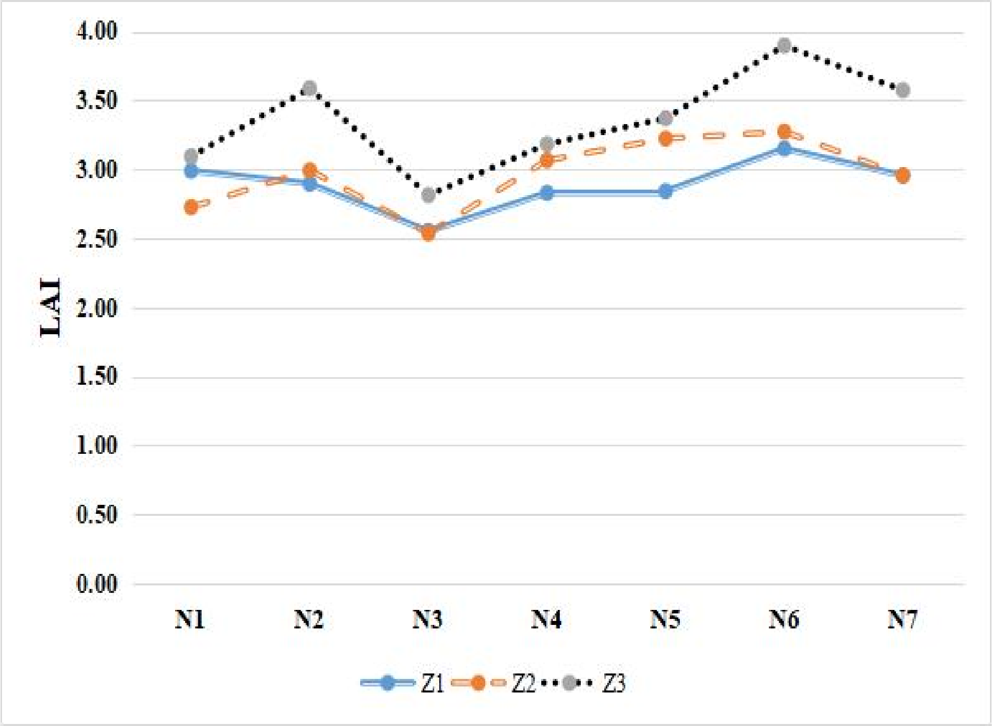
The plausible reason for the findings might be as a result of zinc’s function as a catalyst for several hormonal and enzymatic activities, N metabolism, protein synthesis, chlorophyll production, and photosynthetic activities, which results in enhanced LAI (Nawab *et al.,* 2006). Zinc treatment may result in an increase in the leaf area index by promoting the levels of growth-promoting hormones, which are the main factors affecting the expansion of leaves (Nadergholi *et al.,* 2011). Zinc sprayed on the leaves of maize plants increased the leaf area index (LAI), as suggested by Safyan *et al.* (2012) and Mohsin and co-workers in 2014. The results were consistent with the research findings of Ilyas *et al.* (2022) in wheat crops, who also suggested that combined soil + foliar zinc application improved LAI as compared to sole soil and foliar application. Fertilizer application may have improved both morphological and photosynthetic parameters (LA1 and chlorophyll content), which may have improved radiant energy absorption and utilization, increased photosynthesis, and ultimately increased dry matter accumulation in individual plants (Patidar & Mali, 2004).

Table 4.6: Effect of different treatments on LAI of wheat

Treatments	30 DAS			60 DAS			90 DAS			120 DAS		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification												
Z1: Soil application of Zn	0.68	0.68	0.68	2.45	2.38	2.42	3.28	3.65	3.47	2.89	3.37	3.13
Z2: *Foliar application of Zn	0.67	0.68	0.68	2.61	2.47	2.54	3.47	3.91	3.69	2.97	3.48	3.22
Z3: Soil and foliar application of Zn	0.69	0.68	0.69	3.04	2.96	3.00	3.94	4.36	4.15	3.36	3.87	3.62
SEm(±)	**0.003**	**0.002**	**0.002**	**0.01**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**
CD at 5%	**NS**	**NS**	**NS**	**0.05**	**0.05**	**0.04**	**0.08**	**0.05**	**0.05**	**0.06**	**0.06**	**0.05**
Integrated Nutrient Management												
N1: 50% RDF + 5 t/ha FYM + Azotobacter	0.69	0.68	0.68	2.53	2.45	2.49	3.37	3.85	3.61	2.94	3.48	3.21
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	0.68	0.68	0.68	2.77	2.71	2.74	3.63	4.11	3.87	3.16	3.64	3.40
N3: 50% RDF + 5 t/ha FYM + PSB	0.67	0.68	0.67	2.22	2.27	2.24	3.11	3.36	3.24	2.63	3.12	2.88
N4: 75% RDF + 2.5 t/ha FYM + PSB	0.68	0.68	0.68	2.57	2.41	2.49	3.45	3.93	3.69	3.03	3.48	3.25
N5: 50% RDF + 5 t/ha FYM + ZSB	0.69	0.68	0.69	2.84	2.69	2.76	3.70	4.06	3.88	3.15	3.68	3.41
N6:75% RDF + 2.5 t/ha FYM + ZSB	0.68	0.68	0.68	3.20	3.05	3.12	4.13	4.46	4.30	3.44	3.95	3.70
N7: 100% RDF (120:60:40 N-P-K kg/ha)	0.68	0.69	0.68	2.77	2.64	2.70	3.53	4.06	3.80	3.16	3.66	3.41
SEm(±)	**0.004**	**0.003**	**0.003**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.01**	**0.02**	**0.03**	**0.02**
CD at 5%	**NS**	**NS**	**NS**	**0.05**	**0.04**	**0.03**	**0.06**	**0.06**	**0.04**	**0.05**	**0.08**	**0.05**
Zn X INM	**NS**	**NS**	**NS**	**0.08**	**0.07**	**0.05**	**0.11**	**0.10**	**0.07**	**0.08**	**0.14**	**0.09**

Table 4.7: Interaction effect of agronomic zinc fortification methods with integrated nutrient management on LAI at 120 DAS in wheat

Treatments	2021-2022				2022-2023				Pooled			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	2.99	2.73	3.09	2.94	3.50	3.31	3.62	3.48	3.25	3.02	3.35	3.21
N2	2.90	2.99	3.59	3.16	3.32	3.52	4.08	3.64	3.11	3.26	3.83	3.40
N3	2.55	2.54	2.81	2.63	3.02	2.94	3.42	3.12	2.78	2.74	3.11	2.88
N4	2.83	3.07	3.18	3.03	3.18	3.61	3.66	3.48	3.01	3.34	3.42	3.25
N5	2.84	3.22	3.37	3.15	3.46	3.70	3.88	3.68	3.15	3.46	3.63	3.41
N6	3.15	3.27	3.90	3.44	3.65	3.77	4.44	3.95	3.40	3.52	4.17	3.70
N7	2.96	2.96	3.57	3.16	3.48	3.48	4.01	3.66	3.22	3.22	3.79	3.41
Mean	2.89	2.97	3.36	2.89	3.37	3.48	3.87		3.13	3.22	3.62	
Z×N (CD at 5 %)	**0.08**				**0.14**				**0.09**			



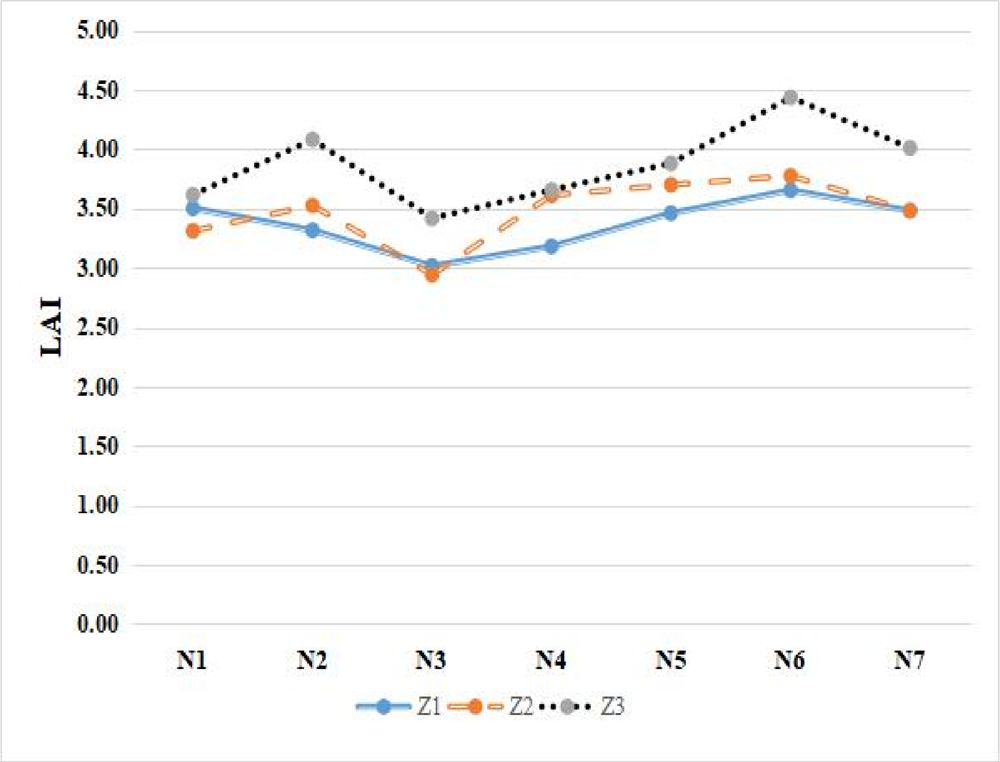


Fig 4.3: Representing the effect of interaction on LAI of wheat at 120 DAS during 2021-22 and 2022-23

Root length (cm)

Zinc application was found to have a significant impact on root length growth from the beginning to the end of crop growth in 2021–2022, except at 30 DAS. At 60, 90 and 120 DAS, maximum root length (14.4, 41.9 and 42.5 cm) was registered with sole soil application of zinc (Z1), whereas minimum (13.7, 36.6 and 36.9 cm) was obtained with foliar application of zinc (Z2). A significant increase of 15.18 % in root length was obtained with sole soil application of zinc (Z1) at 120 DAS as compared to foliar application alone (Z2) (Table 4.8).

It was found that the application of different INM was also found to have a significant effect in escalating the root length of wheat crop except at 30 DAS. Among the different INM approaches, the treatment N4 (15.1, 44.4 and 45.0 cm) increased the root length significantly more than every other treatment, except N6, and was at par with the highest treatment. The minimum root length at 60 DAS was received with 50% RDF + 5 t/ha FYM + ZSB (13.0 cm). A similar trend was followed at 90 and 120 DAS. The interaction due to both aspects of root length was found to be significant except at the initial growth stage. Maximum increment in root length was noticed with Z1N4, which was at par with Z1N6. Z3, when combined with N6 and N7, gave a similar value for root length.

During the second year of study, root length was significantly affected by agronomic zinc fortification approaches except at the initial stage. From 60 to 120 days after sowing, the higher root length was obtained with Z1 and was acquired to the tune of 4.2, 14.6 and 14.1 % higher than the lowest treatment, i.e., foliar application of zinc alone.

Concerning the second aspect of the study, root length was increased significantly with the administration of various INM approaches except at the initial growth stage. At 60 DAS among the different INM approaches, the treatment N4 (15.3 cm) was found to increase the root length significantly than all the rest of the treatments except N6 (15.2 cm), N7 (14.8 cm) and N3 (14.8 cm) which was found to be at par with the highest treatment. The interaction due to both the aspects of root length was found to be significant, with a maximum increase in root length obtained when Z1 interacted with N4 and was statistically similar when Z1 combined with N6 and N7 (Fig 4.4).

From the pooled mean analysis of root length, it was observed that root length was significantly affected by agronomic zinc fortification approaches, integrated nutrient management and their interaction at stages of growth. From 60 till 120 days after sowing higher root length was found to be obtained with soil application of zinc (Z1) (14.6, 42.5 & 43.2 cm) which was succeeded by soil and foliar application of zinc (14.3, 39.9 & 40.3 cm) and foliar application of zinc alone (14.0, 37.1, 37.7 cm). The second aspect of the study also had a significant profound effect on root length. From 60 to 120 DAS, N4 treatment resulted in considerably longer root lengths (15.2, 14.1, and 45.8 cm). Similarly, the root length was found to be similar to the treatment of 75% recommended dose of fertilizer (RDF) + 2.5 tons per hectare of farmyard manure (FYM) + ZSB (15.1, 44.7, and 45.3 cm). The interaction of the two aspects was found to have a substantial influence during the later crop growth period. Even though the interaction was noticed to be insignificant at 30 DAS.

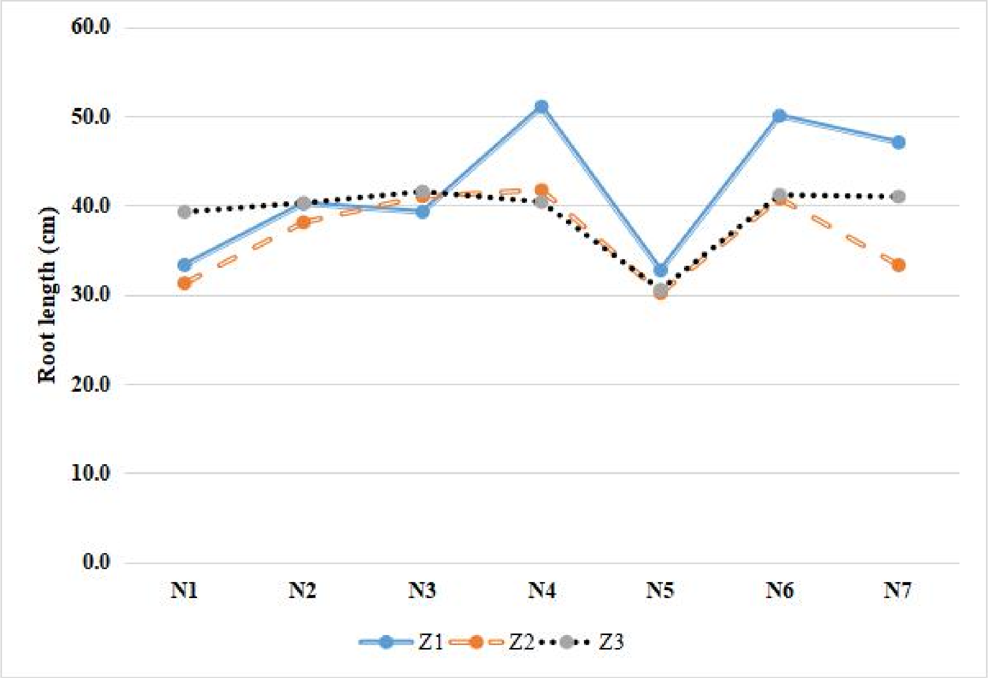
Patidar and Mali (2001) and Sutaliya & Singh (2005) similarly documented comparable effects of PSB + FYM on sorghum growth. The enhanced root morphological characteristics of seedlings following PSB inoculation were likely due to increased synthesis of IAA. This hormone acts as a plant growth regulator and promotes root elongation. Besides P solubilization, PSB inoculation can alter root function by regulating auxin-responsive gene expression (Elhaissoufi *et al.,* 2020). Wheat plants exhibited increased root weight and length after being treated with bacterial strains that solubilize zinc (Kamran *et al.,* 2017; Shakeel *et al.,* 2023). The solubilization of zinc, the synthesis of several plant growth regulators, the solubilization of phosphorus, and the generation of indole acetic acid by the zinc-solubilizers may be the plausible reason for the increased shoot length, root length, and total dry biomass (Naseem *et al.,* 2022). The findings are consistent with those suggested by Goteti *et al.,* 2013 and Vaid *et al.,* 2014, who noted that inoculating rice, soybean, wheat and maize crops with zinc-solubilizing bacteria significantly increased the length of shoot and root as well as improved the total dry biomass.

Table 4.8: Effect of different treatments on root length (cm) of wheat

Treatments	**30 DAS**			**60 DAS**			**90 DAS**		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification									
Soil application of Zn	5.9	6.0	6.0	14.4	14.8	14.6	41.9	43.1	42.5
*Foliar application of Zn	5.7	5.8	5.7	13.7	14.2	14.0	36.6	37.6	37.1
Soil and foliar application of Zn	5.9	6.0	6.0	14.1	14.5	14.3	39.1	40.6	39.9
SEm(±)	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.5**	**0.6**	**0.3**
CD at 5%	**NS**	**NS**	**NS**	**0.5**	**0.4**	**0.2**	**1.8**	**2.3**	**1.1**
Integrated Nutrient Management									
N1: 50% RDF + 5 t/ha FYM + Azotobacter	5.3	5.3	5.3	13.1	13.7	13.4	34.6	35.7	35.2
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	5.8	5.8	5.8	13.5	14.3	13.9	39.5	40.3	39.9
N3: 50% RDF + 5 t/ha FYM + PSB	6.0	5.7	5.8	14.4	14.8	14.6	40.6	42.1	41.4
N4: 75% RDF + 2.5 t/ha FYM + PSB	6.5	6.8	6.6	15.1	15.3	15.2	44.4	45.8	45.1
N5: 50% RDF + 5 t/ha FYM + ZSB	5.1	5.3	5.2	13.0	13.4	13.2	31.1	31.7	31.4
N6:75% RDF + 2.5 t/ha FYM + ZSB	6.1	6.1	6.1	15.0	15.2	15.1	44.0	45.5	44.7
N7: 100% RDF (120:60:40 N-P-K kg/ha)	6.1	6.6	6.4	14.4	14.8	14.6	40.4	42.0	41.2
SEm(±)	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.1**	**0.6**	**0.7**	**0.5**
CD at 5%	**0.3**	**0.2**	**0.2**	**0.6**	**0.5**	**0.4**	**1.6**	**1.9**	**1.3**
Zn X INM	**NS**	**NS**	**NS**	**1.0**	**0.9**	**0.7**	**2.8**	**3.3**	**2.3**

Table 4.9: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on root length (cm) at 90 DAS**

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	33.3	31.3	39.2	34.6	34.2	32.7	40.3	35.7	33.8	32.0	39.8	35.2
N2	40.2	38.1	40.3	39.5	40.9	38.7	41.3	40.3	40.6	38.4	40.8	39.9
N3	39.2	41.0	41.5	40.6	40.2	42.8	43.4	42.1	39.7	41.9	42.5	41.4
N4	51.0	41.7	40.4	44.4	52.1	43.7	41.6	45.8	51.6	42.7	41.0	45.1
N5	32.7	30.2	30.5	31.1	33.3	30.2	31.6	31.7	33.0	30.2	31.1	31.4
N6	50.0	40.7	41.2	44.0	51.4	41.8	43.3	45.5	50.7	41.3	42.2	44.7
N7	47.0	33.3	41.0	40.4	49.8	33.7	42.5	42.0	48.4	33.5	41.7	41.2
Mean	41.9	36.6	39.1		43.15	43.15	43.15		42.5	37.1	39.9	
Z×N (CD at 5 %)	**2.8**				**3.3**				**2.3**			



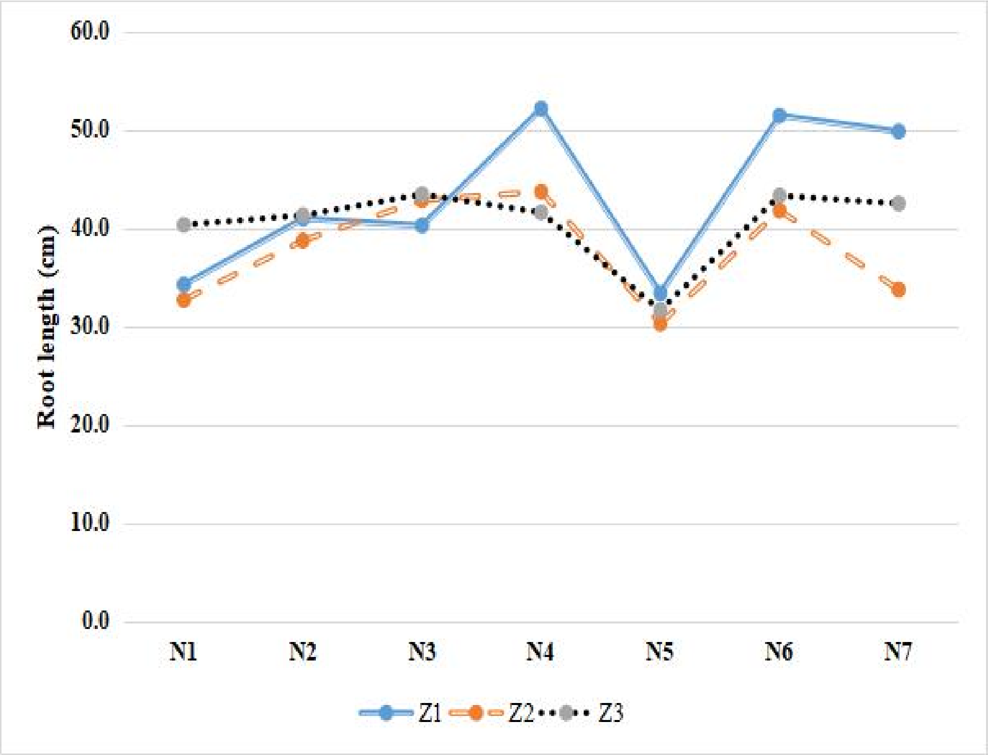


Fig 4.4: Representing the effect of interaction on root length (cm) of wheat at 90 DAS during 2021-22 and 2022-23

Root dry weight (g/plant)

During 2021-22, agronomic zinc fortification was found to have a substantial impact on the wheat root's dry weight throughout all growth stages. Statistically similar values was obtained with soil application of zinc (Z1) and combined soil and foliar application of zinc (Z3) at 30,60 and 90 DAS. A maximum value to the tune of 2.28 cm was obtained at 90 DAS with soil zinc application (Z1). Integrated nutrient management practices were also found to have a substantial impact on the root dry weight throughout all growth stages, with a maximum value to the tune of 2.40 received with N6 application, and the least value at 90 DAS was obtained with N2 and N5 application, respectively. The interaction due to both aspects was also found to have a significant role in improving the root dry weight. Maximum root dry weight (2.43 g) was obtained when Z2 interacted with the N6 method of INM application, which was found to be at par with Z1N7. The root dry weight data is represented in table 4.10.

The second year of study also followed the same trend as that of the first year. Agronomic zinc fortification was found to have a significant role in improving the root dry weight with a maximum value to the range of 2.32 g obtained with soil zinc application (Z1) and was found to be at par with combined soil + foliar zinc application (Z3). INM was also found to have a significant role in improving the root dry weight at all the growth phases, with maximum value obtained with N6 application and minimum root dry weight obtained with N3 method. The interaction due to both aspects was found to have a significant effect with the maximum value obtained when Z1 interacted with N6.

From the pooled analysis of data, the significantly highest value for root dry weight at all growth stages was obtained with soil zinc application (Z1). It was followed by combined soil + foliar zinc application (Z3). Regarding the second aspect of the study, it was discovered that the N6 treatment produced the highest value for root dry weight at 90 DAS (2.37 g), which was statistically equivalent to the N4 treatment. The interaction effect was found to substantially impact the total dry weight of wheat roots. The largest dry weight of roots, amounting to 2.44 g, was seen when Z1 interacted with N6.

Table 4.10: **Effect of different treatments on root dry weight (g/plant) of wheat**

Treatments	30 DAS			60 DAS			90 DAS		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification									
Z1: Soil application of Zn	0.08	0.09	0.08	0.96	1.13	1.04	2.28	2.32	2.30
Z2: *Foliar application of Zn	0.07	0.08	0.08	0.81	0.99	0.90	2.22	2.25	2.23
Z3: Soil and foliar application of Zn	0.08	0.09	0.09	0.95	1.11	1.03	2.26	2.31	2.29
SEm(±)	**0.0008**	**0.0010**	**0.0003**	**0.0094**	**0.0044**	**0.0054**	**0.0116**	**0.0123**	**0.0106**
CD at 5%	**0.003**	**0.004**	**0.001**	**0.04**	**0.02**	**0.02**	**0.05**	**0.05**	**0.04**
Integrated Nutrient Management									
N1: 50% RDF + 5 t/ha FYM + Azotobacter	0.08	0.08	0.08	0.74	1.06	0.90	2.21	2.26	2.23
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	0.08	0.09	0.09	0.85	1.09	0.97	2.20	2.28	2.24
N3: 50% RDF + 5 t/ha FYM + PSB	0.08	0.08	0.08	0.92	1.03	0.97	2.24	2.22	2.23
N4: 75% RDF + 2.5 t/ha FYM + PSB	0.08	0.09	0.08	0.98	1.12	1.05	2.32	2.37	2.35
N5: 50% RDF + 5 t/ha FYM + ZSB	0.07	0.07	0.07	0.85	1.06	0.95	2.20	2.26	2.23
N6:75% RDF + 2.5 t/ha FYM + ZSB	0.07	0.10	0.08	0.99	1.16	1.08	2.35	2.40	2.37
N7: 100% RDF (120:60:40 N-P-K kg/ha)	0.08	0.10	0.09	0.99	1.03	1.01	2.23	2.26	2.24
SEm(±)	**0.0011**	**0.0012**	**0.0008**	**0.0139**	**0.0149**	**0.0101**	**0.0168**	**0.0200**	**0.0133**
CD at 5%	**0.003**	**0.003**	**0.002**	**0.04**	**0.04**	**0.03**	**0.05**	**0.06**	**0.04**
Zn X INM	**0.005**	**0.006**	**0.004**	**0.1**	**0.1**	**0.1**	**0.08**	**0.09**	**0.07**

Table 4.11: **Interaction effect of agronomic zinc fortification methods with integrated nutrient managements on root dry weight (g/plant) at 90 DAS**

Treatments	2021-2022				2022-2023				Pooled			
	Z1	Z2	Z3	Mean	Z1	Z2	Z3	Mean	Z1	Z2	Z3	Mean
N1	2.23	2.18	2.22	2.21	2.25	2.18	2.33	2.26	2.24	2.18	2.28	2.23
N2	2.18	2.17	2.26	2.20	2.27	2.22	2.34	2.28	2.23	2.20	2.30	2.24
N3	2.19	2.30	2.23	2.24	2.17	2.25	2.25	2.22	2.18	2.27	2.24	2.23
N4	2.34	2.34	2.29	2.32	2.39	2.41	2.31	2.37	2.36	2.38	2.30	2.35
N5	2.21	2.13	2.25	2.20	2.28	2.17	2.32	2.26	2.24	2.15	2.29	2.23
N6	2.43	2.30	2.32	2.35	2.45	2.38	2.37	2.40	2.44	2.34	2.35	2.37
N7	2.35	2.09	2.26	2.23	2.42	2.11	2.23	2.26	2.39	2.10	2.25	2.24
Mean	2.28	2.22	2.26		2.32	2.25	2.31		2.30	2.23	2.29	
Z×N (CD at 5 %)	**0.08**				**0.09**				**0.07**			

Yield attributing characteristics

(i) Spike length (cm)

The length of the spike was significantly affected by the different agronomic zinc fortification methods due to different INM practices and interaction between both aspects in both years of study. Spike length varied from 11.3 to 11.9 cm during 2021-22 and 11.4 to 12.2 cm during 2022-23 due to different agronomic zinc fortification approaches. Significantly higher spike length was obtained with combined soil and foliar application of zinc. Our findings corroborated those of Ghasal *et al.* (2017), who discovered that applying zinc to the soil by itself has no appreciable impact on extending spike length. Among the various INM approaches, the application of N6 significantly improved the length of a spike during both the years (2021-22 & 2022-23), and it was discovered that the value was greater than the other treatments, except N2. Although among the pooled data, N6 was found to be at par with N2 and N5. The interaction due to both aspects was observed to be significant (Table 4.12). Maximum spike length was recorded when Z3 was combined with N6 and was found to be statistically similar to Z3N2 during 2021-2022. In the second year, Z3N2 was at par with Z3N6, Z3N5, Z3N7, Z2N6 and Z2N5. From the pooled data, it was observed that the maximum increment in spike length was obtained with Z3N6 and was found to be at par with Z3N2 and Z3N5. Table 4.12 displays the information related to spike length.

(ii) Number of grains/spikes

Table 4.12 displays information about the quantity of grains or spikes. Grain number per spike varied significantly with agronomic zinc fortification, integrated nutrient management and also due to interaction. The application of agronomic zinc fortification resulted in increasing the grains/spike from 48.5 to 52.3 during 2021-22 and from 49.5 to 53.1 during 2022-23. However, grain number per spike varied from 47.0 to 53.2 during 2021-22 and from 47.1 to 54.2 during 2022-23 due to integrated nutrient management treatments. The data unequivocally demonstrate that the number of grains per spike rose dramatically with various agronomic zinc fortification methods, and the biggest increase was observed with Z3. The results also shows that treatments Z1 and Z2 alone was statistically similar to each other. The combined interplay of these factors has a notable impact on enhancing the grain yield per spike

(Table 4.12). When Z3 and N6 were coupled, a noticeably larger grain number per spike was produced in both research years.

(iii) Test weight (g)

Data shown in Table 4.12 reveal that different agronomic zinc fortification approaches and integrated nutrient management approaches significantly increase the test weight (g) of wheat crops even though the interaction effect was found to be insignificant during both study years. Significantly higher test weight was obtained with Z3 application (44.3) and was found to be at par with foliar application of zinc alone (Z2) (42.8) during 2021-22. During the second year and pooled data, significantly higher test weight was registered with combined soil and foliar application of zinc (Z3) (45.3 and 44.8 g) than all the rest of the treatments. Concerning the different INM treatments, the application of N6 acquired the highest test weight (44.3, 44.8 and 44.6 g), and the minimum was obtained with 50% RDF + 5 t/ha FYM + PSB (N3) (41.2, 41.0 and 41.1). The interaction due to both aspects was found to be non-significant. The lesser amounts of zinc in wheat shoots may cause the worse efficacy of soil and foliar treatments of zinc fertilizer alone compared to soil + foliar applications (Ranjbar & Bahmaniar, 2007). Research has indicated that growing anthers and pollen grains require more zinc than other plant components. Zinc is crucial for the formation of pollen grains. Pollen granulocytes require a sufficient quantity of zinc to synthesize cytoplasmic ribosomes (Prask & Plocke, 1971).

Table 4.12: Effect of different treatments on spike length (cm), number of grains per spike and test weight (g) of wheat crop

Treatments	**Spike length (cm)**			**Number of grains/spike**			**Test weight (g)**		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification									
Soil application of Zn	11.3	11.4	11.3	48.5	49.5	49.0	41.3	41.7	41.5
*Foliar application of Zn	11.3	11.5	11.4	49.7	50.3	50.0	42.8	43.6	43.2
Soil and foliar application of Zn	11.9	12.2	12.1	52.3	53.1	52.7	44.3	45.3	44.8
SEm(±)	**0.05**	**0.06**	**0.03**	**0.34**	**0.35**	**0.17**	**0.41**	**0.25**	**0.19**
CD at 5%	**0.2**	**0.3**	**0.1**	**1.3**	**1.4**	**0.7**	**1.6**	**1.0**	**0.7**
Integrated Nutrient Management									
N1: 50% RDF + 5 t/ha FYM + Azotobacter	11.4	11.5	11.5	49.3	50.1	49.7	42.2	43.2	42.7
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	11.6	11.9	11.8	50.5	50.9	50.7	43.0	43.9	43.5
N3: 50% RDF + 5 t/ha FYM + PSB	11.1	11.1	11.1	47.0	47.1	47.1	41.2	41.0	41.1
N4: 75% RDF + 2.5 t/ha FYM + PSB	11.4	11.4	11.4	49.6	50.4	50.0	42.5	43.2	42.8
N5: 50% RDF + 5 t/ha FYM + ZSB	11.5	12.0	11.8	50.9	52.4	51.7	42.8	43.9	43.3
N6:75% RDF + 2.5 t/ha FYM + ZSB	11.8	12.2	12.0	53.2	54.2	53.7	44.3	44.8	44.6
N7: 100% RDF (120:60:40 N-P-K kg/ha)	11.5	11.7	11.6	50.4	51.7	51.1	43.6	44.6	44.1
SEm(±)	**0.07**	**0.09**	**0.06**	**0.39**	**0.46**	**0.29**	**0.47**	**0.32**	**0.28**
CD at 5%	**0.2**	**0.3**	**0.2**	**1.1**	**1.3**	**0.8**	**1.4**	**0.9**	**0.8**
Zn X INM	**0.3**	**0.4**	**0.3**	**2.0**	**2.3**	**1.4**	**NS**	**NS**	**NS**

Table 4.13: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on spike length (cm) at 120 DAS**

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	11.4	11.2	11.8	11.4	12.1	10.5	11.8	11.5	11.7	10.9	11.8	11.5
N2	11.2	11.4	12.2	11.6	11.4	11.8	12.6	11.9	11.3	11.6	12.4	11.8
N3	11.2	10.6	11.6	11.1	11.2	10.5	11.7	11.1	11.2	10.6	11.7	11.1
N4	11.0	11.4	11.8	11.4	10.6	11.6	12.0	11.4	10.8	11.5	11.9	11.4
N5	11.3	11.5	11.9	11.5	11.1	12.5	12.4	12.0	11.2	12.0	12.1	11.8
N6	11.5	11.5	12.4	11.8	12.0	12.2	12.5	12.2	11.7	11.9	12.4	12.0
N7	11.4	11.4	11.9	11.5	11.4	11.4	12.5	11.7	11.4	11.4	12.2	11.6
Mean	11.3	11.3	11.9		11.4	11.5	12.2		11.3	11.4	12.1	
Z×N (CD at 5 %)	**0.3**				**0.4**				**0.3**			

Table 4.14: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on number of grains per spike at 120 DAS**

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	49.4	48.2	50.1	49.3	50.7	49.7	50.0	50.1	50.1	48.9	50.1	49.7
N2	48.3	49.6	53.7	50.5	49.0	49.3	54.3	50.9	48.7	49.4	54.0	50.7
N3	44.7	47.3	49.0	47.0	45.0	47.0	49.3	47.1	44.8	47.2	49.2	47.1
N4	48.2	50.0	50.6	49.6	49.0	50.3	52.0	50.4	48.6	50.2	51.3	50.0
N5	49.1	51.4	52.3	50.9	51.3	52.7	53.3	52.4	50.2	52.1	52.8	51.7
N6	50.4	51.8	57.4	53.2	51.0	53.0	58.7	54.2	50.7	52.4	58.1	53.7
N7	49.3	49.3	52.7	50.4	50.7	50.3	54.0	51.7	50.0	49.8	53.3	51.1
Mean	48.5	49.7	52.3		49.5	50.3	53.1		49.0	50.0	52.7	
Z×N (CD at 5 %)	**2.0**				**2.3**				**1.4**			

Yield

Grain yield (t/ha)

One way to describe economic yield is as a function of all the variables that affect it. In wheat, effective tillers count, the quantity of grains spike^{-1}, and spike length are the main factors that determine grain yield. Examining the grain yield information in table 4.15, fig 4.6 clearly shows that the agronomic zinc fortification approach had a significant impact on grain yield. The combined soil and foliar application of zinc (Z3) achieved a markedly greater grain yield (28.6%) than the sole soil application of zinc (Z1) in the year 2021-22 whereas during the second year 2022-23, the gain in yield was 22.2%. The implementation of integrated nutrient management approaches resulted in a substantial improvement in grain yield. Results revealed that the application of N6 had achieved a substantially greater grain yield (32.5%) in comparison to the lowest treatment, i.e., N3, throughout the study years. Pooled data also showed a similar trend in grain yield, with significantly higher grain yield obtained with 75% RDF + 2.5 t/ha FYM + ZSB (N6) than all the rest of the treatments. The interaction due to both aspects was noticed to have a significant impact on improving grain yield throughout the study years (Fig 4.26). Among the seven different INM approaches, the wheat grain yield recorded from the N6 treatment responded superiorly to the combined soil + foliar zinc application method i.e., Z3, whereas it was noted to be statistically similar with N2 in the first year. However, in 2022-23, N6 treatment with the Z3 method out yielded all the other treatments, and the lowest value of 4.05 t/ha was obtained when soil application of zinc with the N3 treatment combination was implemented. The grain yield received by the adoption of Z3 in N6 treatment was 7.38 per cent more than that received from N7 treatment in 2021-22, and it was to the tune of 5.05 per cent in 2022-23.

The combination of soil and foliar applications of zinc fertilizer was shown to be more successful in increasing yield than either method alone. This was in accordance with the findings of Ranjbar & Bahmaniar, 2007. The soil + foliar treated plots resulted in increased yields as a result of enhanced photosynthetic activity and biomass accumulation. This phenomenon can be attributed to sufficient availability of zinc and a subsequent augmentation in various soil enzymatic activities, resulting in elevated wheat yields (Hussain & Yasin, 2004). Zinc content in plants also promotes seed development, photosynthesis, and the transformation of carbohydrates (Khan *et al.,* 2023).

The lower amounts of zinc in wheat shoots may be the cause of the inferior efficacy of soil and foliar treatments of zinc fertilizer alone as compared to soil + foliar applications. In order to achieve both a high Zn concentration in seeds and a good grain yield, soil + foliar treatment should be regarded as an efficient technique (Yilmaz *et al.,* 1997; Sreethu *et al.,* 2024). Higher tiller counts at harvest, more grains per spike, and increased test weight from the combined soil and foliar zinc application could all be contributing factors to the increased grain yield. Zinc plays a pivotal role in maintaining plant metabolism; it helps in the synthesis of chlorophyll and better root growth and development, which leads to the production of more effective tillers and higher grain yield (Rehman *et al.,* 2018). The results we obtained match up with the research outcomes of Mathpal *et al.* (2015), who proposed that applying zinc to the soil at a rate of 5 mg/kg and to the leaves at a rate of 0.5% increased grain yield. Sultana *et al.* in 2016 and Kumar *et al.* in 2020 also observed that soil along with foliar zinc application improved the crop yield. The increase in yield and yield contributing factors may be the result of a properly controlled supply of zinc up until harvest in plots with both soil and foliar application. This also encourages an increase in enzymatic activity, which enhances photosynthetic activity and the accumulation of dry matter, both of which raise yield contributing factors and final yield (Paramesh *et al.,* 2020).

Nutrient extraction from the soil is a critical stage in the growth of crops, which also produces the food that humans need. To maintain and enhance soil quality and crop yield over time, it is imperative to employ effective and efficient methods to decrease and reverse nitrogen depletion. Inorganic fertilizers worked better when mixed with organic manures like FYM, which may be related to organic matter's potential to improve soil health and boost nutrient availability (Asai *et al.,* 2009; Paramesh *et al.,* 2023). In addition, Khaliq *et al.* (2006) proposed that the maximum yield in wheat and cotton was achieved by utilizing a balanced combination of NPK, organic manure, and beneficial microbes, rather than relying solely on synthetic fertilizer.

(ii) Straw yield (t/ha)

The agronomic zinc fortification methods significantly affected the straw yield. Straw yield had a similar pattern in close succession of grain yield. Z3 method of application improved the straw yield as compared to the other two treatments (Table 4.15). Zinc applied directly to the soil produced the lowest straw yield during both study years. There was found to be a significant increase of 13.4 % in straw yield by the highest treatment as compared to the lowest during 2021-22, whereas, during 2022-23, the per cent increase was to the tune of 8.6%. This could be attributed to the synergistic effect of administering zinc from many sources, which enhanced the plant's nutrient uptake at specific stages of crop growth. As a result, it promoted vegetative growth and ultimately increased straw yield. Zinc actively mediates the metabolism of hormones that stimulate plant growth, resulting in higher tiller density, dry matter accumulation, and, ultimately, better plant growth and production. (Marschner, 1995). Significant improvement in straw yield was observed with the use of various INM practices where the maximum straw yield (7.8, 7.7 and 7.8 t/ha) was received with the aadministration of N6 and minimum (6.1, 6.6 and 6.4 t/ha) was recorded with N3 treatment during 2021-22, 2022-23 and also from pooled data of two years. The interaction related to straw yield between agronomic zinc fortification and integrated nutrient management was observed to be non-significant. As straw is used as cow feed, it is strategically significant in wheat production from an economic perspective. Increased biomass production from greater tiller count translates in achieving increased straw yield (Sandhu *et al.,* 2017).

(iii) Grain: Straw ratio

The data pertaining to the proportion of grain to straw is displayed in table 4.15. Upon analyzing the data, it became evident that none of the two factors had a considerable impact on the grain-straw ratio in the first year. However, agronomic zinc application methods had a considerable impact on grain straw ratio during 2022-23 and also in pooled data. Even though INM and interaction to have an insignificant effect. Moreover, the interaction related to grain straw ratio among agronomic zinc fortification and INM was observed to have an insignificant effect.

(iv) Harvest index

The HI data is shown in Table 4.15. The harvest index demonstrates the degree to which a dry matter crop is transformed into an important economic input. The harvest index and a crop's economic return are highly correlated. HI was significantly affected due to the first aspects of study during both the years of study (2021-22 & 2022-23). Integrated nutrient management was registered to have a significant impact on the harvest index during 2022-23, even though it was found to have an insignificant impact during 2021-22. Combined soil and foliar application of zinc recorded numerically greater value for harvest index than the rest of the two treatments. The interaction related to agronomic zinc fortification and integrated nutrient management on harvest index was registered to be non-significant.

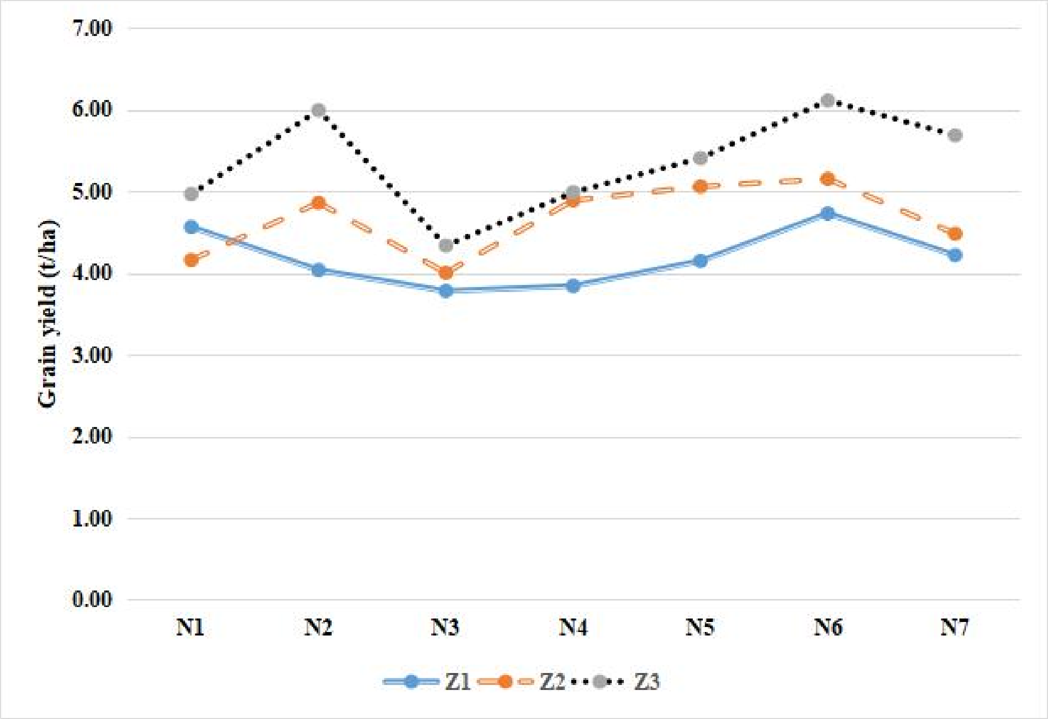
Khan *et al.* (2014), suggested that the use of organic manure, like FYM addition, has a long-term cumulative residual influence on grain yield and might have later increased the harvest index of the crop.

Table 4.15 : Effect of different treatments on grain yield (t/ha), straw yield (t/ha), grain: straw ratio and harvest index (%)

Treatments	Grain yield (t/ha)			Straw yield (t/ha)			Grain: Straw			Harvest Index (%)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Agronomic Zn fortification												
Soil application of Zn	4.2	4.5	4.3	6.7	7.0	6.8	0.6	0.6	0.6	38.7	39.2	38.9
*Foliar application of Zn	4.7	4.9	4.8	7.0	7.1	7.0	0.7	0.7	0.7	40.0	40.7	40.4
Soil and foliar application of Zn	5.4	5.5	5.4	7.6	7.6	7.6	0.7	0.7	0.7	41.3	42.1	41.7
SEm(±)	**0.06**	**0.05**	**0.05**	**0.12**	**0.11**	**0.11**	**0.01**	**0.01**	**0.01**	**0.51**	**0.47**	**0.43**
CD at 5%	**0.2**	**0.2**	**0.2**	**0.5**	**0.5**	**0.4**	**NS**	**0.1**	**0.1**	**NS**	**2.0**	**1.7**
Integrated Nutrient Management												
N1: 50% RDF + 5 t/ha FYM + Azotobacter	4.6	4.9	4.7	7.0	7.1	7.0	0.7	0.7	0.7	39.4	41.0	40.2
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	5.0	4.9	5.0	7.3	7.4	7.3	0.7	0.7	0.7	40.4	39.9	40.2
N3: 50% RDF + 5 t/ha FYM + PSB	4.0	4.3	4.1	6.1	6.6	6.4	0.7	0.6	0.7	40.2	39.1	39.6
N4: 75% RDF + 2.5 t/ha FYM + PSB	4.6	4.7	4.6	7.0	7.0	7.0	0.7	0.7	0.7	39.6	40.1	39.9
N5: 50% RDF + 5 t/ha FYM + ZSB	4.9	5.1	5.0	7.3	7.4	7.3	0.7	0.7	0.7	40.0	41.1	40.6
N6:75% RDF + 2.5 t/ha FYM + ZSB	5.3	5.7	5.5	7.8	7.7	7.8	0.7	0.7	0.7	40.5	42.2	41.3
N7: 100% RDF (120:60:40 N-P-K kg/ha)	4.8	5.2	5.0	7.2	7.4	7.3	0.7	0.7	0.7	39.8	41.2	40.5
SEm(±)	**0.06**	**0.06**	**0.04**	**0.21**	**0.21**	**0.14**	**0.02**	**0.02**	**0.01**	**0.74**	**0.74**	**0.50**
CD at 5%	**0.2**	**0.2**	**0.1**	**0.6**	**0.6**	**0.4**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Zn X INM	**0.3**	**0.3**	**0.2**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 14.16: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on grain yield (t/ha)**

Treatments	2021-2022				2022-2023				Pooled			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	4.6	4.2	5.0	4.6	4.9	4.5	5.2	4.9	4.7	4.3	5.1	4.7
N2	4.0	4.9	6.0	5.0	4.3	4.5	6.0	4.9	4.1	4.7	6.0	5.0
N3	3.8	4.0	4.3	4.0	4.1	4.3	4.4	4.3	3.9	4.1	4.4	4.1
N4	3.8	4.9	5.0	4.6	4.4	5.0	4.7	4.7	4.1	4.9	4.8	4.6
N5	4.1	5.1	5.4	4.9	4.6	5.2	5.7	5.1	4.4	5.1	5.5	5.0
N6	4.7	5.2	6.1	5.3	5.1	5.4	6.4	5.7	4.9	5.3	6.3	5.5
N7	4.2	4.5	5.7	4.8	4.3	5.3	6.1	5.2	4.2	4.9	5.9	5.0
Mean	4.2	4.7	5.4		4.5	4.9	5.5		4.3	4.8	5.4	
Z×N (CD at 5 %)	**0.3**				**0.3**				**0.2**			



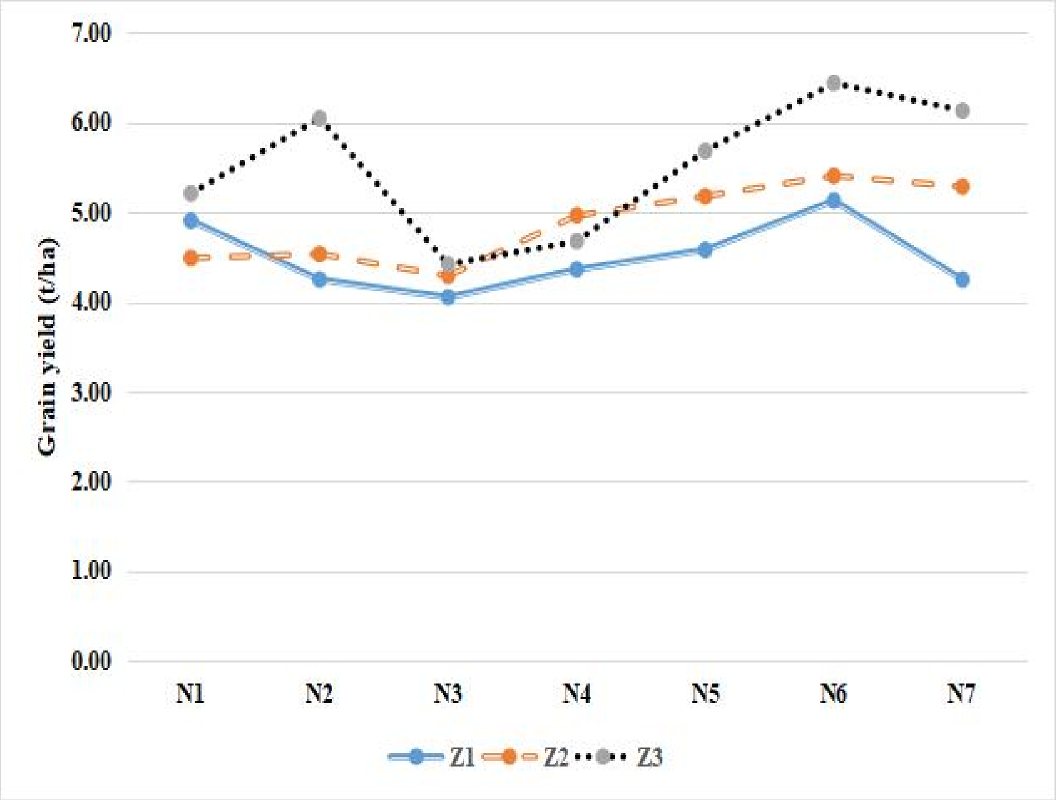


Fig 4.5: Representing the effect of interaction on grain yield (t/ha) of wheat during 2021-22 and 2022-23

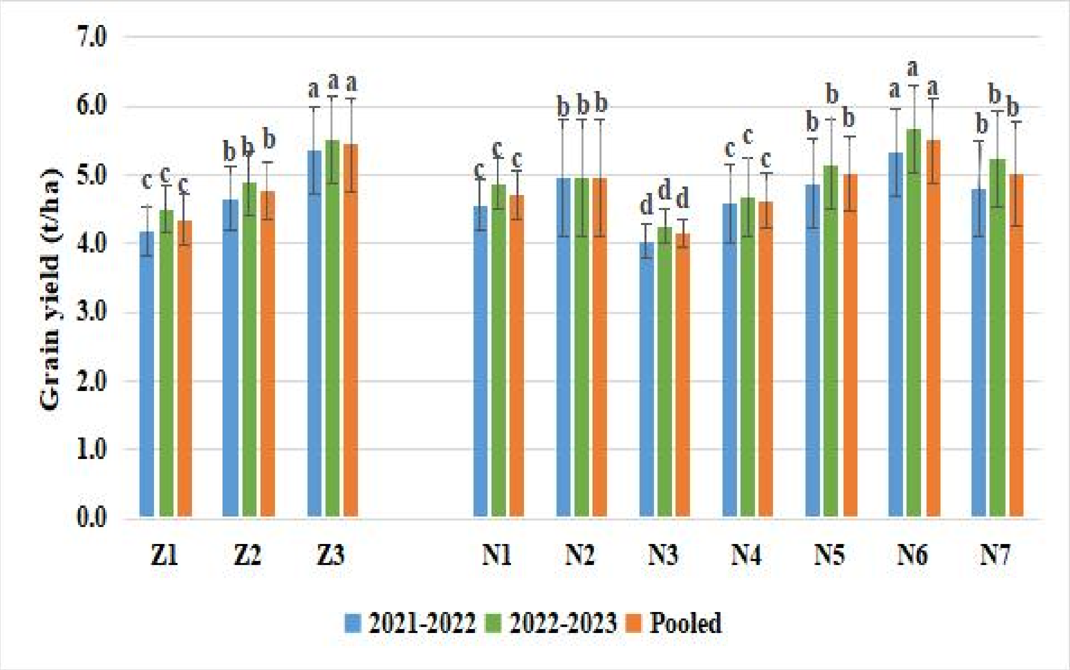


Fig 4.6: Effect of Agronomic Zinc Fortification and INM methods on grain yield (t/ha) of wheat crop

Soil parameters

Available nitrogen (kg/ha)

The perusal of the available nitrogen status data is shown in Table 4.17 , which clearly shows that the INM had a significant impact on the grain yield of wheat crops. Albeit, agronomic zinc fortification and the interaction effect due to both aspects were found to have an insignificant impact on available soil nitrogen status. Maximum availability of nitrogen in soil (259.7 kg/ha) was found to be obtained in N1 and N5 which was found to be statistically at par (259.3 kg/ha) with N3 during 2021-2022. During the second year, maximum soil nitrogen availability (272.2 kg/ha) was registered with N1 and was statistically similar to N3 and N5. The analysis of pooled data also showed a similar pattern to that of the second year of study. The least nitrogen availability in soil (231.4, 243.8 and 237.6 kg/ha) was obtained in RDF-treated plots.

Increased microbial activity in the integrated nutrition management treatments may have facilitated the mineralisation process that helps in increasing the availability (Panwar, 2008). The rapid release of nitrogen from the fertilizer following various transformation losses, including immobilization, fixation of the inorganic portion of nitrogen, leaching and volatilization may be the cause of the noticeably lower amount of nitrogen that was available in treatments that received inorganic fertilizers (Raut *et al.,* 2019).

Available phosphorus (kg/ha)

Table 4.17, presents information on the amount of available phosphorus in the soil following wheat harvest. Soil-available phosphorus was significantly impacted by different integrated nutrient management approaches. However, agronomic zinc fortification was observed to have an insignificant impact on improving the available P status in soil. A significant increment in phosphorus availability in soil (45.6 kg/ha) during 2021-2022 was found with N1 than all the remaining INM treatments except N5, which was at par with the highest treatment. During 2022-2023, maximum phosphorus availability followed the same trend as in the first year, even though it was statistically similar with N3, N5 and N6 treatments. Phosphorus availability was found to be significantly improved in N1 treatment from the pooled data. Least availability during both the years was obtained with N7 treatment where only chemical fertilizers were administered.

Farmyard manure contains organic acids that may solubilize organic phosphorus and organic anions that complex with ligands and chelate P-fixing cations, which may slow down the fixation of P. Phosphorus is more readily available to plants when it is complexed with fulvic and humic acids (Singh *et al.,* 2015). The chelating impact of organic matter may be the cause of the increase in accessible phosphorus, as organic matter also decreases the levels of Al-P and Fe-P in soil (Raut *et al.,* 2019). The inclusion of OM enhanced the assimilation of phosphorus by facilitating the development of phospho-humic complexes, resulting in a reduced fixing of phosphorus by plants (Rajneesh *et al.,* 2017).

Available potassium (kg/ha)

Table 4.17 present data indicating that the implementation of various integrated nutrient management techniques leads to a substantial increment in the accessible amount of potassium in soil following wheat crop harvest. However, the impact of agronomic zinc fortification methods was observed to be non-significant in both study years. Significant improvement in the availability of potassium in soil to the tune of 165.9 kg/ha was found to be obtained with the addition of N1 and was found to be at par with N3. The same trend was followed in the second year of study also. The interaction due to agronomic zinc fortification and INM was found to be non-significant. Organic colloids are released as FYM breaks down in the soil, increasing cation exchange capacity to store more exchangeable potassium. By slowing down the rate of fixation and increasing the release of potassium ions as a result of organic matter's interaction with clay particles, the addition of organic manure enhances the availability of potassium. Additionally, when organic matter breaks down, significant amounts of carbon dioxide are released and these can then dissolve in water to generate carbonic acid, which can break down some primary minerals and release nutrients (Rajneesh *et al.,* 2017).

DTPA available zinc (mg/g)

Available soil zinc status after harvest of the wheat crop was significantly impacted by zinc fortification methods, INM and also due to interaction. Statistically similar values for zinc availability in soil (0.6 mg/g) was obtained with Z3 and Z1 during 2021-2022. During 2022-2023, a significantly higher value for zinc availability in soil was obtained with combined soil +foliar application of zinc (Z3), which was followed by sole soil application (Z1) and then by sole foliar application of zinc (Z2). Similar trends to the second year were also evident in the pooled data. Following wheat harvest, improved zinc availability in the soil was found to be a significant outcome of integrated nutrient management, with noticeably increased zinc availability to the tune of 0.6 mg/g was obtained with N1, N2, N3, N5 and N6 during 2021-2022. Albeit, in the year 2022-2023, significantly higher available zinc in soil was recorded with N5. Based on pooled data, similar values in the range of 0.7 mg/g were observed with N1, N3, N5 and N6.

The interaction due to both aspects was observed to have a significant effect on improving grain yield during 2021-2022 and 2022-2023. Among the seven different INM approaches, the DTPA available soil zinc recorded from the N5 treatment responded superiorly to the combined soil + foliar zinc application method, i.e., Z3, whereas it was recorded to be statistically similar to the N6 treatment in 2021-2022 (Fig 4.7). However, during the second year of study, N5 treatment with the Z3 method out yielded all the other treatments, and the least zinc availability in soil was obtained when foliar zinc application with the N7 treatment combination was administered. This came after the discoveries made by Naveen, (2009) and Veeresha & Gopakkali, (2014).

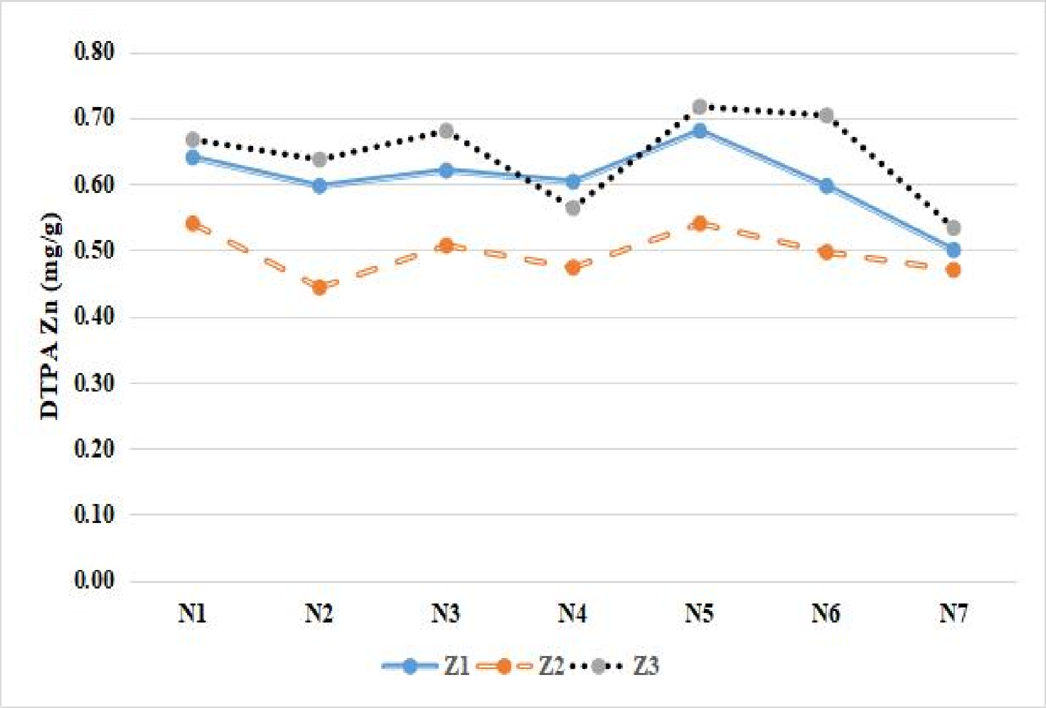
If a high grain yield and a high zinc content in the seeds are sought, then soil + foliar treatment can be regarded as an effective technique (Yilmaz *et al.,* 1997). In addition to FYM's own N contribution, FYM is said to encourage the fixation of nitrogen in the soil, which might have played a role in the soil's increased N content following NPK application. The development of unfavourable conditions for microorganisms may be the cause of the lower nutrient availability observed after applying the recommended dosage of fertilizer. This reduces nutrient availability and causes a variety of losses, including volatilization, leaching, and nutrient immobilization and fixation. After FYM treatment, the breakdown of the FYM may have added macro and micronutrients directly to the soil, increasing the soil nutrient availability. Organic fertilizers have a beneficial effect on these nutrients' availability and absorption, which improves nutrition for the root zone and the plant system as a whole. These conclusions can be drawn from the outcomes of Verma *et al.* (2023) and Ram *et al.* (2014). The results resonate with the findings of Tadesse *et al.* (2013) and Thamaraiselvi *et al.* (2012). This could be explained by the addition of more organic manure, which increases the activity of beneficial bacteria and speeds up the breakdown of soil OM, increasing the amount of nutrients available. Apart from the fact that the inclusion of organic sources such as manure increases the amount of nutrients that are available in the soil, it can also be explained by the fact that the interaction between organic matter and clay reduces nutrient fixation and release (Urkurkar *et al.,* 2010). The continuous application of inorganic fertilizers, along with organic manure like FYM, has a substantial effect on levels of soil's microbial biomass, soil nitrogen and phosphorus, fulvic acid (FA), and humic acid (Srinivasarao *et al.,* 2020). Fliessbach *et al.* (2000) suggested that the use of farm yard manure (FYM) resulted in enhanced microbiological activity and the exchange of substances between the liquid and solid parts of the soil.

Table 4.17: Effect of different treatments on available soil nitrogen (kg/ha), phosphorus (kg/ha), potassium (kg/ha) and zinc (mg/g)

Treatments	Available N (kg/ha)			Available P (kg/ha)			Available K (kg/ha)			DTPA Zn (mg/g)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Agronomic Zn fortification												
Soil application of Zn	252.8	266.1	259.4	44.0	46.3	45.2	161.1	172.7	166.9	0.6	0.7	0.7
*Foliar application of Zn	252.5	262.8	257.7	43.4	45.6	44.5	160.9	170.1	165.5	0.5	0.6	0.5
Soil and foliar application of Zn	253.6	266.7	260.2	43.7	46.2	44.9	160.1	174.5	167.3	0.6	0.8	0.7
SEm(±)	**0.60**	**0.99**	**0.73**	**0.27**	**0.31**	**0.14**	**0.55**	**0.85**	**0.41**	**0.002**	**0.003**	**0.003**
CD at 5%	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.01**	**0.01**	**0.01**
Integrated Nutrient Management												
N1: 50% RDF + 5 t/ha FYM + Azotobacter	259.7	272.2	266.0	45.6	48.0	46.8	165.9	178.3	172.1	0.6	0.7	0.7
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	255.3	267.3	261.3	42.1	44.8	43.5	160.3	171.8	166.0	0.6	0.7	0.6
N3: 50% RDF + 5 t/ha FYM + PSB	259.3	271.8	265.5	44.4	46.7	45.6	164.7	177.1	170.9	0.6	0.7	0.7
N4: 75% RDF + 2.5 t/ha FYM + PSB	252.3	264.2	258.3	42.8	44.9	43.9	161.3	173.7	167.5	0.5	0.7	0.6
N5: 50% RDF + 5 t/ha FYM + ZSB	259.7	272.1	265.9	45.3	47.8	46.6	161.1	172.5	166.8	0.6	0.8	0.7
N6:75% RDF + 2.5 t/ha FYM + ZSB	253.0	265.0	259.0	44.2	46.7	45.4	160.0	171.4	165.7	0.6	0.7	0.7
N7: 100% RDF (120:60:40 N-P-K kg/ha)	231.4	243.8	237.6	41.4	43.4	42.4	151.7	162.3	157.0	0.5	0.6	0.6
SEm(±)	**0.81**	**1.52**	**0.79**	**0.39**	**0.48**	**0.33**	**0.71**	**0.92**	**0.55**	**0.004**	**0.004**	**0.003**
CD at 5%	**2.3**	**4.4**	**2.3**	**1.1**	**1.4**	**1.0**	**2.0**	**2.6**	**1.6**	**0.01**	**0.01**	**0.01**
Zn X INM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.02**	**0.02**	**0.02**

Table 4.18: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on DTPA zinc (mg/g) after harvest**

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	0.6	0.5	0.7	0.6	0.7	0.6	0.8	0.7	0.7	0.6	0.7	0.7
N2	0.6	0.4	0.6	0.6	0.7	0.6	0.8	0.7	0.7	0.5	0.7	0.6
N3	0.6	0.5	0.7	0.6	0.7	0.6	0.8	0.7	0.7	0.6	0.7	0.7
N4	0.6	0.5	0.6	0.6	0.7	0.6	0.7	0.7	0.7	0.5	0.6	0.6
N5	0.7	0.5	0.7	0.7	0.7	0.7	0.9	0.8	0.7	0.6	0.8	0.7
N6	0.6	0.5	0.7	0.6	0.8	0.6	0.8	0.7	0.7	0.6	0.8	0.7
N7	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6
Mean	0.6	0.5	0.6		0.7	0.6	0.8		0.7	0.6	0.7	
Z×N (CD at 5 %)	**0.02**				**0.02**				**0.02**			



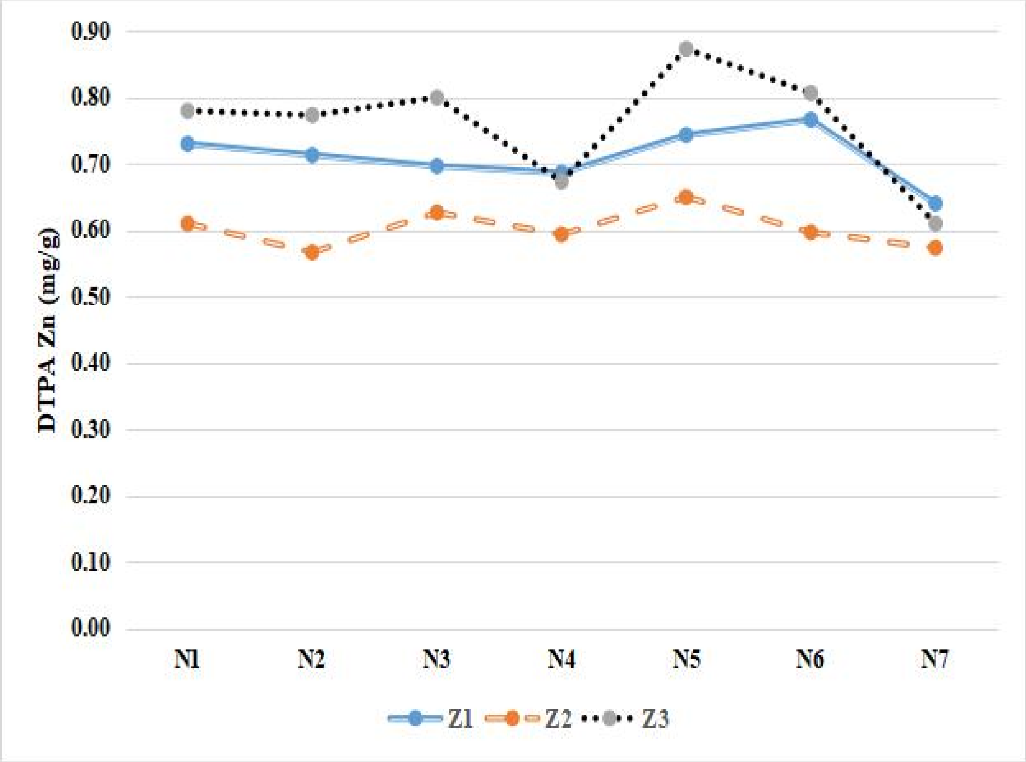


Fig 4.7: Representing the effect of interaction on DTPA zinc (mg/g) status in soil after harvest of wheat during 2021-22 and 2022-23

Bulk density (g/cc)

It is well recognized that a soil's compactness is affected by its air and water content, temperature, and nutrient availability. Higher aeration, greater drainage, and increased nutrient availability for plants are often seen in loosely packed soils with a lower bulk density. Agronomic zinc fortification has a negligible impact on the bulk density of soil. However, integrated nutrient management has a substantial influence on soil bulk density (Table 4.19). The lowest value to the tune of 1.25 g/cc was obtained with N1, N3 and N5 during the first year of study. 2022-2023 also followed the same trend with a bulk density value range of 1.19 g/cc. From the pooled data, a bulk density value of 1.22 g/cc was recorded with N1, N3 and N5, respectively. About 10.7 per cent lower bulk density was obtained from N1, N3 and N5 compared to RDF-treated plots. The interaction effect of agronomic zinc fortification and INM on bulk density was found to be non-significant.

It is known that soil particle binders include bacterial gums and polysaccharides, which are by-products of the microbial degradation of OM. Incorporation of OM to the soil benefits crop plants in several ways, such as increased nutrient availability and enhanced soil characteristics like decreased bulk density and increased aeration (Kaur *et al.,* 2023). INM with organic manure may have caused the bulk density to drop because more organic carbon was added, which improved soil aggregation and created more pore space (Sepehya *et al.,* 2012). Animal dung application resulted in a considerable decrease in the bulk density of soil.

One plausible explanation for the drop in bulk density might be a higher concentration of soil OC, enhancement in soil aggregation and increment in bio pores (Bandyopadhyay *et al.,* 2010). This resonates with the research findings of Pandey *et al.,* 2013. This may be the result of adding these organic manures, which also raised the soil's organic carbon content, increased its nitrogen content (from the conversion of organically bound nitrogen to a mineralizable form), reduced the soil's ability to fix phosphate, increased the amount of available P, and released non-exchangeable K.

Table 4.19 : Effect of different treatments on final bulk density (g/cc) of soil after harvest of wheat crop

Treatments	Bulk density (g/cc)		
	2021-22	**2022-23**	**Pooled**
Agronomic Zn fortification			
Z1: Soil application of Zn	1.30	1.23	1.26
Z2: *Foliar application of Zn	1.29	1.21	1.25
Z3: Soil and foliar application of Zn	1.29	1.23	1.26
SEm(±)	**0.006**	**0.006**	**0.004**
CD at 5%	**NS**	**NS**	**NS**
Integrated Nutrient Management			
N1: 50% RDF + 5 t/ha FYM + Azotobacter	1.25	1.19	1.22
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	1.30	1.23	1.27
N3: 50% RDF + 5 t/ha FYM + PSB	1.25	1.19	1.22
N4: 75% RDF + 2.5 t/ha FYM + PSB	1.30	1.23	1.26
N5: 50% RDF + 5 t/ha FYM + ZSB	1.25	1.19	1.22
N6:75% RDF + 2.5 t/ha FYM + ZSB	1.31	1.24	1.28
N7: 100% RDF (120:60:40 N-P-K kg/ha)	1.39	1.31	1.35
SEm(±)	**0.006**	**0.008**	**0.005**
CD at 5%	**0.02**	**0.02**	**0.02**
Zn X INM	**NS**	**NS**	**NS**

Quality parameters

Grain appearance score

The information on the grain appearance score for the years 2021-2022 and 2022-2023 and the combined data for both years are presented in Table 4.20. The grain appearance score was significantly influenced by both the aspects and their interaction throughout the study years. A significantly higher value (7.7) was noted with combined soil + foliar application of zinc (Z3) which was on par with foliar zinc application (Z2 - 7.6). Minimum value (7.4) was observed with soil zinc application alone (Z1). A similar trend in observations was noticed in second-year data and pooled data.

Integrated nutrient management significantly improved the grain appearance score, and a maximum value to the tune of 7.9 was achieved with N6 treatment, which was statistically similar (7.8) with N7 and N2 during 2021-2022. During 2022-2023, the highest value for grain appearance score (8.0) was attained with N6 and N7 and was found to be at par (7.8) with N1, N2 and N5. The interaction of both the aspects of study positively influenced grain appearance score during 2021-2022, 2022-2023, and also for pooled data analysis, with a maximum value of 8.1 recorded when Z3 combined with N6 in 2021-2022 and a value of 8.2 was recorded with Z3N6 and Z3N7 during 2022-2023 (Table 4.21).

The subjective criterion of grain appearance clearly represents the size, shape, colour, and sheen of the seed. These characteristics of grains, particularly during the grain-filling stage, reflect hereditary and environmental influences (Kaur *et al.,* 2022).

Sedimentation volume (cc)

The effect of agronomic zinc fortification substantially impacts sedimentation volume over both seasons (Table 4.20). Significantly higher sedimentation volume (46.0 cc) was obtained with combined soil + foliar application of zinc (Z3) which was then followed by foliar zinc application (Z2 - 43.6 cc) and sole soil zinc application (42.1 cc) during 2021-2022. Data from the second year and pooled data study on sedimentation value also registered similar observations. Various integrated nutrient management (INM) strategies exhibited a substantial impact on the sedimentation volume of wheat over the duration of the study. Regarding the different INM approaches, the use of N6 recorded a maximum value for sedimentation volume, which was at par with N7. Minimum values to the tune of 41.7, 43.1 and 42.4 cc were registered with N3, respectively. The interactions observed among both factors with respect to sedimentation volume were found to be significant. During 2021-2022, maximum sedimentation volume (8.1 cc) was obtained when Z3 was combined with N6 and was found to be statistically at par with Z3N7 (8.0 cc), Z3N2 (8.00 cc) and Z2N2 (7.9 cc) respectively. At par values for sedimentation volume during the second year of study for sedimentation volume were obtained with Z2N7, Z1N6, Z2N6, Z2N5, Z2N2, and Z3N1 with the maximum value obtained when combined soil + foliar zinc application was done along with N6 or N7. Based on the analysis of the combined data, it clearly shows that the highest value for sedimentation volume was recorded with Z3N6 and Z3N7, which was found to be at par with Z3N2, Z2N2, Z1N6 and Z2N7 (Table 4.22).

Hectolitre value (kg/hl)

Agronomic zinc fortification techniques, as well as various integrated nutrient management strategies, had a substantial impact on hectolitre value during both experimental study years and on pooled data analysis. However, the interaction due to both the aspects of study was found to have an insignificant effect throughout the study years. Superior hectolitre value was obtained with soil and foliar zinc application (Z3) with values to the tune of 81.1 (2021-22), 81.2 (2022-23) and 81.1(pooled) kg/hl. Treatments Z2 and Z1 were found to be at par with each other. Among the different INM practices, a significantly higher hectolitre value (80.8 kg/hl) was obtained with N7 and was at par with N6 and N5. During the second year of study, the maximum value followed the same trend, and it was registered to be at par with N6, N5 and N2.

The crop's circumstances during the grain-filling phase are reflected in the hectolitre weight data. The plumpness of the grain is determined by hectolitre weight, which is regarded as a crucial indicator of grain quality. The enhancement of robust, vertical, shiny, and appealing grains is promoted by the presence of soil and the application of zinc through the leaves during the stages of grain growth and filling, resulting in an overall improvement in the wheat's hectolitre value (Arif *et al.,* 2019).

Table 4.20 : Effect of different treatments on grain appearance score, sedimentation value (cc) and hectolitre value (kg/hl)

Treatments	**Grain appearance score (0-10)**			**Sedimentation value (cc)**			**Hectolitre value (kg/hl)**		
	2021-22	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**	**2021-22**	**2022-23**	**Pooled**
Agronomic Zn fortification									
Z1: Soil application of Zn	7.4	7.6	7.5	42.1	43.7	42.9	79.0	79.0	79.0
Z2: *Foliar application of Zn	7.6	7.8	7.7	43.6	45.0	44.3	79.4	79.6	79.5
Z3: Soil and foliar application of Zn	7.7	7.9	7.8	46.0	47.3	46.6	81.1	81.2	81.1
SEm(±)	**0.03**	**0.04**	**0.03**	**0.18**	**0.21**	**0.16**	**0.32**	**0.39**	**0.25**
CD at 5%	**0.1**	**0.2**	**0.1**	**0.7**	**0.8**	**0.6**	**1.3**	**1.5**	**1.0**
Integrated Nutrient Management									
N1: 50% RDF + 5 t/ha FYM + Azotobacter	7.7	7.8	7.7	42.0	44.3	43.1	79.3	79.4	79.3
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	7.8	7.8	7.8	43.7	46.0	44.8	79.6	79.7	79.7
N3: 50% RDF + 5 t/ha FYM + PSB	7.2	7.4	7.3	41.7	43.1	42.4	78.9	78.9	78.9
N4: 75% RDF + 2.5 t/ha FYM + PSB	7.3	7.6	7.4	43.0	44.1	43.5	79.2	79.3	79.2
N5: 50% RDF + 5 t/ha FYM + ZSB	7.4	7.8	7.6	44.8	46.7	45.7	80.4	80.6	80.5
N6:75% RDF + 2.5 t/ha FYM + ZSB	7.9	8.0	8.0	46.3	47.1	46.7	80.5	80.7	80.6
N7: 100% RDF (120:60:40 N-P-K kg/ha)	7.8	8.0	7.9	46.0	46.3	46.1	80.8	81.0	80.9
SEm(±)	**0.05**	**0.05**	**0.04**	**0.25**	**0.30**	**0.19**	**0.33**	**0.52**	**0.30**
CD at 5%	**0.1**	**0.2**	**0.1**	**0.7**	**0.9**	**0.5**	**0.9**	**1.5**	**0.9**
Zn X INM	**0.2**	**0.3**	**0.2**	**1.2**	**1.5**	**0.9**	**NS**	**NS**	**NS**

Table 4.21: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on grain appearance score**

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	7.7	7.6	7.7	7.7	7.8	7.7	7.9	7.8	7.7	7.7	7.8	7.7
N2	7.7	7.9	8.0	7.8	7.8	7.9	7.8	7.8	7.7	7.9	7.9	7.8
N3	6.9	7.5	7.2	7.2	7.0	7.5	7.8	7.4	6.9	7.5	7.5	7.3
N4	7.2	7.3	7.4	7.3	7.2	7.7	7.8	7.6	7.2	7.5	7.6	7.4
N5	7.4	7.3	7.6	7.4	7.7	7.9	7.8	7.8	7.5	7.6	7.7	7.6
N6	7.8	7.8	8.1	7.9	8.0	7.9	8.2	8.0	7.9	7.8	8.1	8.0
N7	7.6	7.7	8.0	7.8	7.8	8.0	8.2	8.0	7.7	7.9	8.1	7.9
Mean	7.4	7.6	7.7		7.6	7.8	7.9		7.5	7.7	7.8	
Z×N (CD at 5 %)	**0.2**				**0.3**				**0.2**			

Table 4.22: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on sedimentation volume (cc)**

Treatments	**2021-2022**				**2022-2023**				**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	42.4	39.5	44.1	42.0	45.1	42.2	45.5	44.3	43.8	40.9	44.8	43.1
N2	40.4	43.4	47.3	43.7	43.5	46.1	48.4	46.0	41.9	44.7	47.8	44.8
N3	40.5	42.5	42.1	41.7	42.3	39.8	47.2	43.1	41.4	41.2	44.7	42.4
N4	40.0	44.0	45.0	43.0	40.4	46.5	45.4	44.1	40.2	45.3	45.2	43.5
N5	42.1	45.4	46.9	44.8	44.3	48.5	47.3	46.7	43.2	46.9	47.1	45.7
N6	44.7	45.7	48.4	46.3	45.9	46.2	49.0	47.1	45.3	46.0	48.7	46.7
N7	44.8	45.1	48.2	46.0	44.7	45.9	48.2	46.3	44.7	45.5	48.2	46.1
Mean	42.1	43.6	46.0		43.7	45.0	47.3		42.9	44.3	46.6	
Z×N (CD at 5 %)	**1.2**				**1.5**				**0.9**			

Total nitrogen uptake (kg/ha)

Table 4.23 presents the data regarding wheat crop nitrogen uptake. Total nitrogen uptake was significantly impacted by various agronomic zinc fortification methods throughout the two growing seasons of crops. Total N uptake by the crop was highest (168.1, 177.2 & 172.7 kg/ha) with Z3 in comparison with sole soil application (123.3, 130.5 & 126.9 kg/ha) and foliar application (139, 144.6 & 141.8 kg/ha) of zinc in 2021-2022, 2022-2023 and pooled data. The implementation of integrated nutrient management has a notable impact on enhancing the overall nitrogen absorption by the crop. Significantly greater value for total nitrogen uptake of 178.4, 186 and 182.2 kg/ha was obtained with N6 application and were found to be 71.37, 65.78 and 68.55 % higher as compared to the lowest treatment, i.e., N3. The improvement in wheat grain and straw yields can be attributed to improved nutrient application, namely for N, P, K, and Zn, which were applied in balanced amounts. The interaction due to both the aspects of study was found to have a substantial influence on total N uptake by the crop.

The beneficial synergistic effect of zinc spraying on enhancing crop nitrogen uptake may be the cause of this. This was in support with the research outcomes of Ji *et al.* (2022) and Lv *et al.* (2022) who suggested that zinc application in rice crop improved the translocation and nitrogen uptake by the crop. Another possible explanation could be attributed to the gradual breakdown and coordinated release of plant nutrients from farm yard waste throughout the course of crop development. These results nearly corresponds with those of Jat *et al.* (2012) and Patro *et al.* (2005).

Total phosphorus uptake (kg/ha)

Table 4.23 displays information on the total amount of P uptake by the wheat crop. It was noticed that a significant response result of agronomic zinc fortification methods on total phosphorus uptake by wheat crop. Among the agronomic zinc fortification methods, the highest value (34.4, 36.1 & 35.3 kg/ha) was achieved with combined soil +foliar zinc application in both the study years and was seen to be significantly greater than the remaining treatments. Among INM, during 2021-2022, maximum total phosphorus uptake (34.5 kg/ha) by the crop was obtained with N2 and was similar with N4, N6 & N7 and higher than N1, N3 & N5 respectively. The highest value, reaching 37.6 kg/ha, was achieved during the second year of the trial with N7. This value was comparable to those obtained with N2, N4, and N6. The same trend was also revealed by pooled data analysis as that of 2022-2023.

The interaction due to both aspects of the study was found to have a significant role in influencing the total P uptake by the crop (Table 4.24). The interaction study during the first-year study revealed that maximum total P uptake was obtained when Z3 was combined with N2 and was at par with Z3N7. However, the maximum value was obtained with Z3N7 during 2022-2023, which was found to be at par with Z3N2, Z3N6 and Z2N4. The maximum value from pooled analysis showed the same trend as in the first year.

Total potassium uptake (kg/ha)

Total potassium uptake was significantly affected by agronomic zinc fortification methods and different INM practices (Table 4.23). A significantly higher value for total K uptake (143.5, 145.5 and 144.5 kg/ha) during 2021-2022, 2022-2023 and pooled data analysis of two years was obtained with combined soil + foliar zinc application was followed by foliar zinc (119.9, 125.4 & 122.7 kg/ha) and soil zinc application (115.5, 123.5 & 119.5 kg/ha) alone. With respect to the second aspect of the study, a significantly superior value (148.5, 151.0 & 149.8 kg/ha) was acquired through the use of N6 than all other treatments throughout the study. Minimum total potassium uptake (97.4 and 108.3 kg/ha) by the crop during 2021-22 and 2022-23 was recorded by N3 treatment. The per cent increment in total K uptake when the highest treatment, i.e., N6, was compared with the lowest treatment, was 52.5, 39.4 and 45.7%. In the course of both study years, it was discovered that the interaction between the two study aspects had no significant impact on the crop's overall uptake of K. However, the pooled analysis of data for total K uptake showed a significant interaction between agronomic zinc fortification methods and different INM approaches. A significantly greater value amounting to 168.3 kg/ha was obtained when Z3 interacted with the N6 method.

Total zinc uptake (g/ha)

Total zinc uptake is shown in Table 4.23. It was found that agronomic zinc fortification methods, different INM approaches and their interaction were discovered to have a noteworthy impact on improving the total zinc uptake. Significantly higher value was obtained with combined soil + foliar zinc application (390.3 g/ha in 2021-2022, 412.1 g/ha in 2022-2023 & 401.2 g/ha in pooled data) and it was then followed by foliar zinc application (332.7 g/ha in 2021-2022, 358.2 g/ha in 2022-2023 & 345.4 g/ha in pooled data) and soil zinc application alone (285.9 g/ha in 2021-2022, 313.9 g/ha in 2022-2023 & 299.9 g/ha in pooled data. Considering the second aspect of the study, the application of N6 obtained significantly higher total zinc uptake (411.1 g/ha in 2021-2022, 434.3 g/ha in 2022-2023 & 422.7 g/ha in pooled data) than all the rest of the treatments. The treatments N5 (366.8 g/ha) and N2 (357.9 g/ha) were determined to be statistically indistinguishable from each other for the 2021-2022 period. During the 2022-2023 period, N5 (391.1 g/ha) showed no significant difference in yield compared to N7 (378.6 g/ha) and N2 (376.4 g/ha). During both years, the interaction due to both the aspects of study also showed a significant effect on influencing the zinc uptake by crop where the highest value (458.9 g/ha in 2021-2022, 490.3 g/ha in 2022-2023 and 474.6 g/ha in pooled data) was obtained when Z3 interacted with N6 and was found to be at par with Z3N2. By applying more zinc to the soil and leaves of the wheat, it may be possible to increase the amount of zinc accessible in the vegetative tissues and grain zinc sink (Xia *et al.,* 2020).

Table 4.23 : Effect of different treatments on total nitrogen (kg/ha), phosphorus (kg/ha), potassium (kg/ha) and zinc uptake (g/ha)

Treatments	Total N uptake (kg/ha)			Total P uptake (kg/ha)			Total K uptake (kg/ha)			Total Zn uptake (g/ha)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Agronomic Zn fortification												
Z1: Soil application of Zn	123.3	130.5	126.9	30.4	34.1	32.3	115.5	123.5	119.5	285.9	313.9	299.9
Z2: *Foliar application of Zn	139.0	144.6	141.8	31.3	33.9	32.6	119.9	125.4	122.7	332.7	358.2	345.4
Z3: Soil and foliar application of Zn	168.1	177.2	172.7	34.4	36.1	35.3	143.5	145.5	144.5	390.3	412.1	401.2
SEm(±)	2.1	1.3	1.4	0.4	0.2	0.2	3.5	2.4	1.7	3.2	4.0	2.7
CD at 5%	6.9	5.2	4.9	1.2	0.7	0.6	10.9	7.0	7.4	12.5	15.6	10.4
Integrated Nutrient Management												
N1: 50% RDF + 5 t/ha FYM + Azotobacter	136.6	145.9	141.2	30.6	33.0	31.8	121.5	126.4	123.9	325.6	354.4	340.0
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	157.5	159.3	158.4	34.5	36.1	35.3	131.7	136.3	134.0	357.9	376.4	367.1
N3: 50% RDF + 5 t/ha FYM + PSB	104.1	112.2	108.1	28.5	30.8	29.7	97.4	108.3	102.8	261.2	286.7	273.9
N4: 75% RDF + 2.5 t/ha FYM + PSB	137.9	135.7	136.8	33.6	35.9	34.7	121.0	123.8	122.4	292.5	308.4	300.4
N5: 50% RDF + 5 t/ha FYM + ZSB	152.3	160.4	156.3	29.2	33.0	31.1	132.1	137.2	134.7	366.8	391.1	378.9
N6:75% RDF + 2.5 t/ha FYM + ZSB	178.4	186.0	182.2	34.1	36.5	35.3	148.5	151.0	149.8	411.1	434.3	422.7
N7: 100% RDF (120:60:40 N-P-K kg/ha)	137.7	155.9	146.8	33.8	37.6	35.7	131.8	137.4	134.6	339.1	378.6	358.8
SEm(±)	2.0	2.0	1.6	0.8	1.0	0.7	4.0	3.5	2.4	6.0	6.4	4.2
CD at 5%	6.02	5.8	4.39	2.3	2.8	2.1	11.0	9.9	6.3	17.3	18.5	12.0
Zn X INM	10.4	10.1	7.6	3.9	4.9	3.6	NS	NS	10.8	30.0	32.0	20.8

Table 4.24: Interaction effect of agronomic zinc fortification methods with integrated nutrient management on total nitrogen uptake (kg/ha) by wheat

Treatments	2021-2022				2022-2023				Pooled			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	137.8	114.6	157.2	136.6	145.4	126.1	166.2	145.9	141.6	120.4	161.7	141.2
N2	116.4	146.4	209.6	157.5	130.3	142.3	205.4	159.3	123.3	144.3	207.5	158.4
N3	103.2	96.5	112.5	104.1	108.8	99.1	128.8	112.2	106.0	97.8	120.6	108.1
N4	108.8	147.4	157.5	137.9	116.5	148.7	141.9	135.7	112.7	148.1	149.7	136.8
N5	117.3	164.9	174.6	152.3	129.2	167.4	184.7	160.4	123.2	166.2	179.6	156.3
N6	152.9	174.4	208.0	178.4	158.4	179.5	220.0	186.0	155.6	176.9	214.0	182.2
N7	126.7	129.0	157.4	137.7	124.7	149.3	193.8	155.9	125.7	139.2	175.6	146.8
Mean	123.3	139.0	168.1		130.5	144.6	177.2		126.9	141.8	172.7	
Z×N (CD at 5 %)	10.4				10.1				7.6			

Table 4.25: Interaction effect of agronomic zinc fortification methods with integrated nutrient management on total phosphorus uptake (kg/ha) by wheat

Treatments	2021-2022				2022-2023				Pooled			
	Z1	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**	**Z1**	**Z2**	**Z3**	**Mean**
N1	31.2	26.9	33.8	30.6	34.2	29.7	35.3	33.0	32.7	28.3	34.5	31.8
N2	30.3	32.3	40.8	34.5	34.2	31.8	42.3	36.1	32.2	32.1	41.5	35.3
N3	28.3	29.4	28.0	28.5	31.1	32.8	28.6	30.8	29.7	31.1	28.3	29.7
N4	30.0	36.6	34.2	33.6	34.6	39.5	33.5	35.9	32.3	38.0	33.9	34.7
N5	27.9	29.6	30.2	29.2	33.0	33.1	32.8	33.0	30.5	31.3	31.5	31.1
N6	32.7	35.1	34.6	34.1	37.1	34.7	37.9	36.5	34.9	34.9	36.2	35.3
N7	32.8	29.4	39.1	33.8	34.8	35.5	42.6	37.6	33.8	32.4	40.8	35.7
Mean	30.4	31.3	34.4		34.1	33.9	36.1		32.3	32.6	35.3	
Z×N (CD at 5 %)	3.9				4.9				3.6			

Table 4.26: **Interaction effect of agronomic zinc fortification methods with integrated nutrient management on total potassium uptake (kg/ha)**

Treatments	**Pooled**			
	Z1	**Z2**	**Z3**	**Mean**
N1	123.8	113.6	134.4	123.9
N2	116.3	125.4	160.4	134.0
N3	98.1	98.9	111.5	102.8
N4	108.5	124.5	134.3	122.4
N5	127.5	130.4	146.0	134.7
N6	141.3	139.7	168.3	149.8
N7	121.1	126.2	156.5	134.6
Mean	119.5	122.7	144.5	
Z×N (CD at 5 %)	**10.8**			

Table 4.27: Interaction effect of agronomic zinc fortification methods with integrated nutrient management on total zinc uptake (g/ha)

Treatments	2021-2022				2022-2023				Pooled			
	Z1	Z2	Z3	Mean	Z1	Z2	Z3	Mean	Z1	Z2	Z3	Mean
N1	327.5	277.5	371.8	325.6	348.7	316.7	397.7	354.4	338.1	297.1	384.8	340.0
N2	265.2	359.9	448.4	357.9	304.4	365.4	459.5	376.4	284.8	362.6	453.9	367.1
N3	218.8	265.5	299.2	261.2	242.4	296.3	321.3	286.7	230.6	280.9	310.2	273.9
N4	214.1	317.1	346.3	292.5	240.6	333.5	350.9	308.4	227.4	325.3	348.6	300.4
N5	315.6	384.2	400.5	366.8	347.9	399.8	425.6	391.1	331.7	392.0	413.1	378.9
N6	362.5	411.8	458.9	411.1	398.4	414.1	490.3	434.3	380.4	413.0	474.6	422.7
N7	297.8	312.9	406.7	339.1	314.7	381.5	439.5	378.6	306.3	347.2	423.1	358.8
Mean	285.9	332.7	390.3		313.9	358.2	412.1		299.9	345.4	401.2	
Z×N (CD at 5 %)	**30.0**				**32.0**				**20.8**			

Chlorophyll content (mg/g)

The total chlorophyll content at 30 DAS showed a non-significant effect due to agronomic zinc fortification and INM approaches and also due to their interaction during 2021-22. At 60, 90 and 120 DAS, agronomic zinc fortification and INM approaches have a significant effect on total chlorophyll content (Table 4.28). However, the interaction due to both the aspects of study was found to have an insignificant effect at all the growth stages. First-year study showed that a significantly higher value for total chlorophyll content at 60, 90 and 120 DAS to the range of 2.08, 2.97 and 2.16 was obtained with combined soil and foliar zinc application (Z3), which was observed to be at par with foliar zinc application (2.06, 2.92 and 2.13) respectively.

With respect to the second aspect, 75% RDF + 2.5 t/ha FYM + ZSB obtained significantly better value than every other treatment, with the exception of N5 and N7 at 60 and 120 DAS. However, the maximum value at 90 DAS followed the same trend as that of 60 and 120 DAS.

During 2022-2023, higher total chlorophyll content at 60, 90, and 120 DAS followed the same pattern as that in the first year for agronomic zinc fortification methods and INM approaches. The lowest value was obtained with sole soil application in all the consecutive stages when the agronomic zinc fortification method was considered. The pooled analysis of data also followed the same pattern as that of both years of study.

The amount of total chlorophyll was likewise increased by the application of zinc-solubilizing bacteria. These results support their involvement in zinc absorption since zinc shortage causes a significant decrease in chlorophyll concentration. Increased chlorophyll levels in plants treated with zinc solubilizers are attributed to Zn and its ability to stimulate the development of photosynthetic pigments. On the other hand, chlorophyll production is disrupted in plants with low levels of zinc (Pellegrino *et al.,* 2015). Chlorophyll measurements are a suitable means of verifying the advantageous function of zinc-solubilizing bacteria and improving the nutritional condition of the host plant, as plants lacking in zinc have chlorotic streaks on their leaves (Shakeel *et al.,* 2023).

Table 4.28: Effect of different treatments on total chlorophyll content (mg/g) of wheat

Treatments	30 DAS			60 DAS			90 DAS			120 DAS		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Agronomic Zn fortification												
Z1: Soil application of Zn	1.44	1.48	1.46	2.03	2.09	2.06	2.88	2.95	2.92	2.12	2.14	2.13
Z2: *Foliar application of Zn	1.44	1.48	1.46	2.06	2.11	2.09	2.92	3.03	2.97	2.13	2.17	2.15
Z3: Soil and foliar application of Zn	1.44	1.49	1.47	2.08	2.15	2.12	2.97	3.04	3.00	2.16	2.21	2.19
SEm(±)	**0.005**	**0.007**	**0.002**	**0.009**	**0.01**	**0.01**	**0.01**	**0.012**	**0.009**	**0.008**	**0.003**	**0.005**
CD at 5%	**NS**	**NS**	**NS**	**0.03**	**0.04**	**0.03**	**0.05**	**0.05**	**0.03**	**0.03**	**0.01**	**0.02**
Integrated Nutrient Management												
N1: 50% RDF + 5 t/ha FYM + Azotobacter	1.44	1.47	1.46	1.96	2.03	2.00	2.84	2.98	2.91	2.11	2.15	2.13
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	1.44	1.49	1.47	2.03	2.15	2.09	2.96	3.01	2.99	2.12	2.16	2.14
N3: 50% RDF + 5 t/ha FYM + PSB	1.43	1.47	1.45	1.99	2.04	2.01	2.86	2.72	2.79	2.10	2.15	2.13
N4: 75% RDF + 2.5 t/ha FYM + PSB	1.44	1.47	1.46	1.99	2.07	2.03	2.90	2.98	2.94	2.11	2.16	2.14
N5: 50% RDF + 5 t/ha FYM + ZSB	1.43	1.50	1.47	2.13	2.18	2.15	2.92	3.10	3.01	2.14	2.19	2.17
N6:75% RDF + 2.5 t/ha FYM + ZSB	1.44	1.50	1.47	2.16	2.19	2.17	3.08	3.14	3.11	2.18	2.21	2.20
N7: 100% RDF (120:60:40 N-P-K kg/ha)	1.45	1.49	1.47	2.13	2.18	2.16	2.88	3.11	3.00	2.16	2.20	2.18
SEm(±)	**0.007**	**0.008**	**0.005**	**0.013**	**0.01**	**0.01**	**0.02**	**0.022**	**0.014**	**0.013**	**0.009**	**0.007**
CD at 5%	**NS**	**NS**	**NS**	**0.04**	**0.03**	**0.03**	**0.05**	**0.06**	**0.04**	**0.04**	**0.03**	**0.02**
Zn X INM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Protein content (%)

The addition of zinc through agronomic practices greatly affected the grain's protein content. The protein concentration reached its peak when zinc was administered both to the soil and as a foliar spray (Z3 - 12.7, 13.0, and 12.8). This value was found to be statistically similar to the foliar application of zinc and significantly higher than applying zinc to the soil alone (Table 4.29).

With respect to the second aspect of the study, the maximum value for grain protein content was recorded with N6 (12.7) and was discovered to be substantially greater than every other treatment, with the exception of N7, N5 and N2, where it was found to be at par with highest treatment during 2021-2022. However, during 2022-2023, maximum grain protein content was received in two treatments viz., N6 and N2 and was found to be at par with N1, N5 and N7. Pooled analysis of data from the two studies confirms that maximum value grain protein content was obtained with N6 and N2 (12.8) and was significantly better than all the remaining treatments except N5 (12.7) where it was found to be at par. The combined influence of both study factors was determined to have an insignificant impact on the grain protein content in wheat crop.

High bicarbonate concentrations in alkaline soil prevent zinc from being absorbed by plants and from transitioning to the shoot, where it precipitates in inaccessible forms (Dogar & Van Haj, 1980). Nonetheless, zinc shortage in plants cultivated on calcareous soils may be very easily made up by applying inorganic zinc salts, such $ZnSO_4$, through soil and foliage application. Studies confirm that grain yield and protein content improved linearly as a result of this external treatment (Morshedi & Farahbakhsh, 2010). Research done by Khattak *et al.*(2006) on maize concluded an increase in grain protein content when zinc was foliarly supplied at 0.5%. Protein synthesis is thought to be impacted by zinc shortage through a process involving decreased RNA, ribosomal deformation and reduction (Khattak *et al.,* 2015). As zinc is essential for protein synthesis, meristematic tissues where nucleic acid and protein synthesis are actively occurring—need a comparatively high quantity of zinc (Brown *et al.,* 1993). In areas where zinc insufficiency is a severe issue, Yilmaz *et al.* (1997) state that combined zinc soil and foliar sprays may be required for short-term remedies to zinc deficits in plants. The increase in protein content with inoculation of

ZSB along with 75% RDF and 2.5 t/ha of FYM might be because zinc-solubilizing bacteria play a crucial role in increasing zinc availability, which raises wheat grain's NUE. Nitrogen is also essential for synthesizing amino acids and enhancing protein synthesis. Akram *et al.* (2017) further supported and suggested a positive impact of zinc and nitrogen on enhancing the grain protein content.

Table 4.29: Effect of different treatments on grain protein content (%) of wheat

Treatments	Protein content (%)		
	2021-22	**2022-23**	**Pooled**
Agronomic Zn fortification			
Z1: Soil application of Zn	12.3	12.4	12.3
Z2: *Foliar application of Zn	12.4	12.7	12.6
Z3: Soil and foliar application of Zn	12.7	13.0	12.8
SEm(±)	0.06	0.08	0.04
CD at 5%	0.3	0.3	0.2
Integrated Nutrient Management			
N1: 50% RDF + 5 t/ha FYM + Azotobacter	12.4	12.8	12.6
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	12.6	12.9	12.8
N3: 50% RDF + 5 t/ha FYM + PSB	12.0	12.2	12.1
N4: 75% RDF + 2.5 t/ha FYM + PSB	12.4	12.5	12.5
N5: 50% RDF + 5 t/ha FYM + ZSB	12.5	12.8	12.7
N6:75% RDF + 2.5 t/ha FYM + ZSB	12.7	12.9	12.8
N7: 100% RDF (120:60:40 N-P-K kg/ha)	12.5	12.8	12.6
SEm(±)	0.07	0.06	0.04
CD at 5%	0.2	0.2	0.1
Zn X INM	NS	NS	NS

Economics

Table 4.30 shows the economic parameters of wheat for two cropping seasons (2021–2022, 2022–2023) under agronomic zinc fortification and integrated nutrient management.

Maximum gross return of 136204 ₹/ha during 2021-2022 and 145489 ₹/ha during 2022-2023 was attained with combined soil and foliar application of zinc. It was found to be significantly higher than both the other zinc application methods. The least gross return to the tune of 109408 ₹/ha during 2021-2022 and 122443 ₹/ha during 2022-2023 was achieved with sole soil application of zinc in the course of both years. Among the different INM approaches, significantly higher gross return (136557 ₹/ha during 2021-2022 and 149133 ₹/ha during 2022-2023) was registered with N6 application than all the other treatments.

The net return also followed the same trend as that of gross return with a maximum net return to the tune of 72463 ₹/ha during 2021-22 and 81749 ₹/ha during 2022-23 was obtained with combined soil and foliar application of zinc and was found to be significantly higher than the other two application zinc methods. Concerning the second aspect of the study, the maximum net return was incurred with the use of N6, and the least was obtained under the application of N3 during the course of both years of study.

The treatment with the highest B: C ratio achieved maximum economic benefit. Soil and foliar application of zinc (Z3) obtained Maximum B: C in the range of 1.14 during 2021-22 and 1.28 during 2022-23. With respect to the second aspect, the B: C ratio varied from 0.73 to 1.22 during 2021-2022 and 0.92 to 1.43 during 2022-2023, where maximum B: C was recorded under the application of N6 during the study years.

Table 4.30: Effect of different treatments on economic viability

Treatments	Gross return ₹/ha		Net return ₹/ha		B:C	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Agronomic Zn fortification						
Z1: Soil application of Zn	1,09,408	1,22,443	51,205	64,240	0.88	1.10
Z2: *Foliar application of Zn	1,19,940	1,30,493	58,775	69,328	0.96	1.13
Z3: Soil and foliar application of Zn	1,36,204	1,45,489	72,463	81,749	1.14	1.28
SEm(±)	**1219**	**1152**	**1219**	**1152**	**0.02**	**0.02**
CD at 5%	**4786**	**4525**	**4786**	**4525**	**0.08**	**0.07**
Integrated Nutrient Management						
N1: 50% RDF + 5 t/ha FYM + Azotobacter	1,18,182	1,30,189	57,956	69,963	0.96	1.16
N2: 75% RDF + 2.5 t/ha FYM + Azotobacter	1,27,054	1,33,100	65,747	71,794	1.06	1.16
N3: 50% RDF + 5 t/ha FYM + PSB	1,04,123	1,15,787	43,794	55,457	0.73	0.92
N4: 75% RDF + 2.5 t/ha FYM + PSB	1,18,131	1,25,701	56,720	64,291	0.92	1.05
N5: 50% RDF + 5 t/ha FYM + ZSB	1,25,277	1,37,041	64,965	76,729	1.07	1.27
N6:75% RDF + 2.5 t/ha FYM + ZSB	1,36,557	1,49,133	75,164	87,740	1.22	1.43
N7: 100% RDF (120:60:40 N-P-K kg/ha)	1,23,631	1,38,706	61,355	76,431	0.98	1.22
SEm(±)	**1556**	**1545**	**1556**	**1545**	**0.02**	**0.02**
CD at 5%	**4464**	**4431**	**4464**	**4431**	**0.07**	**0.07**
Zn X INM	**8283.1**	**8179.9**	**8283.1**	**8179.9**	**0.13**	**0.13**

CHAPTER - 5

SUMMARY AND CONCLUSIONS

A research trial was conducted to investigate the "Effect of Integrated Nutrient Management and Agronomic Zn fortification on growth, yield and quality of Wheat (*Triticum aestivum* L.)" at Lovely Professional University, Phagwara, during *rabi* seasons of 2021-22 and 2022-23. A split-plot design was used to experiment. Three zinc application methods, i.e., soil (Z1), foliar (Z2) and soil + foliar application (Z3), were considered in main plots and seven INM practices as subplot factors. Key findings are outlined below:

- Out of the three zinc application methods, the maximum plant height (103.5 and 106.7 cm) during both years was found to be obtained with the combined soil+ foliar zinc application method. However, some soil and foliar applications were found to be at par with each other.
- In both years, among the different INM practices, the maximum improvement in the height of the plant (103.9 and 107.6 cm) was attained with the application of 75% RDF + 2.5 t/ha FYM + Azotobacter.
- In both years, the highest productive tiller count/m^2 (384.6 and 387.9) was obtained with the combined soil+ foliar zinc application method, and the lowest count (335.5 and 340.9) was obtained with soil zinc application.
- Among the different integrated nutrient management, the maximum effective tiller count per m^2 (389.8 and 394.3) was obtained with Z6: 75% RDF + 2.5 t/ha FYM + ZSB throughout the two study years.
- Maximum accumulation of dry matter at harvest was achieved in both years with Z3: combined soil + foliar zinc application treatment. Treatments Z1: soil zinc application and Z2: foliar zinc application were found to be statistically at par with each other.
- Maximum accumulation of dry matter (870.1 and 873.3 g/m^2) during both years with respect to different integrated nutrient management was obtained with Z6 treatment. It was found to be at par with Z5 and Z7 treatments.
- The highest LAI during both study years was obtained with combined soil+ foliar zinc application (Z3) as compared to the other two modes of zinc application.

- Application of N6: 75% RDF + 2.5 t/ha FYM + ZSB recorded maximum LAI (3.44 and 3.95) and the minimum (2.63 and 3.12) was found to be obtained with N3: 50% RDF + 5 t/ha FYM + PSB.
- Maximum root length (41.9 and 43.1 cm) with different zinc application methods during both the years of study was found to be obtained with sole soil zinc application. Significant improvement in root length (44.4 and 45.8 cm) with different integrated nutrient management approaches with highest increment obtained with the application of N4: 75% RDF + 2.5 t/ha FYM + PSB.
- In each of the two years, maximum root dry weight per plant (2.28 and 2.32 g) at 90 DAS was obtained with Z1: Soil application of Zn and was found to be at par with Z3: Soil and foliar application of Zn. However, the least dry weight was obtained with Z2: foliar zinc application.
- Concerning different integrated nutrient management, maximum root dry weight per plant (2.35 and 2.40 g) was recorded with N6: 75% RDF + 2.5 t/ha FYM + ZSB, which was found to be at par with N4: 75% RDF + 2.5 t/ha FYM + PSB respectively in each of the study years.
- The combined application of soil and foliar Zn during both years produced maximum spike length (11.9 and 12.2 cm).
- Among the different INM approaches, the application of N6: 75% RDF + 2.5 t/ha FYM + ZSB was found to be fruitful in achieving a maximum increment in spike length of 11.8 and 12.2 cm, respectively.
- In each of the study years, the maximum grain number per spike was obtained with the Z3: soil and foliar zinc application method. The least count was obtained with soil zinc application even though it was found to be at par with foliar zinc application alone.
- Significantly higher grain number per spike (53.2 & 54.2) throughout both the years of study was recorded when N6: 75% RDF + 2.5 t/ha FYM + ZSB was applied. A minimum number of grains per spike was obtained when N3: 50% RDF + 5 t/ha FYM + PSB was applied.
- Maximum test weight (44.3 and 45.3 g) for two years was obtained with soil and foliar application of Zn. Among the different INM treatments, N6:75% RDF + 2.5 t/ha FYM + ZSB was found to be similar to N7: 100% RDF (120:60:40 N-P-

K kg/ha), with the highest value for test weight (44.3 and 44.8 g) obtained with N6 respectively during both the years of study.

- The simultaneous application of zinc to the soil and foliage resulted in a substantial increase in grain output, reaching 5.4 and 5.5 t/ha. The lowest grain production (4.2 and 4.5 t/ha) was achieved when zinc was applied to the soil.
- When comparing the different INM treatments, the highest grain yield (5.3 and 5.7 t/ha) during both years was obtained with the application of N6: 75% RDF + 2.5 t/ha FYM + ZSB, and the lowest value (4.0 and 4.3 t/ha) was recorded with the administration of N3: 50% RDF + 5 t/ha FYM + PSB, respectively. The interaction between agronomic zinc fortification and INM was significant in improving the grain yield.
- Different zinc application methods significantly influenced straw yield, with the maximum value obtained with Z3: combined soil and foliar zinc application.
- The highest straw yield among the various INM techniques was attained when N6: 75% RDF + 2.5 t/ha FYM + ZSB was applied during both years respectively.
- The grain: straw ratio was found to have an insignificant effect due to different zinc application methods during 2021-21, whereas during the second year of study, the Grain: straw ratio was found to be significantly influenced by agronomic zinc fortification methods, with a similar value (0.7) obtained with Z3: combined soil and foliar zinc application and Z2: foliar zinc application.
- HI was found to be substantially higher (41.3 and 42.1) throughout the two years it was obtained with Z3: combined soil and foliar zinc application. Application of N6: 75% RDF + 2.5 t/ha FYM + ZSB recorded higher harvest index (40.5 and 42.2) during both years.
- Following crop harvest in both years, different agronomic zinc fortification methods did not greatly affect the amount of available primary nutrients in the soil. However, among the different INM approaches, significantly higher available nitrogen, phosphorus and potassium in soil were obtained with the application of N1: 50% RDF + 5 t/ha FYM + Azotobacter.
- The soil's DTPA Zinc status was enhanced in both years by the application of Z3: Soil and foliar zinc application. Among the different INM approaches, the highest

DTPA Zinc status during 2022-2023 was registered when N5: 50% RDF + 5 t/ha FYM + ZSB was applied.

- Bulk density for both years was not influenced by different agronomic zinc fortification methods. However, the lowest bulk density during both years was obtained with N1: 50% RDF + 5 t/ha FYM + Azotobacter, N3: 50% RDF + 5 t/ha FYM + PSB, and N5: 50% RDF + 5 t/ha FYM + ZSB. Higher bulk density was obtained with the application of N7: 100% RDF (120:60:40 N-P-K kg/ha) during both years.
- During both years, the application of Z3: soil and foliar application of Zn significantly influenced the grain appearance score, sedimentation value, and hectolitre due to agronomic zinc fortification. Similarly, the application of N6: 75% RDF + 2.5 t/ha FYM + ZSB obtained a significantly higher grain appearance score, sedimentation value, and hectolitre.
- Among the many methods of adding zinc to crops, the combined use of soil and foliar application of zinc resulted in a much better uptake of nutrients.
- Regarding the various INM techniques, the implementation of N6: 75% RDF + 2.5 t/ha FYM + ZSB resulted in higher total nitrogen, phosphorus, potassium and zinc uptake.
- The content of chlorophyll was not significantly affected during 30DAS due to the agronomic zinc fortification method. At 60, 90 and 120DAS, a substantially higher value for chlorophyll content was obtained with the application of Z3: Soil and foliar application of Zn. The lowest value was obtained with the administration of Z1: Soil application of Zn. Chlorophyll content at later stages was influenced by INM approaches, with the highest value obtained when N6: 75% RDF + 2.5 t/ha FYM + ZSB was applied.
- The agronomic zinc application method significantly improved the protein content in wheat crops with maximum increment obtained when Z3: Soil and foliar application of Zn was applied. During 2021-22, maximum protein content was obtained with the application of N6: 75% RDF + 2.5 t/ha FYM + ZSB. However, similar values for protein content during 2022-23 were obtained when N6: 75% RDF + 2.5 t/ha FYM + ZSB and N2: 75% RDF + 2.5 t/ha FYM + Azotobacter was applied.

- Among the different zinc application methods, the combined soil and foliar zinc application obtained the maximum gross return, net return, and benefit-to-cost ratio. With respect to INM practices, the maximum economic benefit was noticed with the N6: 75% RDF + 2.5 t/ha FYM + ZSB method.

Conclusions

- It can be concluded that Z3N6 (Z3: combined soil+foliar zinc application; N6: 75 % RDF + 2.5 t/ha FYM+ ZSB) helps improve crop growth and yield.
- Simultaneous application of fertilizers to both the soil and the leaves of plants had given the highest yield attributes, viz. grain number per spike (52.7), length of the spike (12.1 cm), grain yield (5.4 t/ha) and straw yield (7.6 t/ha) in comparison to sole soil and foliar application.
- Among the different INM approaches, 75% RDF along with 2.5 t/ha of FYM and zinc solubilizing bacteria (ZSB) was determined to be the most effective in achieving the highest yield characteristics like number of grains per spike (53.7) and spike length (12.0 cm) leading to maximum grain yield (5.5 t/ha).
- It was observed that the interaction of Z3 (combined soil + foliar zinc application) and N6 (75 % RDF+ 2.5 t/ha FYM + ZSB) helped in fetching maximum grain yield to the tune of 6.3 t/ha. The adoption of this method also helps enrich the soil's nutrient status, particularly in alkaline soil conditions.
- It was observed that quality parameters like grain protein content (12.8%), nutrient uptake (172.7 kg/ha N uptake, 35.3 kg/ha of P uptake, 144.5 kg/ha of K uptake and 401.2 g/ha of zinc uptake), sedimentation volume (46.6 cc) and hectolitre weight (81.1 kg/hl) were improved with the combined soil and foliar application of zinc compared to sole soil and foliar zinc application.
- Similarly, the integrated nutrient management practice, viz., the application of 75% RDF along with 2.5 t/ha of FYM and zinc solubilizing bacteria, was superior in terms of grain quality and resulted in the highest grain zinc uptake (422.7 g/ha).
- In economic terms, combined soil and foliar zinc application recorded a maximum B:C ratio (1.21). Concerning different integrated nutrient management, a 20.5 per cent improvement in the B: C ratio was obtained with the application of 75% RDF + 2.5 t/ha FYM + ZSB (1.33) compared to 100 % RDF application.

- Hence, from the two-year experimentation, it can be suggested that combined soil and foliar zinc application along with 75% RDF + 2.5 t/ha FYM + ZSB is suitable for improving the quality and productivity of wheat in an economically viable manner and is helpful for the advancement of science and the farming community.

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Appendix- I

Weekly average of meteorological data during crop season 2021-22

Std. m. week	Temperature (^0C)		Relative humidity (%)	Wind speed (km/hr)	Rainfall (mm)
	Maximum	Minimum	Morning		
46	26.7	13.6	56	2.3	0
47	24.2	13.3	57	1.4	0
48	21.4	11	56.4	0.6	0
49	21.3	11.4	66.4	1.4	0
50	19.9	9.1	65.3	1.7	0
51	20.1	9	67.1	0.9	0
52	18.9	8.8	65	1	0.1
1	16.3	8.4	74.1	1.1	9
2	14.6	10.3	76	3.1	6.1
3	17.4	11.4	74.9	2	0.3
4	14.9	11.7	76.9	2.3	0
5	16.4	8.4	78.3	2.6	0.1
6	12.6	8.7	77.3	1.7	0
7	17.1	8.4	75.7	2.3	0
8	19.6	10.4	68.7	1.7	0
9	17.1	9.3	60.9	3.1	2.3
10	21.3	14.3	54.7	1.1	0
11	26.9	19.9	55.1	2.3	0
12	31.9	21.6	52.4	2.3	0
13	31.4	21	51.1	4	0
14	33.1	24.1	47.3	3.4	0
15	41.3	27.1	44.6	4	0.1
16	39.4	28.7	41.7	12.3	0

Appendix- II

Weekly average of meteorological data during crop season 2022-23

Std. m. week	Temperature(^{0}C)		Relative humidity (%)	Wind speed (km/hr)	Rainfall (mm)
	Maximum	Minimum	Morning		
46	27.7	14.9	54	16	0
47	28.1	18.3	73.9	6.7	0
48	24.9	13.7	85.4	2.3	0
49	27	10.9	86.6	3.3	0
50	26.7	11.4	89.1	8.4	0
51	24.6	9.9	90.4	4.6	0
52	21.6	8.6	94.3	7.3	0.3
1	14.4	5.5	94.1	6.6	0
2	13.5	8.4	95.6	8.9	0.3
3	14.4	5.9	91.4	6.7	0
4	18.7	7.6	84.1	7.7	4.9
5	20.1	8.7	94.6	11.4	1.8
6	23.7	11.8	80.3	10.1	0
7	26	10.8	63	9.6	0
8	28.1	14.3	92.3	9.9	0
9	27.4	14	66.3	9.1	0
10	29.4	14	46.4	8.7	0
11	27.8	16.7	74.4	10.6	2.1
12	24.7	13.9	93.3	1.8	5.5
13	27.6	15.7	88.7	10.1	0.3
14	27.8	14.2	65.1	2.9	0.3
15	35.5	16.1	75.7	3.4	0
16	35.3	17.2	79.6	4.9	1.3

Appendix-III
Total cost of cultivation 2021-22

Particulars	Treatment combinations																				
	Z1N1	**Z1N2**	**Z1N3**	**Z1N4**	**Z1N5**	**Z1N6**	**Z1N7**	**Z2N1**	**Z2N2**	**Z2N3**	**Z2N4**	**Z2N5**	**Z2N6**	**Z2N7**	**Z3N1**	**Z3N2**	**Z3N3**	**Z3N4**	**Z3N5**	**Z3N6**	**Z3N7**
A.Fixed cost (Rs/ha)																					
Land preparation																					
Ploughing	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740
Layout Preparation (labour)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Levelling	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Planting material and sowing																					
Seed rate	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
Sowing	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Inter cultural operations																					
Weeding	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
Herbicide	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376
Labour for herbicide application	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Irrigation																					
Tube well irrigation	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Labour for irrigation	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Harvest& threshing	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Rental value of land	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Total variable cost	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816

Particulars	**Treatment combinations**																				
	Z1N1	**Z1N2**	**Z1N3**	**Z1N4**	**Z1N5**	**Z1N6**	**Z1N7**	**Z2N1**	**Z2N2**	**Z2N3**	**Z2N4**	**Z2N5**	**Z2N6**	**Z2N7**	**Z3N1**	**Z3N2**	**Z3N3**	**Z3N4**	**Z3N5**	**Z3N6**	**Z3N7**
B.Variable cost (Rs/ha)																					
1. Urea	630	945	630	945	630	945	1260	630	945	630	945	630	945	1260	630	945	630	945	630	945	1260
2.DAP	1760	2646	176	2646	1760	2646	3523	1760	2646	1760	2646	1760	2646	3523	1760	2646	1760	2646	1760	2646	3523
3.MOP	1132	1700	1132	1700	1132	1700	2268	1132	1700	1132	1700	1132	1700	2268	1132	1700	1132	1700	1132	1700	2268
4.$ZnSO_4.7H_2O$ (Soil)	1375	1375	1375	1375	1375	1375	1375	0	0	0	0	0	0	0	1375	1375	1375	1375	1375	1375	1375
5.$ZnSO_4.7H_2O$ (Foliar)	0	0	0	0	0	0	0	137	137	137	137	137	137	137	137	137	137	137	137	137	137
5. FYM	1375	688	1375	688	1375	688	0	1375	688	1375	688	1375	688	0	1375	688	1375	688	1375	688	0
6. Bio-fertilizer	104	104	208	208	190	190	0	104	104	208	208	190	190	0	104	104	208	208	190	190	0
7. Labour cost	1200	1200	1200	1200	1200	1200	1200	5400	5400	5400	5400	5400	5400	5400	6600	6600	6600	6600	6600	6600	6600
Total cost	57393	58474	57497	58578	57479	58560	59442	60355	61436	60459	61540	60441	61522	62405	62930	64011	63034	64115	63016	64097	64980
C. Production (t/ha)																					
Main product	4.56	4.04	3.78	3.84	4.15	4.73	4.22	4.16	4.86	4	4.89	5.06	5.15	4.48	4.97	5.99	4.34	4.99	5.41	6.11	5.69
Byproduct	7.23	6.42	5.96	6.02	6.71	7.46	6.89	6.37	7.25	5.73	7.35	7.54	7.76	6.9	7.44	8.1	6.57	7.48	7.55	8.21	7.9
D.Sales price (t/ha)																					
Main product	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750	19750
Byproduct	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250
Gross return	120864	107013	100011	101478	110467	125110	112590	109217	126816	103385	127816	131959	134778	117841	129726	152778	113539	130316	138855	155644	145885
Net return	63472	48539	42515	42900	52988	66551	53147	48862	65380	42926	66276	71518	73256	55436	66796	88767	50505	66201	75839	91547	80905
B:C	1.11	0.83	0.74	0.73	0.92	1.14	0.89	0.81	1.06	0.71	1.08	1.18	1.19	0.89	1.06	1.39	0.8	1.03	1.2	1.43	1.25

Appendix-IV

Total cost of cultivation 2022-23

Particulars	**Treatment combinations**																				
	Z1N1	**Z1N2**	**Z1N3**	**Z1N4**	**Z1N5**	**Z1N6**	**Z1N7**	**Z2N1**	**Z2N2**	**Z2N3**	**Z2N4**	**Z2N5**	**Z2N6**	**Z2N7**	**Z3N1**	**Z3N2**	**Z3N3**	**Z3N4**	**Z3N5**	**Z3N6**	**Z3N7**
A. Fixed cost (Rs/ha)																					
Land preparation																					
Ploughing	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740	5740
Layout Preparation (labour)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Levelling	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Planting material and sowing																					
Seed rate	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
Sowing	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Inter cultural operations																					
Weeding	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
Herbicide	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376	376
Labour for herbicide application	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Irrigation																					
Tube well irrigation	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Labour for irrigation	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Harvest& threshing	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Rental value of land	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Total variable cost	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816	49816

Particulars	**Treatment combinations**																				
	Z1N1	**Z1N2**	**Z1N3**	**Z1N4**	**Z1N5**	**Z1N6**	**Z1N7**	**Z2N1**	**Z2N2**	**Z2N3**	**Z2N4**	**Z2N5**	**Z2N6**	**Z2N7**	**Z3N1**	**Z3N2**	**Z3N3**	**Z3N4**	**Z3N5**	**Z3N6**	**Z3N7**
B.Variable cost (Rs/ha)																					
1. Urea	630	945	630	945	630	945	1260	630	945	630	945	630	945	1260	630	945	630	945	630	945	1260
2.DAP	1760	2646	176	2646	1760	2646	3523	1760	2646	1760	2646	1760	2646	3523	1760	2646	1760	2646	1760	2646	3523
3.MOP	1132	1700	1132	1700	1132	1700	2268	1132	1700	1132	1700	1132	1700	2268	1132	1700	1132	1700	1132	1700	2268
4.$ZnSO_4.7H_2O$ (Soil)	1375	1375	1375	1375	1375	1375	1375	0	0	0	0	0	0	0	1375	1375	1375	1375	1375	1375	1375
5.$ZnSO_4.7H_2O$ (Foliar)	0	0	0	0	0	0	0	137	137	137	137	137	137	137	137	137	137	137	137	137	137
5. FYM	1375	688	1375	688	1375	688	0	1375	688	1375	688	1375	688	0	1375	688	1375	688	1375	688	0
6. Bio-fertilizer	104	104	208	208	190	190	0	104	104	208	208	190	190	0	104	104	208	208	190	190	0
7. Labour cost	1200	1200	1200	1200	1200	1200	1200	5400	5400	5400	5400	5400	5400	5400	6600	6600	6600	6600	6600	6600	6600
Total cost	57393	58474	57497	58578	57479	58560	59442	60355	61436	60459	61540	60441	61522	62405	62930	64011	63034	64115	63016	64097	64980
C.Production (t/ha)																					
Main product	4.9	4.3	4.1	4.4	4.6	5.1	4.3	4.5	4.5	4.3	5	5.2	5.4	5.3	5.2	6	4.4	4.7	5.7	6.4	6.1
Byproduct	7.2	7	6.9	6.3	7.2	7.6	6.8	6.7	7.2	6.5	7.3	7.3	7.3	7.4	7.4	7.9	6.6	7.3	7.5	8.4	8
D.Sales price (t/ha)																					
Main product	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150	20150
Byproduct	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250	4250
Gross return	129405	115501	110760	114797	122915	135528	114339	118765	122002	114012	131035	135490	139984	138078	136346	155513	116957	125346	146478	165296	157431
Net return	72013	57027	53264	56219	65436	76968	54897	58410	60566	53553	69495	75049	78462	75674	73416	91502	53923	61231	83462	101199	92451
B:C	1.25	0.98	0.93	0.96	1.14	1.31	0.92	0.97	0.99	0.89	1.13	1.24	1.28	1.21	1.17	1.43	0.86	0.96	1.32	1.58	1.42

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1. VIIth International Conference in Hybrid Mode on Global Research Initiatives for Sustainable Agriculture & Allied Sciences (GRISAAS-2022) during 21-23 November 2022, Meerut (U.P.).
2. International Conference on Impact of climate change on Socio economics and Ecological Transformation in Himalayan Region, held during 21-22 September, 2023, Jammu and Kashmir.
3. 4th International Conference on Recent Advances in Fundamental and applied Sciences (RAFAS 2023) during 24-25 March 2023, Punjab
4. 5th International Conference on Advances in Agriculture Technology and Allied Sciences (ICAATAS 2022) on June 4-5, 2022.
5. 2nd International Conference on Plant Physiology and Biotechnology (ICPPB-2023) 20-21 April, Punjab.
6. International Conference on Advances in Agriculture and Food System towards Sustainable Development Goals (AAFS- 2022) on 22-24 August 2022, New Delhi.
7. International Conference on Recent trends in smart and sustainable agriculture for food security (SSAFS-2022) held from 21-22 January 2022, Punjab.
8. International Conference on Agri Startups: Innovations to impact 2023, conducted by MANAGE, Hyderabad during 15-19 February, 2023.
9. International conference on emerging issues in agricultural, environmental & Applied Sciences for sustainable development (EIAEASSD- 2018) held during 27-29 November, 2018.