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Pushpendra Kumar
Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

SD Dubey
Assistant Professor, Department of Crop Physiology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Deepak Kumar Rawat
Ph.D. Scholar, Department of Crop Physiology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Sunil Kumar Prajapati
Ph.D. Research Scholar, Division of Agronomy, ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Bimlesh Kumar Prajapati
Ph.D. Research Scholar, Department of Soil Conservation and Water Management, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Chhote Lal Rawat
Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Corresponding Author:
Sunil Kumar Prajapati
Ph.D. Research Scholar, Division of Agronomy, ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Direct Effect of FYM, vermicompost, biofertilizer, sulphur and zinc on growth and yield on maize (*Zea mays* L.) and their residual effect on succeeding wheat (*Triticum aestivum* L.) in maize-wheat cropping system

Pushpendra Kumar, SD Dubey, Deepak Kumar Rawat, Sunil Kumar Prajapati, Bimlesh Kumar Prajapati and Chhote Lal Rawat

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Abstract
A field experiment was conducted at the Student Instructional Farm (SIF), CS Azad University of Agriculture and Technology, Kanpur, during the kharif and Rabi seasons of 2018-19 and 2019-20. The experiment comprised fourteen treatment combinations involving the application of Nitrogen, FYM (Farm Yard Manure), Vermicompost, Sulphur, Zinc, Azotobacter, and PSB (Phosphate Solubilizing Bacteria) for maize, while only RDF (Recommended Dose of Fertilizer) in the ratio 120:60:40 was given to all wheat treatments. The experiment was laid out in a randomized block design (RBD) and replicated thrice. The growth and yield of maize showed a significant increase with rising doses of RDN (Recommended Dose of Nitrogen) from 75% to 100%. Marked improvement in yield was observed with the additional application of 25% RDN through Vermicompost (VC) or FYM in addition to 100% RDN through chemical fertilizer. The application of RDN significantly increased the grain, stover, and biological yield of maize, which further increased with the addition of 25% N-VC either with 75% or 100% RDN. The application of 100% RDN + 25% N-VC + S + Zn + Az + PSB significantly produced higher maize yields compared to any other treatments except 100% RDN + 25% N-FYM + S + Zn + AZ + PSB. Vermicompost was found to be more effective for higher yields than FYM. The nutrient content and uptake by maize increased with increasing doses of RDN. For wheat, the applied 75% or 100% RDN + S + Zn + AZ + PSB with Vermicompost or FYM significantly increased the growth and yield. Wheat yield varied from 37.61 to 47.85 q ha^{-1}, with the highest and significantly superior yield recorded in T_{14} followed by T_{13}. The system yield, which represents the cumulative yield (maize + wheat), is the result of direct and residual responses to nutrients applied in kharif and Rabi. The highest and significantly superior system yield was found in treatments involving VC or FYM followed by RDN with S and/or Zn.

Keywords: FYM, maize, wheat, vermicompost, biofertilizers, sulphur, zinc, growth, yield

1. Introduction
The cultivation of Maize (*Zea mays*) - Wheat (*Triticum aestivum*) as a combined cropping system has emerged as one of the most economically lucrative agricultural strategies in the Indo-Gangetic Plains of India. Amongst various cropping patterns centered on maize, the maize-wheat sequence takes precedence, standing as the third most significant sequence after rice-wheat and rice-rice (Jat *et al.*, 2015) [22]. Spanning an area of 1.8 million hectares (Jat *et al.*, 2011) [22], this system contributes approximately 3% of India's total food grain production and holds pivotal importance for ensuring food security, nutritional sustenance, and environmental stability. Of the various states involved, Uttar Pradesh plays a prominent role with a contribution of 19.83 lakh hectares to the overall cropped area. Notably, 80.4% of this area is irrigated, exhibiting a cropping intensity of 153.54%. In terms of net cropped area, food grains dominate, encompassing around 78%. Uttar Pradesh's contribution to the national gross cropped area stands at 14%, while its share in total NPK consumption is 21%. Maize, commonly referred to as corn (*Zea mays*), is a key player in global agriculture, serving as a staple food for humans, animal feed, and a valuable raw material for various industries.

On a global scale, approximately 58% of maize goes into animal feed, 16% into human consumption, and 26% into bioethanol production (HLPE 2013) [19]. It ranks as the third most cultivated food crop, trailing only rice and wheat in terms of both area and production. Notably, the United States of America (USA) emerges as the world's leading maize producer, contributing nearly 35% of the global production. Maize significantly drives the US economy, boasting an astonishing productivity of over 9.6 tons per hectare - twice the global average of 4.92 tons per hectare. In contrast, India's average maize productivity stands at 3.02 tons per hectare. India cultivates maize over an area of 9.47 million hectares, yielding 28.72 million tonnes with an average productivity of 3032 kg per hectare. States like Andhra Pradesh, Karnataka, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh, and Himachal Pradesh collectively contribute over 80% of the total maize production. For Uttar Pradesh specifically, maize makes up 7.87% of the area and 5.14% of the production, with an average productivity of 1981 kg per hectare (Anonymous 2018) [3]. Renowned for its adaptability across diverse agro-ecosystems, maize possesses the highest genetic yield potential among food grain crops, often dubbed the "queen of cereals." Flourishing in tropical, subtropical, and temperate regions, maize's ability to efficiently utilize solar radiation sets it apart. The composition of maize grain includes 72% starch, 10% protein, 4.8% oil, 5.8% fiber, 3.0% sugar, and 1.7% ash (Choudhary, 1983) [12], rendering it a prime candidate for high carbohydrate accumulation per unit area per day (Aldrich *et al.*, 1975) [1]. Wheat, another cornerstone of global agriculture, stands out due to its substantial contribution in terms of area, production, and nutritional value. Accounting for about 20% of the world's total food needs, wheat provides over 19% of calories and 11% of proteins essential for human nutrition. India holds the second position globally in terms of wheat production, covering an area of 29.58 million hectares and yielding 99.70 million tonnes, with an average productivity of 3371 kg/ha. In this context, Uttar Pradesh's role is significant; with an area of around 9.75 million hectares contributing to a total production of 31.88 million tonnes and an average yield of 3269 kg/ha (Anonymous 2018) [3].

Both maize and wheat demand substantial nutrients and respond positively to elevated levels of inorganic fertilizers, showcasing their full yield potential when supplied with balanced nutrients at the right time. Undoubtedly, to counter soil nutrient depletion, the use of chemical fertilizers is imperative. Chemical fertilizers play a pivotal role in boosting yield and maintaining nutrient equilibrium by replenishing soil nutrients, ultimately enhancing soil fertility and productivity. Recent data suggests that nearly 50% of the increase in food grain production can be attributed to fertilizer usage. For instance, producing 1 tons of cereal grains necessitates approximately 20 kg of nitrogen and 4 kg of phosphorus per hectare. Without fertilizers, India would have required two to three times more land to meet its food grain requirements. However, the long-term health of the soil and sustained crop productivity cannot be solely maintained by fertilizers alone, given their lack of secondary and micronutrients. The continuous and disproportionate application of high-analysis inorganic fertilizers, coupled with insufficient organic matter addition in intensive cropping systems, has resulted in the significant decline of soil organic matter. This has led to the emergence of multiple nutrient deficiencies, particularly in secondary and micronutrients. Furthermore, soil degradation, including erosion, compaction, salinization, and acidification, has added to the predicament, resulting in reduced soil fertility and diminished crop yields. These challenges pose significant hurdles in achieving the necessary agricultural intensification to provide quality food for the rapidly growing population.

Sulphur has emerged as the fourth major limiting nutrient element in crop production, alongside the well-known NPK trio. Intensive agricultural practices, high-yielding varieties, and the prevalence of sulphur-free fertilizers have led to deficiencies in soils, particularly in intensive cropping systems. This underscores the need to prioritize sulphur as a vital plant nutrient (Nader and Nadia, 2011) [27]. In contrast to the substantial usage of nutrients like nitrogen, phosphorus, and potassium (NPK), sulphur (S) supplementation through fertilizers remains quite limited. In fact, the addition of sulphur via fertilizers is as low as 2.38 kg per hectare in Uttar Pradesh, comprising a mere 2.32% of the total NPKS consumption. This lack of sulphur input results in a negative balance, with the removal of sulphur by crops far exceeding its replenishment. This imbalance has led to the depletion of soil sulphur reserves, which is consequential for soil fertility. Sulphur significantly influences primary metabolism in plants and the synthesis of secondary metabolic products in specific plant groups. It plays a pivotal role in managing crops by aiding in environmental stress resistance and combating pests and diseases. Additionally, sulphur contributes not only to increased yield but also to improved crop quality through its influence on protein metabolism and oil synthesis. A study by Das *et al.* (1975) [13] demonstrated that applying sulphur at a rate of 30 kg per hectare led to noteworthy increases of 5.0%, 8.0%, and 1.0% in cystine, methionine, and protein content, respectively. Turning to micronutrients, zinc deficiency stands out as a widespread concern due to intensive agricultural practices, the utilization of high-analysis NPK fertilizers, and the limited or absence of zinc application by farmers (Rakshit *et al.*, 2017) [33]. A significant proportion of Indian soils, approximately 48.1%, are classified as very low in available zinc (Gupta, 2005) [17]. Zinc plays a pivotal role in various plant functions, including enzymatic reactions, photosynthesis, DNA transcription, and auxin activity. It holds particular importance for improving pollen viability and zinc assimilation, particularly in the apical part of maize, ensuring grain development. Consequently, the application of zinc fertilizers becomes imperative in such zinc-deficient soils to guarantee both cereal yield and zinc concentration in the grain.

In addition to chemical fertilizers, organic manures offer an excellent source of nutrients, including nitrogen, phosphorus, potassium, and secondary and trace elements. They also enhance soil organic matter content, promoting desirable soil structure and porosity vital for root growth, gas exchange, and water retention. These organic sources release nutrients gradually due to slow decomposition, ensuring sustained nutrient availability and longer-lasting effects in the soil. This contributes to enhanced soil physical, chemical, and biological properties, ultimately bolstering soil health and crop productivity. Various organic manures, such as well-rotted farmyard manure, vermicompost, and green manures, are employed to achieve these benefits. Vermicompost, produced through the digestive processes of different earthworm species, holds significant nutritional value and introduces beneficial microbes and active metabolites like gibberellic acid, cytokinin, auxin, and vitamins. The application of well-decomposed farmyard manure (FYM) has stood the test of time, playing a crucial role in enriching crop yields, enhancing soil organic matter, and fostering microbial activity, which in turn enhances soil fertility and aggregation. Achieving a balance between the application of N, P, K fertilizers and FYM has proven to be a successful strategy for boosting crop yields in maize-wheat cropping systems (Brar *et al.*, 2015) [9].

In the realm of sustainable soil management, biofertilizers have garnered significant attention. They play a crucial role in maintaining long-term soil fertility and sustainability by fixing atmospheric di-nitrogen and mobilizing macro and micronutrients in forms easily accessible to plants. Various microorganisms, including Bacillus, Pseudomonas, and fungal genera like Penicillium and Aspergillus, contribute to this role. These environmentally friendly and cost-effective agricultural inputs supplement mineral nutrition, supporting plant growth. Common biofertilizers include nitrogen-fixing soil bacteria (Azotobacter, Rhizobium), nitrogen-fixing cyanobacteria (Anabaena), phosphate-solubilizing bacteria (*Bacillus*, *Pseudomonas* spp.), and arbuscular mycorrhizal (AM) fungi. Azotobacter, a free-living nitrogen-fixing aerobic diazotroph, finds application in various non-leguminous crops, especially paddy, cotton, and vegetables. However, its growth is influenced by soil organic matter content. Similarly, phosphate-solubilizing bacteria are non-specific microbes that enhance phosphorus availability by converting insoluble forms into soluble forms, effectively promoting phosphorus uptake by plants. These biofertilizers play an integral role in the complex realm of Integrated Nutrient Management (INM), contributing significantly to soil sustainability and long-term crop productivity. The use of these microorganisms offers an environmentally friendly and low-impact approach to enhancing plant nutrition. This study aims to evaluate the impact of various treatments on the growth and yield attributes of maize and wheat, while also assessing their direct and residual effects.

2. Methods and Materials

2.1 Experimental site: The Student's Instructional Farm (SIF) at Chandra Shekhar Azad University of Agriculture and Technology in Kanpur, Uttar Pradesh, India, was the site of the field experiment. The site is located in the alluvial tract of the Indo-Gangetic plains in the central part of Uttar Pradesh, between 25º 26' to 26º 58' North latitude and 79º 31' to 80º 34' East longitude, at an elevation of 125.9 m above mean sea level. The region is classified as agro-climatic zone V (Central Plain Zone) of Uttar Pradesh. The experimental field was located in the same area for both years of the study, as shown in Figure 1.

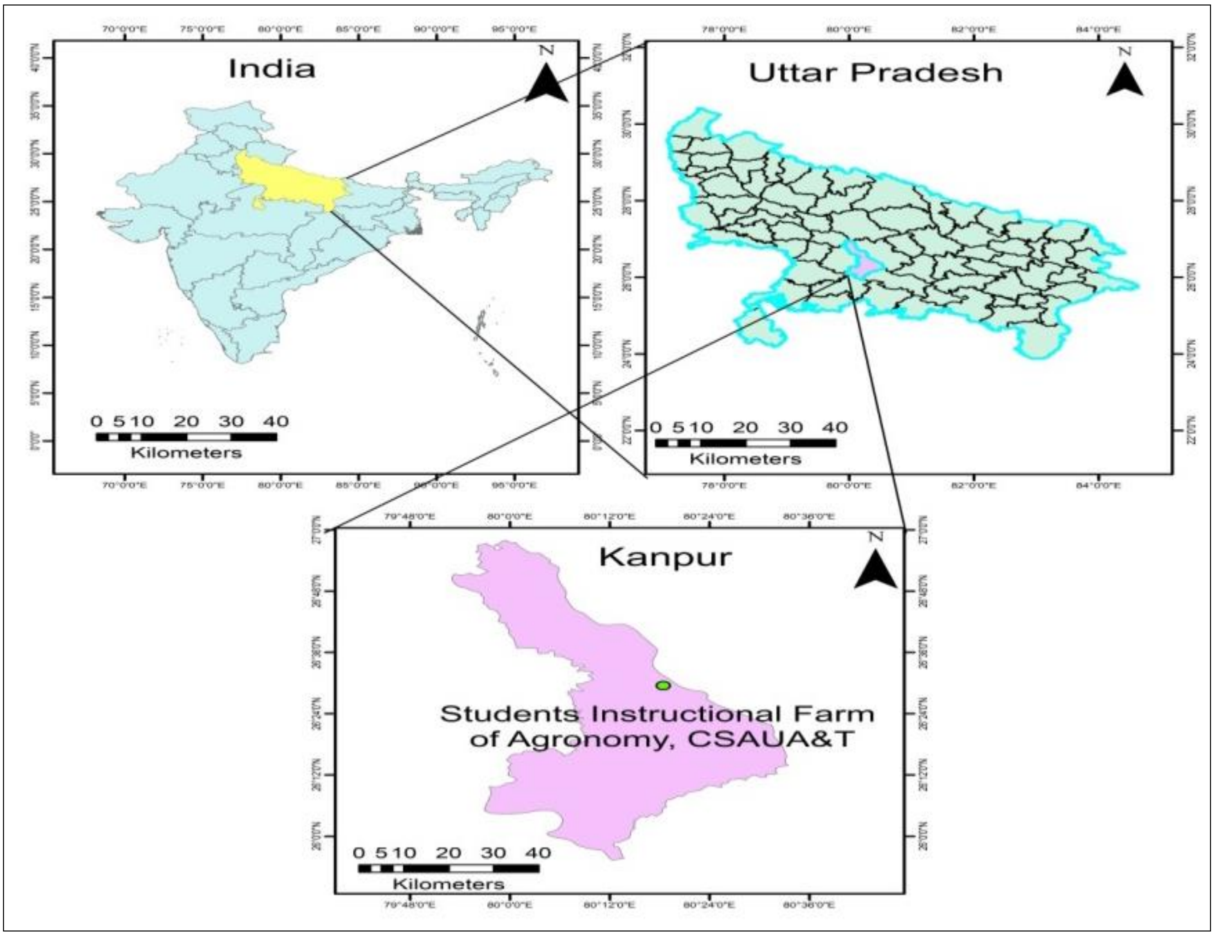

Fig 1: Location Map of the Study Area

2.2 Climate and weather conditions: This zone has semi-arid climatic conditions, having alluvial fertile soil. The normal rainfall of the area is about 890 mm per annum. Most of the rains are received from mid-June to end of September. The winter months are cooler with occasional rains and frost during last week of December to mid-January. The temperature in the month of May and June may go up to 44-47ºC or beyond and during winter it may go down to 2-3ºC. Mean relative humidity (7.00 AM) remains nearly constant at about 80- 90% from July to end of March and after March slowly declines to about 40-50% by the end of April and remains constant at 80% up to May.

2.3 Soil Characteristics: The properties of the soil, as a medium for plant growth, are bound to profoundly affect the rate of plant growth and ultimately the final yield. A representative soil sample was drawn from randomly selected samples up to 0-15 cm soil depth from different parts of the field and mixed up thoroughly. The Scientific or proved methods adopted for the determination of physical and chemical properties of the soil The soil in the experimental field was characterized as sandy loam with a pH of 7.92-8.07, electrical conductivity of 0.26 dSm^{-1} at 25ºC, bulk density of 1.39 g cm^{-3}, particle density of 2.51 g cm^{-3}, organic carbon content of 3.35 g kg^{-1}, available nitrogen content of 156.22 kg ha^{-1}, available P_2O_5 content of 10.34 kg ha^{-1}, available K_2O content of 198.16 kg ha^{-1}, available Zn content of 0.36 g ha^{-1}, available Fe content of 8.02-8.07 mg kg^{-1}, Sulphur content 14.20 kg ha^{-1}.

2.4 Experimental Details: Maize was grown during kharif which was followed by wheat during rabi of 2018-19 and 2019-2020 with a view to compare production potential of maize and wheat under management of nitrogen through the integrated use of organic and inorganic fertilizers, their residual effect on wheat crop and to find out the economic viability of the system under irrigated conditions of Central Uttar Pradesh. The experiment was carried out in Randomized Block Design (RBD) having three replications and fourteen treatment combinations *viz.*, Table 1. The size of each plot was (18 m^2), 6.0 m long and 8.0 m width. The equal doses of P, K, S and Zn was applied as basal in all the plots of maize @ 60:40:25:5.0 kg ha^{-1}. Whereas, wheat crop was given recommended dose of fertilizers @ (120:60:40) during *Rabi* in the all plots of different treatments applied to preceding maize crop.

Treatment Symbol	Treatment combination (For Maize)
T_1	Control
T_2	75% RDN
T_3	75% RDN+25% N through FYM
T_4	75% RDN+25% N through VC
T_5	75% RDN+25% N through FYM + S + Zn + Azotobacter + PSB
T_6	75% RDN+25% N through VC + S + Zn + Azotobacter + PSB
T_7	100% RDN
T_8	100% RDN + S
T_9	100% RDN + S + Zn
T_{10}	100% RDN + S + Zn + Azotobacter + PSB
T_{11}	100% RDN + 25% N through FYM
T_{12}	100% RDN + 25% N through VC
T_{13}	100% RDN + 25% N through FYM + S + Zn + Azotobacter + PSB
T_{14}	100% RDN + 25% N through VC + S + Zn + Azotobacter + PSB

2.5 Crop Varieties

Maize variety 'Azad Uttam': Maize composite 'Azad Uttam' was used in the study. It was developed at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur and released for general cultivation of state's farmers by state varietal release committee. Plants are medium in height with 140-145 cm; maturity period is about 60-70 days under normal conditions. Seeds are oval shape with orange color. Average yield potential is 30-35 q ha^{-1}.

Wheat variety 'HD-2967: High yielding variety 'HD-2967' was used for investigation. It was developed and released at ICAR-Indian Agricultural Research Institute, New Delhi. It is resistant to important pests and diseases. Maturity period varies from 158-160 days; plant height varies from 105-108 cm and small in seed size. Average yield potential of this variety is 55-60 q ha^{-1}.

2.6 Agronomical Practices Adopted: The experimental field was prepared after pre-sowing irrigation for maize and in wheat; the field was prepared without pre-sowing irrigation. At optimum moisture condition, ploughing was done with tractor drawn soil turning plough, followed by two cross harrowing with tractor drawn harrow for both the crops. Planking was done after each ploughing to make the field friable, well levelled and to conserve the moisture for proper germination of the seeds. The maize was sown on July 16, 2018 and June 21, 2019 with maintaining row to row spacing of 60 cm and plant to plant spacing of 20 cm. The optimum plant population of maize was maintained during both the years by thinning extra plants during seedling emergence. The recommended seed rate for maize, 20 kg ha^{-1} was used. Wheat was sown on November 21, 2019 and November 23, 2020 with row spacing of 22.5 cm. The recommended seed rate is 100 kg ha^{-1} was used. Well decomposed FYM and Vermicompost were computed as per treatment on fresh weight basis and incorporated uniformly in the plots of treatments before 15 days of sowing of maize. The Urea, Di-ammonium phosphate, Muriate of potash, Elemental sulphur and Zinc oxide were used as source of N, P, K, S and Zn. In maize, half of N, full of P_2O_5, K_2O, S and Zn doses were applied as basal and remaining amount of nitrogen was top dressed at knee high stage. The N, P_2O_5, K_2O, S and Zn were given @ 150, 60, 40, 25 and 5.0 kg ha^{-1}, respectively and considered as 100% of their doses. In order to protect the crop from adverse effects of weeds and to pulverize the soil, the weeding and hoeing operations were performed by manual labor with the help of kharif during both the years of experimentation in both the crops. The experiment was given irrigation at various stages during *Rabi* season. Four irrigations were given at different stages of wheat crop during both the years. The irrigation for maize was not given during both the seasons. The flowers of maize (tassel) were removed just after its emergence from the tops of the maize plants and placing them on the ground during both the years of experimentation. The cobs were plucked manually after harvest and wheat crop was harvested when 85 percent panicles turned pale. Harvesting of wheat was done with the help of sickles. The harvesting of each net plot area was done separately and left in the same plots for three days for sun dry. Later on, the harvested material from each net plot was carefully bundled, tagged and finally brought to the threshing floor for threshing, done by beating with the help of sticks. The main produce of the crop was separated from straw by winnowing. The straw yield per plot was determined by subtracting the grain yield from the biological yield per plot. Finally grain and straw yields were converted into t ha^{-1}. The cobs were plucked from the plants of each treatment's net plot and the husk was removed.

2.7 Observations Recorded: During the study, the biometrical observations were collected at various stages of growth. To minimize any potential sampling error, all necessary precautions were taken. The growth attributes and yield parameters of maize and wheat such as plant population height, system yield, grain, straw, biological and harvest index were recorded (Prajapati *et al.*, 2022) [32].

2.8 Statistical analyses: The experimental plot adhered to the designated design in assigning various treatments. Following this, the data collected on diverse growth parameters, yield characteristics, and seed yield of maize and wheat during the research underwent subsequent analysis. The acquired data were subjected to suitable statistical methods based on the approach detailed by Gomez and Gomez (1984) to determine any differences among the treatment means. To assess these differences, the Least Significant Difference (LSD) test was used to compare treatment means at a 5% level of probability.

3. Results and Discussion

Maize

Plant population: The plant count at initial and at harvest stage could not differ significantly due to application of different treatments. The maximum plant stand at initial and at harvest stage was recorded with treatment of T_{14} followed by T_{13}. The increase in plant stand might be attributed to fact as organic manure adds sufficient amount of organic matter thereby improved soil physical conditions i.e., soil porosity and water holding capacity (Bhattacharyya *et al.*, 2008) [8]. At initial stage the plant number could not differ significantly might be due to fact that the seed germination largely depends upon vigor and genetic makeup of the seed. The other factors like moisture, light and air were commonly available to the all seeds applied in the different treatments. Whereas, at final stand the plant stand was recorded maximum in T_{14} whilst lowest in T_1 (control). Population was gradually decreased from initial to final stage in both the years, due to biotic and abiotic stress during crop growth period. Similar results were also reported by Balasubramaian and Ramamoorthy (1996) [5]. Integrated application of inorganic sources with organic manures increased the continuous availability of nutrients to plant resultantly improved nourishment of plant in comparison to only inorganic source of nutrients. A similar result of higher final plant population observed with application of integration of organic manures with fertilizers was observed by (Gunri and Nath, 2012) [16] and (Kumar *et al.*, 2013) [25].

Plant height: The plant height was significantly influenced with the application of any level of nutrients than control (T_1) during both the years. The application of N through VC or FYM either with 75% or 100% RDN significantly contributed for the enhancement of plant height over their respective RDN. The application of 100% RDN with 25% N through FYM or VC besides Sulphur, Zinc, Azotobacter and PSB attained maximum plant height than any other treatment but among them no significant effect was observed however, application of VC was found numerically best for enhancement of plant height of maize. On pooled basis the plant height varied from 175.63 to 179.35 cm. This might be attributed due to the fact that better nourishment accelerates the rate of photosynthesis, assimilation, cell division, cell expansion and enlargement which ultimately affect the vegetative growth of the plants. These results are in close conformity with the findings of (Naveed *et al.* 2008) [28].

Grain yield: Integrated application of inorganic as well as organic fertilizers along with biofertilizers i.e. Azotobacter and PSB significantly enhanced the yield of maize during both the years and on pooled mean basis. The application of 100% RDN (T_7) gained significantly higher grain yield than control (T_1) and 75% RDN (T_2) and it was recorded numerically higher grain yield than T_3 (75% RDN+25% N-FYM) and T_4 (75% RDN+25% N-VC) but had statistically at par effect during both the years. The application of T5 and T6 recorded significantly higher grain yield over T_1 (control), T_2, T_3 and T_4. This exhibited combined effect of Sulphur, Zinc, Azotobacter and PSB and contributed by 21.08 and 20.54% as compared to T3 (75% RDN + 25% N-FYM) during first and second year, respectively. Whereas, the application of T_6 (75% RDF+25% N-VC +S + Zn + Az + PSB) recorded significantly higher grain yield by 20.24 and 19.42% over T4 (75% RDN+25% RDN-VC) and numerically higher than T_5 but both were found statistically at par during both the years. These results are also in concurrence with Negassa *et al.* (2001**)** [29] who found that corn yield was increased by 35% when combined (inorganic and organic) nutrients were applied. The increase in grain yield may be due to organic and chemical treatments was mainly due to more number of cobs per plant and better grain development due to adequate nutrient supply. Use of organic manure in combination with inorganic fertilizers gave maximum grain yield (Balai *et al.* 2011) [4].

Stover yield: The maximum stover yield was recorded with T_{14} (100% RDN+25% N-VC + S + Zn + Az + PSB) which was significantly superior to all other treatments except T_{13}, T_{10}, T_6 and T_5 during both the years. It clearly reveals that the combined application of 75% RDN with 25% N through FYM or VC along with Sulphur, Zinc and Azotobacter and PSB gained significantly higher stover yield than 100% RDN (T_7), 100% RDN + S (T_8) and 100% RDN + S + Zn (T_9) but found at par with the treatments of 100%RDN+S+Zn+Azotobacter & PSB (T_{10}). Yang *et al.* (2004) were reported beneficial effect of Azotobacter on maize yield.

Biological yield: The biological yield of maize increased significantly with the addition of any dose of RDN i.e., 75% or 100% with or without FYM or VC along with S, Zn, Azotobacter and PSB over control during both the years. The application of T_6 (75% RDN+25% N-VC +S +Zn + Az + PSB) recorded significantly higher biological yield over control, T2, T_3, T_4 however, it had statistically at par effect with the treatment of T_5 (75% RDN + 25% RDN-FYM + S + Zn + Az + PSB) and T_{10} (100% RDN + S + Zn + Az + PSB). The probable reason for increase in biological yield might be due to improvement in growth and yield attributes. The application of 100% RDN+25% N through FYM or VC gained more yield than 100% RDN during first and second year but could not succeed to T_{10}.

Harvesting index: The highest value of harvest index was noted with T_{14} (100% RDN + 25% RDN + S + Zn + Az + PSB) while the minimum in T_1 (control) during both the years and on pooled mean basis. The application of T6 exhibited significantly superior to all the treatments of 75% RDN with or without FYM or VC however, at par with the T_5 and it was numerically higher. The addition of FYM or VC along with 75 or 100% RDN significantly increased the harvest index of maize during both the years. The application of organic manure increase the microbial activities, participate in various growth promoting substances like IAA and GA3 secreted by these microbes which resultantly improved the uptake, translocation and synthesis of photosynthate assimilates thereby increased the plant growth parameters which converted into maximum yield. The similar results were reported by (Singh *et al.*, 2006 and Suke *et al.*, 2010) [37, 39].

Wheat

Plant population: The plant stand of wheat was recorded at harvest stage. It varied from 28.55 to 30.17 and 28.67 to 30.71 during first and second years, respectively. The plant stand at harvest could not influence markedly due to different treatments. However, there was much survival of plant at harvest using any inputs over control. The maximum plant stand were recorded with treatment of T_{14} (100% RDN+25% N-VC + S + Zn + Az + PSB) followed by T_{13} but could not show significant difference. This may be due to better soil condition with application of organics and biofertilizers. This is in conformity with the results of (Amruthesh *et al.*, 2003) [2] and (Hameeda *et al.*, 2008) [18] who observed such increased germination due to biofertilizers application.

Plant height: The results of plant height clearly revealed that the application of different treatments in maize significantly influenced the plant height of wheat during both the years and on pooled mean basis. Among the 75% RDN combinations, the application of T6 (75% RDN+25% N-VC + S + Zn + Az + PSB) recorded significantly taller plants than any treatments of 75% RDN combinations however, it remained statistically at par with T_5 (75% RDN+25% N-FYM + S + Zn + Az + PSB). The plant height was measured with T_{14} and T_{13} were significantly superior over rest of the treatments during both the years. This might be attributed due to the fact that better nourishment accelerated the rate of photosynthesis, assimilation, cell division, cell expansion and enlargement which ultimately affect the vegetative growth of the plants. These findings are corroborated with the results of (Chandel *et al.* 2014) and (Ram and Mir, 2006) [10, 34].

Grain yield: The application of 25% N through FYM or VC with 75% N through inorganic source during kharif increased the wheat yield as compared to75% RDN. The application of T5 (75% RDN + 25% NFYM + S + Zn +AZ + PSB) and T_6 (75% RDN + 25% RDNVC + S + Zn + AZ + PSB) in maize further increased the grain yield of wheat significantly over treatments of 75% RDN with or without FYM or VC. The applied Sulphur in maize besides 100% RDN (T8) significantly contributed for higher grain yield than 100% RDN only. The application of T_9 (100% RDN + S + Zn) in maize improved the wheat yield over T_8 (100% RDN + S), but had at par effect. The application of T_{10} (100% RDN + S + Zn + AZ + PSB) in maize recorded higher yield than T_8 (100% RDN+S) and T_9 (100% RDN + S + Zn) but all were statistically at par during both the years. The application of T_{13} (100% RDN+25% N-FYM + S + Zn + Az + PSB) in maize produced significantly higher grain yield of wheat than any of the kharif treatments except T6 (75% RDN + 25% N-VC + S + Zn + Az + PSB), T5 (75% RDN + 25% N-FYM + S + Zn + Az + PSB), and T_{10} (100% RDN + S + Zn + Az + PSB) during both the years where, S + Zn + Az + PSB were commonly given. Likewise, the treatment T_{14} recorded significantly highest grain yield than any of the treatment applied in maize but at par to treatment of T_6, T_{10} where, S + Zn + Az + PSB were commonly given in maize crop. While comparing T_{13} and T_{14}, T_{14} recorded highest yield but had at par effect with the treatment of T_{13}. The wheat grain yield was recorded maximum where 25% N was applied through FYM or VC + S + Zn + Az + PSB (T_{13} and T_{14}) and both were statistically at par but VC was found superior to FYM. Thus, it clearly revealed that the application of FYM and VC were found effective for enhancing the yield of succeeding crop of wheat. The results are in accordance with the finding of Chaudhary *et al.* (2014) who also obtained similar carry over effect of FYM and vermicompost on wheat in rice-wheat cropping system. Vats *et al.* (2001) also reported significant residual response of applied FYM in kharif to succeeding wheat crop. Raman *et al.* (2018) [35] observed residual effect of organic manure on the yield of succeeding crops in bush bean-rice-rice cropping system. The carry over effect of fertilizers and manures applied to maize had also been reported in wheat (Jamwal 2005) [20]. The positive effect of S on yield may be due to enrichment of organic matter in the soil enhances easy and faster mineralization of S thereby increases availability and uptake of S ultimately converted into higher yield of crop. The increase in yield due to Zn may be attributed to its function as catalyst or stimulant in most of the physiological and metabolic processes and metal activator of enzyme, resulting in increased growth and development of plant, which ultimately gave higher grain and straw yield of wheat (Pandey and Chauhan, 2016) [30]. Grain yield is the end result of morphological and physiological processes occurring during growth and development of crop. The marked improvement in productivity of wheat with the residual effect of S and Zn could be ascribed to the enhancement of S and Zn content in soil. These finding are in agreement with those reported by (Chaube *et al.*, 2007; Singh *et al.*, 2015) [11, 36].

Straw yield: The Straw yield could not make difference due to application of 75 or 100% RDN in kharif however these were significantly superior to control. The application of T_8 (100% RDN +S) and T_9 (100% RDN + S + Zn) in maize improved the straw yield markedly than T_7 (100%RDN) but remained statistically at par. The application of T_{10} (100% RDN + S + Zn + Az + PSB) in maize improved the straw yield over T_8 (100% RDN+S) and T_9 (100% RDN + S + Zn) during both the years but all were statistically at par. The wheat straw yield was recorded maximum where 25% N was applied through FYM or VC +S + Zn + Az + PSB (T_{13} and T_{14}) while comparing between FYM and VC, Vermicompost was found better for higher straw yield. Such an increase in the straw yield of succeeding wheat crop may be due to residual effect of Vermicompost or farmyard manure, which may be attributed to the slow release of major and minor nutrients. Gaur *et al.* (1984) [15] further clarified that the application organic manure contributes less than 30% of N, about 60% to 70% of P, and 75% of K become available to the immediate crop, and the remaining amount of nutrients are to be used by the subsequent crops. Banik *et al.* (1997) [6] also reported that FYM appeared to play a beneficial role in improving the water holding capacity of the soil, which may in turn supply the requisite soil moisture for proper metabolic activities of the succeeding crop. Apart from this, due to application of organic manures, the activity of beneficial microbes and colonization of micorrhizal fungi and enzymes activity increases which play an important role in mobilization of nutrients and thereby leading to better availability of nutrients facilitating in better growth and grain and straw production as reported by (Kaushik *et al.*, 2012) [12].

Biological yield: The biological yield of wheat markedly influenced with application of FYM and VC. Maximum biological yield was noticed with the application of T_{14} (100% RDN+25% N-VC + S + Zn + Az + PSB) in kharif which yielded statistically at par with T_{13}, T_6, T_5 and T_{10} but significantly superior to rest of the treatments. Organic manures act as nutrient reservoir and upon decomposition produces organic acids; thereby absorbed ions are released slowly for the entire growth period leading to higher yields (Kumar *et al.* 2005) [24]. It evidently proved that the application of FYM or VC with S, Zn and biofertilizer in previous crop had carry over effect in succeeding wheat.

Harvesting index: The highest percentage of harvest index was noted with treatment of T_{14} (100% RDN + 25% N-VC + S + Zn + Az + PSB) followed by T_{13}, T_6, T_5 and T_{10}. It clearly revealed that the combined application of FYM or VC with S, Zn and biofertilizer (Azotobacter and PSB) in maize had considerable carry over effect on succeeding wheat crop. Integrated nutrient management (INM) or balanced fertilization (NPK organics) by replacing a substantial part (25-50%) of the N through different organic amendments improves the grain yield by facilitating the translocation of nutrients to the economic part of the crop. Faujdar and Sharma (2013) also noticed that harvest index of succeeding wheat crop increased significantly with the application of residual FYM @ 10 t ha^{-1} to maize as compared to no FYM application. The more or less similar results reported by (Mitran and Mani, 2017) [26].

System Yield (Maize + Wheat): The system yield was calculated as cumulative yield of maize and wheat year-wise. These reflect the total yield of maize and wheat which indicates the cumulative response of treatments given to maize and wheat. The system yield indicates about the residual response of applied nutrients in maize and succeeding wheat crop. It was clear from table that any applied treatments (maize + wheat) over control produced significantly higher system yield during both the years as well as on pooled mean basis. The application of 75% RDN in maize and RDF in wheat produced 24.38% higher yield than T_1. On average, VC, FYM, S, Zn and Azotobacter +PSB contributed by 8.27, 6.73, 4.88, 2.57 and 4.45 per cent respectively as a residual response on system yield. The T_{14} (100% RDN+ 25% N-VC + S + Zn + Az + PSB) applied in kharif and RDF in rabi produced significantly maximum system yield to any of the treatments but at par to T_{13} where FYM was applied instead of VC. Results are in conformity with the findings of (Bejbaruha *et al.*, 2009) [7]. From above findings, it is evident that the application of FYM or VC, Az + PSB + S + Zn had considerable residual response on succeeding wheat crop. This might be due to the residual effect of the nutrients available through organic sources to the succeeding winter season crops. The yield of wheat was increased when Vermicompost or FYM was included in an integrated nutrient management system due to higher availability of nutrients.

Table 1: Effect of different treatments on plant population and height of maize

Treatments Combinations	Plant population per running meter						Plant height (cm)		
	Initial			Final					
	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean
T_1	6.11	6.13	6.14	5.98	5.95	5.97	175.63	175.61	175.62
T_2	6.20	6.22	6.21	6.07	6.10	6.09	177.85	177.88	177.87
T_3	6.23	6.25	6.24	6.11	6.14	6.13	178.23	178.26	178.25
T_4	6.25	6.27	6.26	6.13	6.16	6.15	178.32	178.35	178.34
T_5	6.43	6.46	6.45	6.32	6.35	6.34	179.05	179.09	179.07
T_6	6.45	6.48	6.47	6.43	6.47	6.45	179.13	179.17	179.15
T_7	6.28	6.30	6.29	6.16	6.19	6.18	178.42	178.45	178.44
T_8	6.32	6.35	6.34	6.18	6.21	6.20	178.51	178.54	178.53
T_9	6.41	6.44	6.43	6.33	6.37	6.35	178.8	178.83	178.82
T_{10}	6.48	6.51	6.50	6.37	6.41	6.39	179.2	179.24	179.05
T_{11}	6.37	6.40	6.39	6.28	6.31	6.30	178.66	178.69	178.68
T_{12}	6.40	6.43	6.42	6.30	6.33	6.32	178.75	178.78	178.77
T_{13}	6.53	6.56	6.55	6.44	6.57	6.51	179.28	179.32	179.13
T_{14}	6.55	6.58	6.57	6.47	6.59	6.53	179.33	179.37	179.35
S.E.M±	0.28	0.31	0.20	0.28	0.25	0.18	0.45	0.62	0.39
C.D. at 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	1.30	1.81	1.10

Table 2: Effect of different treatments on grain, stover, biological and harvest index of Maize

Treatments	Grain Yield (q ha^{-1})			Stover Yield (q ha^{-1})			Biological yield (q ha^{-1})			Harvest Index (%)		
Combinations	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean
T_1	12.75	12.46	12.61	33.85	33.28	33.57	46.60	45.74	46.17	27.36	27.24	27.30
T_2	20.30	21.42	20.86	51.77	53.41	52.59	72.07	74.83	73.45	28.17	28.62	28.40
T_3	22.72	23.90	23.31	57.48	59.23	58.36	80.20	83.13	81.67	28.33	28.75	28.54
T_4	23.42	24.67	24.05	59.02	60.88	59.95	82.44	85.55	83.99	28.41	28.84	28.63
T_5	27.51	28.81	28.16	67.4	69.3	68.35	94.91	98.11	96.52	28.99	29.36	29.18
T_6	28.16	29.46	28.81	68.71	70.59	69.65	96.87	100.05	98.46	29.07	29.45	29.26
T_7	23.58	24.75	24.17	59.19	60.92	60.06	82.77	85.67	84.22	28.49	28.89	28.69
T_8	25.6	26.82	26.21	63.74	65.51	64.63	89.34	92.33	90.84	28.65	29.05	28.85
T_9	26.72	27.97	27.35	65.91	67.86	66.89	92.63	95.83	94.23	28.85	29.19	29.02
T_{10}	28.33	29.63	28.98	68.84	70.68	69.76	97.17	100.31	98.74	29.16	29.54	29.35
T_{11}	25.91	27.16	26.54	64.32	66.09	65.21	90.23	93.25	91.74	28.72	29.13	28.93
T_{12}	26.63	27.92	27.28	65.82	67.75	66.79	92.45	95.67	94.06	28.80	29.18	28.99
T_{13}	30.71	31.96	31.34	74.32	76.02	75.17	105.03	107.98	106.51	29.24	29.60	29.42
T_{14}	31.40	32.68	32.04	75.67	77.34	76.51	107.07	110.02	108.55	29.33	29.70	29.52
S.E.M±	0.82	0.95	0.615	1.67	1.92	1.25	2.00	2.16	1.45	0.18	0.25	0.15
C.D. at 5%	2.38	2.76	1.75	4.87	5.57	3.54	5.83	6.28	4.10	0.52	0.73	0.43

Table 3: Effect of different treatments on plant population and height of wheat

Treatments Combinations	Plant population per running meter			Plant Height (cm)		
	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean
T_1	28.55	28.67	28.61	82.76	82.78	82.77
T_2	29.32	29.48	29.40	83.62	83.65	83.64
T_3	29.53	29.79	29.66	84.68	84.70	84.69
T_4	29.58	29.86	29.72	84.70	84.73	84.72
T_5	29.96	30.35	30.16	85.00	85.04	85.02
T_6	30.02	30.50	30.26	85.03	85.07	85.05
T_7	29.4	29.58	29.49	84.66	84.69	84.68
T_8	29.61	29.91	29.76	84.75	84.78	84.77
T_9	29.67	29.99	29.83	84.77	84.80	84.79
T_{10}	29.89	30.29	30.09	84.96	85.00	84.98
T_{11}	29.76	30.12	29.94	84.79	84.83	84.81
T_{12}	29.8	30.20	30.00	84.81	84.85	84.83
T_{13}	30.11	30.59	30.35	85.08	85.12	85.10
T_{14}	30.17	30.71	30.44	85.11	85.15	85.13
S.E.M±	0.78	0.89	0.73	0.080	0.97	0.033
C.D. at 5%	N.S.	N.S.	N.S.	0.23	0.28	0.068

Table 4: Effect of different treatments on grain, stover, biological yield and harvest index of wheat

Treatments Combinations	Grain Yield (q ha^{-1})			Straw Yield (q ha^{-1})			Biological yield (q ha^{-1})			Harvest Index (%)		
	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean	2018-19	2019-20	Pooled Mean
T_1	37.23	37.98	37.61	57.26	58.37	57.81	94.49	96.35	95.42	39.41	39.43	39.42
T_2	41.06	42.12	41.59	62.39	63.92	63.16	103.45	106.04	104.75	39.69	39.72	39.71
T_3	42.50	44.00	43.25	64.34	66.50	65.42	106.84	110.50	108.67	39.78	39.82	39.80
T_4	42.72	44.27	43.50	64.62	66.85	65.73	107.34	111.12	109.23	39.80	39.84	39.82
T_5	45.41	47.36	46.39	68.03	70.80	69.42	113.44	118.16	115.80	40.03	40.08	40.06
T_6	45.93	47.91	46.92	68.72	71.54	70.13	114.65	119.45	117.05	40.06	40.11	40.09
T_7	41.80	43.23	42.52	63.38	65.47	64.43	105.18	108.70	106.94	39.74	39.77	39.76
T_8	42.93	44.53	43.73	64.85	67.19	66.02	107.78	111.72	109.75	39.83	39.86	39.85
T_9	43.56	45.22	44.39	65.72	68.14	66.93	109.28	113.36	111.32	39.86	39.89	39.88
T_{10}	45.00	46.90	45.95	67.58	70.29	68.94	112.58	117.19	114.89	39.97	40.02	40.00
T_{11}	43.85	45.62	44.74	66.05	68.60	67.33	109.90	114.22	112.06	39.90	39.94	39.92
T_{12}	44.10	45.88	44.99	66.34	68.91	67.63	110.44	114.79	112.62	39.93	39.97	39.95
T_{13}	46.29	48.36	47.33	69.18	72.18	70.68	115.47	120.54	118.00	40.09	40.12	40.11
T_{14}	46.79	48.90	47.85	69.86	72.95	71.41	116.65	121.85	119.25	40.11	40.13	40.12
S.E.M±	0.81	0.97	0.68	1.23	1.36	0.93	1.54	1.85	1.48	0.09	0.07	0.05
C.D. at 5%	2.35	2.83	1.93	3.59	3.91	2.63	4.49	5.39	4.40	0.15	0.13	0.14

Table 5: Effect of different *Kharif* and *Rabi* treatments on system yield (maize and wheat)

Treatments combinations	System yield (q ha^{-1})		
	2018-19	2019-20	Pooled Mean
T_1	49.98	50.44	50.21
T_2	61.36	63.54	62.45
T_3	65.22	67.90	66.56
T_4	66.14	68.94	67.54
T_5	72.92	76.17	74.55
T_6	74.09	77.37	75.73
T_7	65.38	67.98	66.68
T_8	68.53	71.35	69.94
T_9	70.28	73.19	71.74
T_{10}	73.33	76.53	74.93
T_{11}	69.76	72.78	71.27
T_{12}	70.73	73.80	72.27
T_{13}	77.00	80.32	78.66
T_{14}	78.19	81.58	79.89
S.E.M±	1.63	1.92	1.16
CD (5%)	4.73	5.59	3.68

4. Conclusion

The application of Recommended Dose of Nitrogen (RDN) played a crucial role in enhancing maize yields, with a notable positive response observed when supplementing with Vermicompost (VC) or Farm Yard Manure (FYM). The combination of 100% RDN, 25% N-VC, and other essential nutrients (S, Zn, Az, PSB) significantly outperformed alternative treatments, showcasing the effectiveness of comprehensive nutrient management practices. Furthermore, Vermicompost emerged as a more effective option for boosting maize yields compared to FYM. The nutrient content and uptake by maize demonstrated a positive correlation with increasing doses of RDN, emphasizing the importance of proper nitrogen management in crop production. For wheat, a similar positive impact on growth and yield was observed with the application of 75% or 100% RDN in combination with S, Zn, Az, PSB, and organic amendments like Vermicompost or FYM in maize. The highest and significantly superior system yield, representing the cumulative yield of maize and wheat, was found in treatments involving VC or FYM followed by RDN with S and/or Zn. These findings highlight the significance of a well-planned nutrient management strategy, incorporating organic amendments and essential nutrients, in optimizing crop yields and ensuring sustainable agricultural practices. The study provides valuable insights for farmers and researchers aiming to enhance productivity in both kharif and Rabi seasons through effective nutrient management practices

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6. Competing Interests

Authors have declared that no competing interest exists.

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