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Comparative Effects of Inorganic Fertilizer, Farmyard Manure, Humic Acid, and Their Integrated Application on Growth, Biomass, and Grain Yield of Maize (Zea mays L.)

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Abstract

Integrated nutrient management can combine complementary nutrient sources to improve crop growth and productivity. The present study evaluated the comparative effects of inorganic fertilizer, farmyard manure (FYM), humic acid, and their integrated application on maize (Zea mays L.) growth, biomass accumulation, and grain yield under controlled pot conditions. A pot experiment was conducted at Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan, using five treatments and three replications in a Completely Randomized Design (CRD).The pot diameter was 26cm and 50cm depth. Each pot, with a surface area of 26cm, was filled with 18 kg of clay loamy soil. A representative soil sample was collected and analyzed. The soil was characterized as sandy loam, with an EC of 1.21 dS m^{-1}, available phosphorus of 17.84 mg kg^{-1}, extractable potassium of 30 mg kg^{-1}, and saturation percentage of 27%. The treatments were T_1 (control), T_2 (inorganic fertilizer), T_3 (FYM), T_4 (humic acid), and T_5 (integrated application of inorganic fertilizer, FYM, and humic acid). Plant height, number of leaves, stem diameter, leaf area index (LAI), root fresh and dry weight, stem fresh and dry weight, and grain yield were evaluated. Significant treatment effects were observed for the measured growth and biomass variables. The integrated treatment (T_5) produced the highest LAI (10.33), root fresh weight (1438.5 kg ha^{-1} equivalent), root dry weight (1011.3 kg ha^{-1} equivalent), stem fresh weight (4120.7 kg ha^{-1} equivalent), stem dry weight (1281.4 kg ha^{-1} equivalent), and grain yield (3165.9 kg ha^{-1} equivalent). Grain yield under T_5 was approximately 28% higher than the unfertilized control and 5% higher than the sole inorganic fertilizer treatment. These findings indicate that the integrated application of inorganic fertilizer, FYM, and humic acid improved maize growth and productivity under the conditions of this pot experiment. Field-scale validation across soils and agroecological environments is required before broader fertilizer recommendations are made.

Key Words: Maize, inorganic fertilizer, organic fertilizer, humic acid, integrated nutrient management, growth parameters, biomass

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Introduction

Maize (Zea mays L.) is one of the most significant cereal crops in the world, and along with wheat and rice, provides the basis for food security worldwide. Since its domestication about 9,000 years ago in Mesoamerica, maize has been steadily gaining ground as the world's largest annual cereal crop, surpassing one billion metric tons of production (Erenstein et al., 2022). Maize is a key food crop, along with rice and wheat, providing at least 30% of the food calories consumed by over 4.5 billion people in 94 developing countries, and more than 20% of dietary calories in parts of Africa and Mesoamerica (Shiferaw et al., 2011). In addition to being a staple food, maize is a multi-purpose crop that is widely used as animal feed, as a raw material for industry, and in biofuel production, and is still contributing to the improvement of farm incomes and rural living standards in developing economies like Nigeria and Pakistan (Adiaha, 2018). However, average maize production in many developing regions is far from its genetic potential, due to soil fertility loss, mismatched fertilizer application, and the increasing frequency of abiotic stresses from climate variability (FAO, 2022).

In the past, farmers have been using inorganic (chemical) fertilizers, especially nitrogen, phosphorus, and potassium (NPK) fertilizers, to bridge this yield gap, as inorganic fertilizers quickly and reliably boost plant height, leaf number, and grain yield when applied in balanced proportions (Pandey & Awasthi, 2014; Endris & Dawid, 2015). The use of inorganic fertilizers, however, has some well-documented costs: high cost for resource-poor farmers, relatively short soil residual effect, and long-term overuse of inorganic fertilizers has been associated with reduction in soil organic matter, soil structure deterioration, and soil, water, and air pollution (Ali, J. et al. 2023; FAO, 2022). This has brought nutrient management strategies that minimize reliance on synthetic inputs and maintain productivity back into the spotlight of science and policy.

One such alternative is organic fertilizers such as farmyard manure, poultry manure, compost, and crop residues. Organic sources of nutrients release nutrients slowly, increase the cation exchange capacity and water-holding capacity of soil, and promote beneficial microbial activity, which collectively increase nutrient management effectiveness and promote more resilient crop growth under stress conditions (Ali, J. et al. 2023). However, their major drawback is that the large amounts needed to satisfy the nutrient requirement of a crop are not always available in a single growing season, and organic sources are often insufficient to provide the nutrient requirement of a high nutrient-demanding crop such as maize in a single cropping season (Ali, J. et al. 2023). This has prompted researchers to seek a more balanced nutrient management strategy by combining organic and inorganic sources and by using additional biostimulants.

Humic acid, one of the most abundant bioactive components of soil humic substances, which is produced during the decomposition of plant and microbial residues, is one of the most promising biostimulants. Humic acid is structurally composed of carboxyl, phenolic, hydroxyl, and carbonyl functional groups, which enable it to chelate nutrients, buffer soil pH, and enhance soil aggregation and water retention (Nabi et al., 2025). Physiologically, humic acid affects the activity of plasma-membrane transporters and promotes elongation and division of root cells, expanding the root system and enhancing the plant's ability to absorb

water and nutrients, while the low-molecular-weight fractions of humic acid also have auxin- and cytokinin-like hormonal activity that affects shoot development and photosynthesis (Nabi et al., 2025; Nardi et al., 2021). In maize, exogenous application of humic acid has been reported to alleviate salinity stress by improving physiological and biochemical parameters (Kaya et al., 2018), to reduce seedling drought stress in hybrid maize when applied with salicylic acid (Bijanzadeh et al., 2019), to enhance seedling growth under alkaline soil conditions (Yang et al., 2023), and to improve shoot and root growth, antioxidative capacity, and ion balance under saline soil conditions when applied with biochar (Malik et al., 2022). In general, humic substances have been referred to as a link between soil ecology and crop productivity, as they promote nutrient cycling, microbial activity, and stress resistance at the same time (Canellas et al., 2024; Ampong et al., 2022).

On the basis of these single lines of evidence, a few field studies have been conducted specifically on the combined or integrated use of inorganic fertilizer, organic manure, and humic acid on maize growth and yield. Abd Al Ameer, W. A., & Bushra, M. (2018) reported that mineral fertilizer, organic residues, and foliar humic acid application resulted in significantly higher plant height, chlorophyll content, and grain yield than mineral fertilizer alone and no fertilizer control in Iraq. Likewise, in Vietnam, foliar application of humic and fulvic acids at higher rates resulted in higher thousand-seed weight, protein content, and grain yield of sticky maize, and cultivar-specific effects were seen in ear length and yield (Nguyen, V. D., & Tran, D. H., 2020). The complementary Pakistani study revealed that soil-available nitrogen, phosphorus, and potassium showed a significant positive correlation with maize grain yield under combined organic–inorganic fertilization, and suggested that the combined application of optimum rates of inorganic fertilizers with organic manures is a sustainable approach to enhance and stabilize crop productivity (Ali, J. et al., 2023). Together, these results indicate that no single nutrient source (chemical, organic, or biostimulant) can be used alone to achieve sustainable maximum maize productivity, and that the judicious use of a combination of these sources may have additive or even synergistic effects on growth and yield, while minimizing the environmental and economic costs of over-fertilization.

Although there is an increasing amount of evidence, comparative studies that simultaneously assess the use of inorganic fertilizer, organic fertilizer, humic acid, and combinations of these fertilizers under a single controlled experimental design are still limited, especially under the agro-climatic conditions found in many maize-growing regions. The majority of the previous studies have focused on individual or partial combinations of these inputs, and the relative and interactive effects of each nutrient source on various growth parameters (plant height, leaf area, stem girth) and yield components (cob length, grain rows, thousand grain weight, and grain yield) of maize remain unknown. This is a critical need to improve site-specific fertilizer recommendations and to develop more sustainable and cost-effective maize production systems.

The present study aimed to compare the effects of sole inorganic fertilizer, farmyard manure, humic acid, and their integrated application on vegetative growth, biomass accumulation, and grain yield of maize (Zea mays L.) under controlled pot conditions.

Materials and Methods

Experimental Design and Treatments

A pot experiment was conducted at Pir Mehr Ali Shah Arid Agriculture University (PMAS-AAUR), Rawalpindi, Pakistan, under controlled environmental conditions to evaluate the effects of inorganic fertilizer, farmyard manure (FYM), humic acid, and their integrated application on maize growth, biomass accumulation, and grain yield. The experiment was arranged in a Completely Randomized Design (CRD) comprising five treatments with three replications, giving 15 experimental pots. Each pot was treated as an independent experimental unit, and treatments were assigned randomly. The pot diameter was 26cm and 50cm depth. Each pot, with a surface area of 26cm, was filled with 18 kg of clay loamy soil. A representative soil sample was collected and analyzed. The soil was characterized as sandy loam, with an EC of 1.21 dS m^{-1}, available phosphorus of 17.84 mg kg^{-1}, extractable potassium of 30 mg kg^{-1}, and saturation percentage of 27%. These baseline soil properties were used to characterize the experimental soil before fertilizer and amendment application. Maize (Zea mays L.) cultivar Pak Afghoi was used as the experimental crop. Five healthy seeds were sown in each pot, and after seedling establishment, the plants were thinned to three uniform and vigorous seedlings per pot. Thus, all final growth and yield observations were based on three retained plants per pot. Standard agronomic practices, including irrigation and weed management, were uniformly maintained throughout the experimental period.

Crop Establishment

Following the establishment of the experimental design, maize cultivar Pak Afghoi was sown in each pot according to standard agronomic practices. After the pots were prepared with the specified soil and amendments, five seeds of Pak Afghoi were sown per pot and subsequently thinned to three uniform seedlings. Crop management practices, including irrigation and weed control, were uniformly applied to all treatments throughout the growing period.

Fertilizer and Amendment Application

The experimental treatments were arranged in a completely randomized design with five treatments and three replications, totaling 15 pots. Each pot was filled with 18 kg of air-dried, sieved sandy loam soil collected from the university research farm. The treatments consisted of T_1 (control), T_2 (inorganic fertilizer at 150 kg N ha^{-1}), T_3 (FYM at 10 t ha^{-1}), T_4 (humic acid at 20 kg ha^{-1}), and T_5 (integrated application at 75 kg N ha^{-1} + 5 t FYM ha^{-1} + 10 kg humic acid ha^{-1}).

Data Collection

For the vegetative parameters, the data were recorded on a weekly basis, including measurements of plant height, number of leaves, and stem diameter, and the yield parameters were recorded after the harvesting of the crop. Growth observations were recorded weekly during the three-week measurement period. Plant height (cm), number of leaves per plant, and stem diameter (mm) were measured at each weekly observation. Leaf area index (LAI) was assessed during the growth period. At physiological maturity, plants were harvested and separated into shoots and roots. Stem fresh weight, stem dry weight, root fresh weight, and root dry weight were recorded. Dry biomass was determined after oven-drying samples at 65°C until constant weight. Grain yield was recorded at harvest and expressed on a per-pot basis before any hectare-equivalent conversion.

Statistical Analysis

The recorded data were subjected to

analysis of variance (ANOVA) using Statistica 8.1 software to determine the significance of treatment effects. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$).

Results and Discussion

Number of Leaves per Plant

The number of leaves per plant increased over the three weekly observations in all treatments, with clear treatment differences (Figure 1). The integrated treatment (T_5) had the highest mean leaf number (11.00), followed by inorganic fertilizer (T_2, 10.33), FYM (T_3, 9.33), humic acid (T_4, 8.67), and the control (T_1, 7.33). The stronger response under integrated nutrient management is consistent with reports that combining mineral and organic nutrient sources can improve maize vegetative growth (Essilfie et al., 2024; Gao et al., 2020; Soomro et al., 2024). The lower numerical response under FYM than under inorganic fertilizer may reflect differences in nutrient-release timing, because nutrients from mineral fertilizer are generally more immediately available than nutrients released through manure mineralization. The strong response of leaf number to nitrogen supply is well documented. Habibi et al. (2025) reported that leaf number per maize plant was significantly higher with nitrogen fertilization, with the highest N treatment having 20.64 leaves per plant compared to 12.35 leaves per plant in the unfertilized control, and Hammad et al. (2022) also reported that nitrogen application increased the number of leaves per maize plant, which in turn increased the height of the plant due to the elongation of the internodes.

Figure 1. Mean number of leaves per maize plant recorded at three weekly observation dates under the five fertility treatments (T_1-T_5).

Annexure (A)

Stem Diameter (mm)

At week one, stem diameter ranged from 10.33 (T_1) to 14.40 (T_5); by week three, this range had widened to 19.60 (T_1) and 26.60 (T_5), representing increases over the control of 8.7% (T_4), 16.8% (T_3), 27.6% (T_2) and 35.7% (T_5). The distinct differences between T_2 and T_3 at all measurement dates are in line with the overall integrated nutrient management literature on maize. In a pot-culture experiment on Vertisols, Teressa et al. (2024) reported that the combined manure and blended inorganic fertilizer produced significantly higher vegetative growth than either input alone, and the pot-culture experiment of Masood et al. (2014) showed that the combination of FYM and recommended NPK gave the highest growth of maize compared to the unfertilized control and the sole inorganic treatment, respectively, directly paralleling the superiority of T_5 over T_2 and T_3 recorded here. The early response of T_2 compared to T_3 is again due to the immediate availability of nitrogen and potassium from mineral sources, which are essential for cell division and secondary cell-wall thickening in developing stems, while the nutrients from FYM are released to the plant as manure organic matter is progressively mineralized.

Figure 2. Mean stem diameter of maize plants recorded at three weekly observation dates under the five fertility treatments (T_1-T_5).

Annexure (B)

Plant Height (cm)

The three parameters measured had the greatest absolute and proportional differences among treatments for plant height. By week one, the mean height was 51.67 cm (T_1) and by week three it was 93.30 cm (T_5), and this difference increased steadily throughout the week (Figure 4.3). Expressed as a percentage increase over the

unfertilized control at week three, the treatments ranked T_5 (47.6%) > T_2 (38.8%) > T_3 (22.5%) > T_4 (13.2%). Interestingly, the proportional advantage of T_5 over the control increased only slightly over the three weeks (43.2%, 44.2%, and 47.6% in weeks one, two, and three, respectively), suggesting that the benefit of the combined treatment was gained early and was not disproportionately increased over time.

The superiority of the combined treatment over any single nutrient source is well supported in the literature. Gao et al. (2020) found that biofertilizer and organic amendment mixtures significantly improved maize plant height compared to sole application, and Chen et al. (2021) showed that the application of humic acid with a phosphate fertilizer resulted in an increase in plant height and photosynthetic capacity beyond the effect of either application alone, which was attributed to increased endogenous hormone levels. In pot-culture experiments with maize, Teressa et al. (2024) and Masood et al. (2014) found the same qualitative trend: that combined organic-inorganic fertilizer treatments resulted in significantly taller plants than sole manure, sole inorganic fertilizer, or unfertilized treatments. In the present study, the central role of nitrogen availability in the height response was confirmed by Habibi et al. (2025), who found a strong, near-linear relationship between nitrogen rate and maize height (from 107 cm under a control to 191 cm at 300 kg N ha^{-1}).

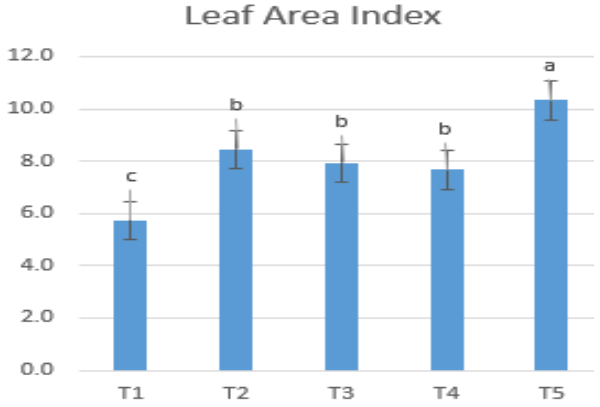
Figure 3. Mean plant height of maize plants recorded at three weekly observation dates under the five fertility treatments (T_1-T_5).

Annexure (C)

Leaf Area Index

The significantly higher leaf area index (LAI) under the integrated nutrient management treatment (T5) suggests that the combined application of inorganic fertilizer, farmyard manure (FYM), and humic acid was more conducive to the development of the canopy than the individual nutrient sources. Under integrated management, balanced nutrient availability leads to increased leaf initiation, expansion, and delayed senescence, which increases radiation interception, dry matter accumulation, and ultimately grain yield. The results are in line with Abrol et al. (2024), who found that the combination of mineral fertilizers and FYM had a positive effect on the growth of the maize canopy, biomass production, and grain yield, as well as soil organic carbon, microbial activity, and the release of nutrients. Likewise, Susilowati et al. (2024) reported that the use of inorganic fertilizers along with organic amendments and biofertilizers resulted in higher leaf area and biomass due to better nutrient cycling and uptake. Wali et al. (2020) also showed that humic acid alone gave moderate vegetative growth, while humic acid with mineral nitrogen gave significant improvement in leaf area and crop vigor, which is similar to the better LAI obtained under T5 than under T4 (humic acid alone).

Figure 4. Effect of the five fertility treatments (T_1-T_5) on leaf area index (LAI) of maize.



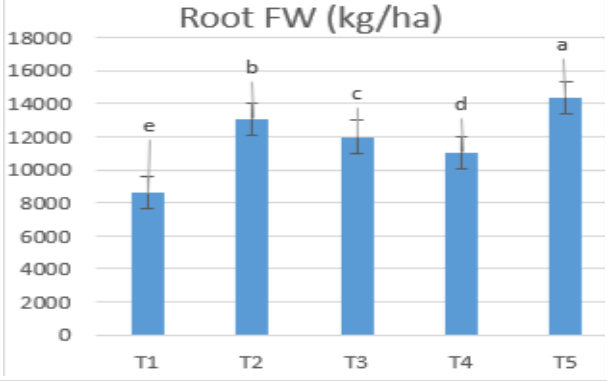
Root Fresh Weight (kg/ha)

The integrated nutrient management treatment (T5) had the highest root fresh weight (1438.5 kg ha^{-1} equivalent), which is about 67% higher than the root fresh

weight of the control (860.56 kg ha^{-1} equivalent). This improvement suggests that the use of inorganic fertilizer, farmyard manure (FYM), and humic acid provided a good soil environment for the growth of roots. Mineral fertilizers provided easily available nutrients; FYM enhanced soil structure, moisture-holding capacity, and microbial activity; and humic acid enhanced root cell division, membrane permeability, and nutrient absorption, which led to increased root proliferation.

The results are similar to those of Susilowati et al. (2024), who found that the use of inorganic fertilizer combined with organic amendments had a significant effect on the growth of maize roots, which was caused by the increase in nutrient availability and the activity of microorganisms in the rhizosphere. Likewise, Abrol et al. (2024) showed that FYM application along with mineral fertilizers resulted in better root development due to the increase in soil organic carbon, aggregation, and biological activity. Canellas and Olivares (2014) also reported that humic substances promote lateral root growth and root hair development, which enhances nutrient uptake. The effect of humic acid alone (T4) was better than the control but not as good as the integrated treatment, suggesting that its effect is best when used in conjunction with proper mineral nutrition.

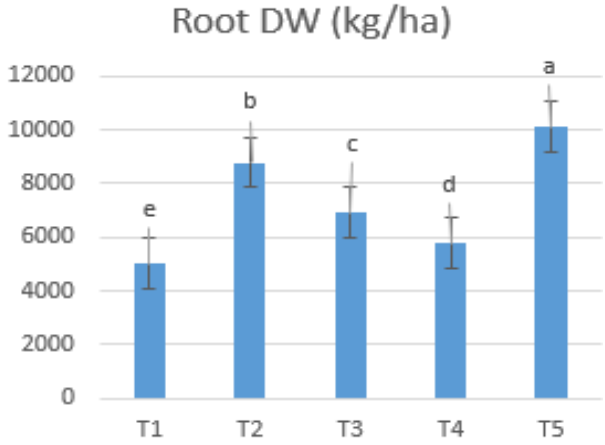
Figure 5. Effect of the five fertility treatments (T_1-T_5) on root fresh weight of maize.



Root Dry Weight (kg/ha)

Root dry weight also varied significantly among treatments, with the highest value of 1011.3 kg ha^{-1} equivalent in the integrated nutrient management treatment (T5) compared to the control at 502.52 kg ha^{-1} equivalent, which is about 101% higher. The large increase in dry biomass suggests that integrated nutrient management stimulated the production of structural root tissue, not just water content. A more extensive and mature root system will enable better soil exploration, nutrient uptake, and water absorption, which will help to promote more vegetative growth and crop yield. The present results corroborate those of Khan et al. (2019), who found that the application of humic acid along with nitrogen fertilizer significantly increased maize root biomass due to its ability to increase nutrient transport, N use efficiency, and physiological activity. Similarly, Sapkota et al. (2025) linked integrated nutrient management to better nutrient uptake and higher crop productivity, highlighting the importance of better root development for efficient use of soil resources. Agegnehu et al. (2016) also found that the use of organic amendments in combination with inorganic fertilizers resulted in better soil microbial biomass, mineralization of nutrients, and soil physical properties, which led to better soil conditions for continued root growth. The results corroborate the present study, which showed that the use of inorganic fertilizer, FYM, and humic acid resulted in the highest root dry biomass, indicating better below-ground growth in integrated nutrient management.

Figure 6. Effect of the five fertility treatments (T_1-T_5) on root dry weight of maize.

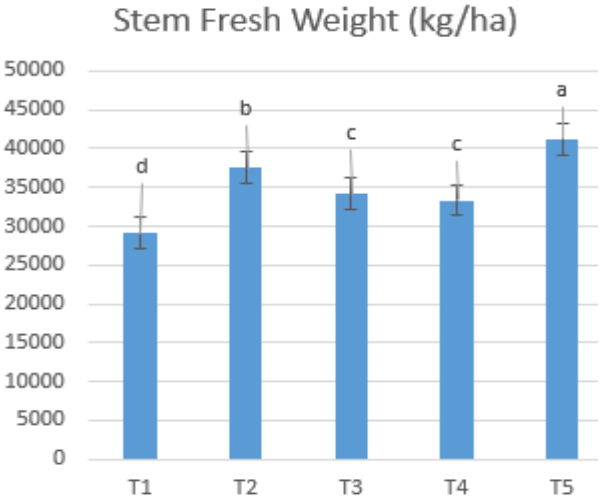


Stem Fresh Weight (kg/ha)

The different fertility treatments significantly affected stem fresh weight, in the order T5 > T2 > T3 ≈ T4 > T1. The integrated nutrient management treatment (T5) had the highest stem fresh weight (4120.7 kg ha^{-1} equivalent), which was about 41% higher than the control (2914.6 kg ha^{-1} equivalent). This improvement suggests that the use of inorganic fertilizer, farmyard manure (FYM), and humic acid together resulted in the development of a balanced and continuous supply of nutrients, which led to vigorous stem growth. Mineral fertilizer provided easily available nitrogen for quick cell division and stem elongation, and FYM enhanced soil physical properties and microbial activity. The nutrient uptake and root metabolic activity were also increased with the use of humic acid, leading to higher biomass accumulation.

The results are consistent with Abrol et al. (2024), who found that FYM application along with mineral fertilizers resulted in substantial improvement in vegetative biomass of maize due to the increase in soil organic carbon, nutrient availability, and microbial activity. Likewise, Susilowati et al. (2024) found that the use of inorganic fertilizers along with organic amendments increased the production of shoot biomass and dry matter due to the increase in rhizosphere biological activity and nutrient uptake. The combined application of FYM and mineral fertilizer also gave higher stem growth compared to mineral fertilizer or FYM alone, as reported by Oad et al. (2004), which is in agreement with the better stem fresh weight obtained under T5 in the present study.

Figure 7. Effect of the five fertility treatments (T_1-T_5) on the fresh weight of maize stems.

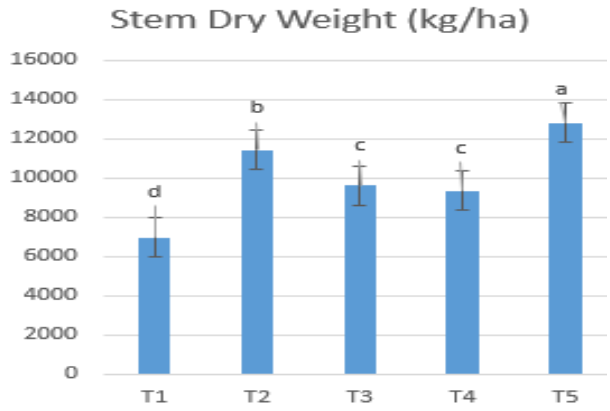


Stem Dry Weight (kg/ha)

The stem dry weight also varied significantly among treatments, with the highest being in the integrated nutrient management treatment (T5) at 1281.4 kg ha^{-1} equivalent, which is about 84% higher than the control. The higher stem dry matter production suggests that integrated nutrient management improved assimilate production and deposition of structural carbohydrates in stem tissues, leading to more efficient biomass partitioning. The present results corroborate those of Canellas and Olivares (2014), who reported humic substances as natural biostimulants that enhance nutrient uptake, enzyme activity, photosynthetic efficiency, and consequently dry matter accumulation. Similarly, Khan et al. (2019) found that the use of humic acid along with nitrogenous fertilizer had a significant positive effect on the biomass production of maize due to the improvement of N use efficiency and nutrient translocation. Wali et al. (2020)

reported that humic acid alone had only slight effects on biomass production, while the application of humic acid with nitrogen fertilizer had a significant effect on shoot growth and dry matter accumulation. The results of the present study corroborate the results of the above study, as the integrated use of inorganic fertilizer, FYM, and humic acid resulted in the maximum stem dry weight, followed by humic acid and FYM, and mineral fertilizer.

Figure 8. Effect of the five fertility treatments (T_1-T_5) on stem dry weight of maize.

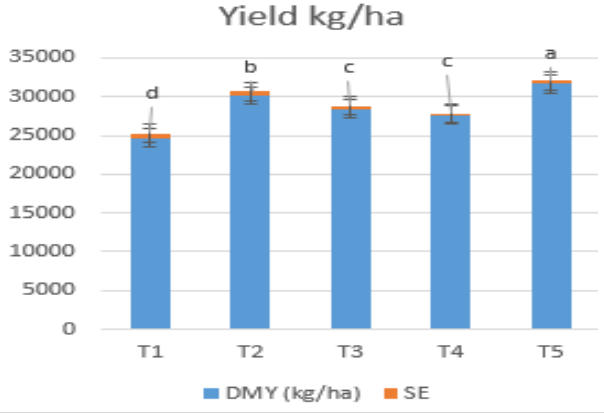


Grain Yield (kg ha^{-1})

The integrated nutrient management treatment (T5) yielded the highest grain yield (3165.9 kg ha^{-1} equivalent), which was about 28% higher than the control and 5% higher than inorganic fertilizer alone (T2). The results show that the application of inorganic fertilizer, farmyard manure (FYM), and humic acid together was more effective in improving the productivity of maize than any of the nutrients alone. The mineral fertilizer, FYM, and humic acid complement each other to give superior yield under T5. Mineral fertilizer provides easily available nutrients; FYM increases soil organic matter, structure, moisture-holding capacity, and microbial activity; and humic acid promotes root growth, nutrient uptake, and photosynthetic efficiency. These combined effects increase nutrient use efficiency, biomass production, and assimilate translocation, resulting in increased grain yield. The present results are in line with the results of Abrol et al. (2024), who reported that FYM application along with mineral fertilizers improved soil organic carbon, nutrient availability, microbial activity, and significantly enhanced the yield of maize grain. Likewise, Sapkota et al. (2025) and Susilowati et al. (2024) reported that integrated nutrient management increased grain yield by synchronizing nutrient release, increasing nutrient uptake, and increasing dry matter production. Agegnehu et al. (2016) also found that the use of both organic and inorganic nutrient sources enhances soil health and fertilizer use efficiency, which leads to better crop productivity.

The findings are also in line with Canellas and Olivares (2014) and Khan et al. (2019), who found that humic substances promote root growth, uptake of nutrients, photosynthetic activity, and nitrogen use efficiency, leading to higher biomass and grain production. The present study, however, revealed that humic acid alone was not enough to achieve the maximum yield, which means that the use of humic acid along with mineral fertilizer and FYM is more beneficial. In summary, the higher grain production in T5 is a result of better root system, leaf area, biomass production, and nutrient uptake throughout the crop's life.

Figure 9. Effect of the five fertility treatments (T_1-T_5) on grain yield of maize.



Annexure (D)

Conclusion

The present study showed that the growth and yield performance of maize was significantly enhanced under integrated nutrient management compared with inorganic fertilizer, farmyard manure, and humic acid alone. The treatment of inorganic fertilizer, farmyard manure and humic acid (T_5) always gave the best plant growth, leaf area index, root and stem biomass and grain yield among all the treatments. The integrated treatment, which included the nutrient provision of inorganic fertilizer, the soil improvement of farmyard manure, and the biostimulant effect of humic acid, improved nutrient availability and uptake. The individual application of FYM or humic acid alone, however, produced moderate improvement, which was less effective than the integrated approach. The results suggest that integrated nutrient management is a sustainable and efficient approach to boost maize productivity and soil fertility and nutrient management effectiveness. These findings should be replicated in the field in various soil types and agroecological zones to provide practical recommendations for sustainable maize production in the future.

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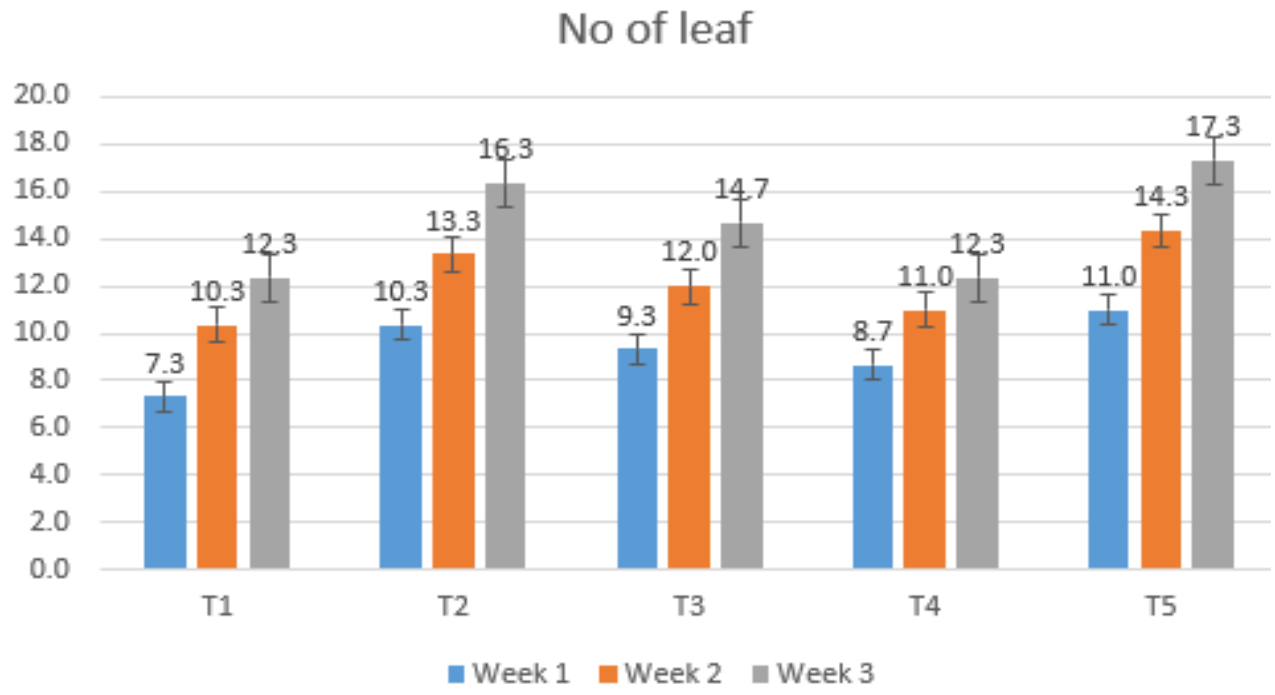
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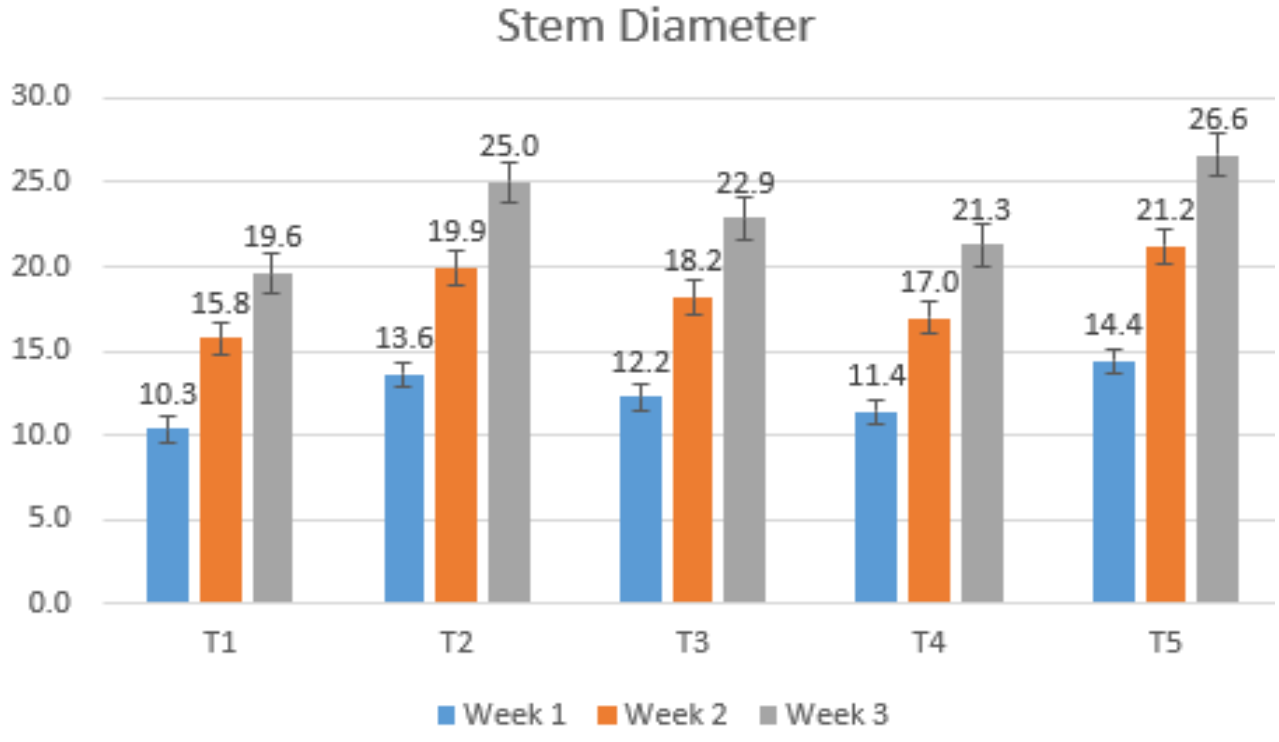
Annexure (A)

Figure 1. Mean number of leaves per maize plant recorded at three weekly observation dates under the five fertility treatments (T_1-T_5).



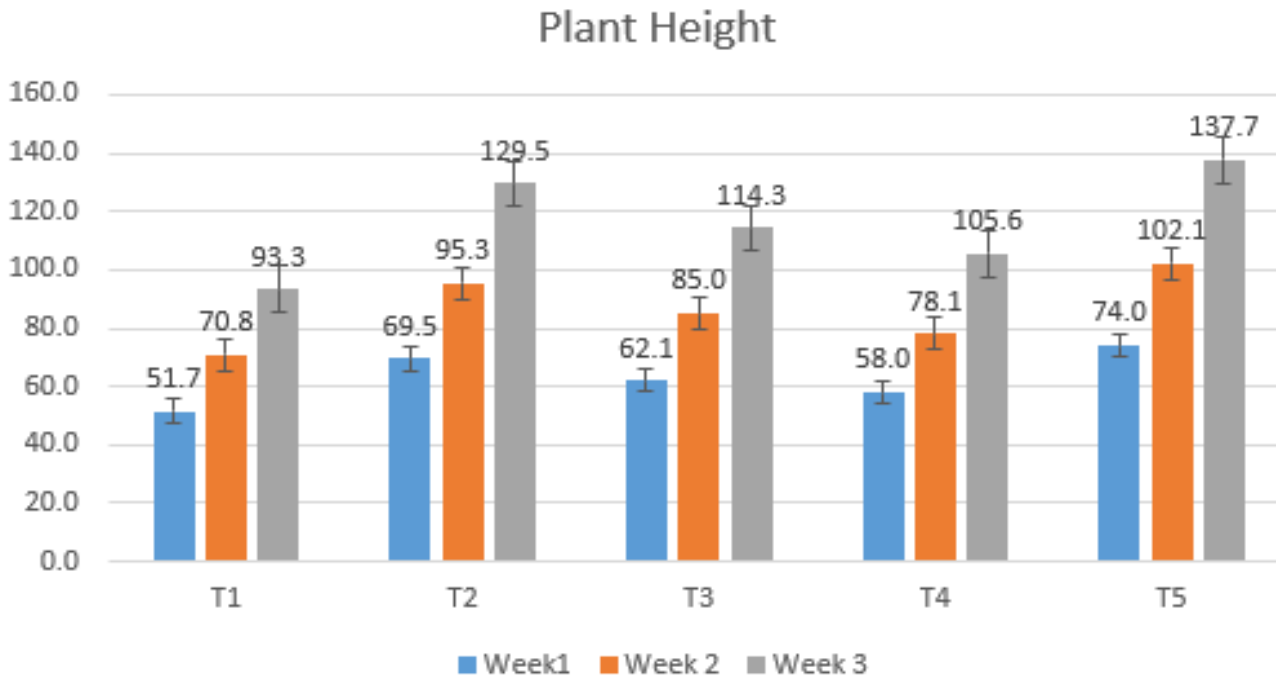
Annexure (B)

Figure 2. Mean stem diameter of maize plants recorded at three weekly observation dates under the five fertility treatments (T_1-T_5).



Annexure (C)

Figure 3. Mean plant height of maize plants recorded at three weekly observation dates under the five fertility treatments (T_1-T_5).



Annexure (D)

Table 1. Treatment means for leaf area index, root and stem biomass, and grain yield of maize under the five fertility treatments.

Treatment	Leaf Area Index (LAI)	Root Fresh Weight (kg ha^{-1} equivalent)	Root Dry Weight (kg ha^{-1} equivalent)	Stem Fresh Weight (kg ha^{-1} equivalent)	Stem Dry Weight (kg ha^{-1} equivalent)	Grain Yield (kg ha^{-1} equivalent)
T1	5.7267c	860.56e	502.52e	2914.6d	697.24d	2468.6d
T2	8.4433b	1306.5b	879.41b	3750b	1143.2b	3015.1b
T3	7.9267b	1199.8c	690.96c	3417.1c	961.07c	2845.5c
T4	7.6767b	1105.5d	577.9d	3335.5c	935.94c	2763.9c
T5	10.333a	1438.5a	1011.3a	4120.7a	1281.4a	3165.9a
CV	4.83	3.47	2.97	2.14	3.82	2.74