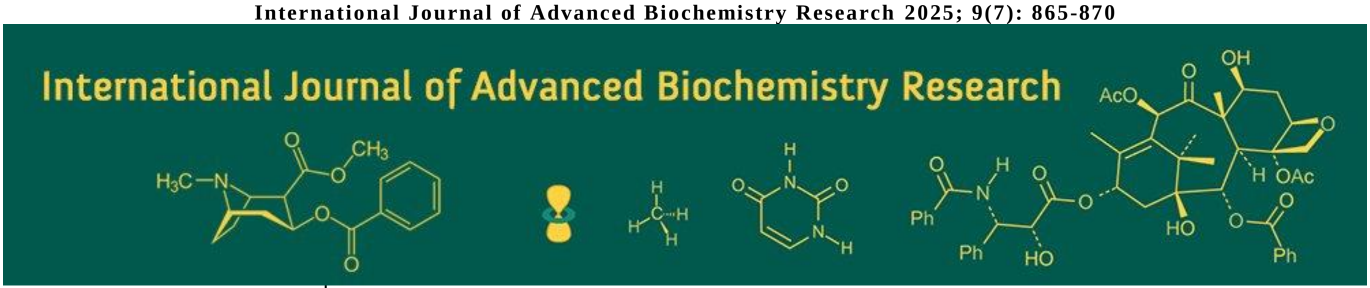

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Effect of soil and foliar application of different sources and levels of zinc on growth and yield of maize (*Zea mays* L.)

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Abstract
The present investigation was carried out at Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture & Technology, Udaipur. To optimize zinc doses and to enhance maize growth and yield, the present investigation was conducted to assess the effect of different sources and levels of zinc on maize as a test crop. This experiment was conducted in randomized block design with 9 treatment combinations. The significantly higher chlorophyll content at 60 DAS, plant height at harvest, grain, stover yield (5675, 8912 kg ha^{-1}) and biological yield was obtained under 100% $ZnSO_4$ + two sprays of functional zinc sulphate over rest of the treatments. The harvest index, physico-chemical properties *i.e*., pH, EC, organic carbon didn't influence significantly with the application of different sources and levels of zinc. The lowest parameters *i.e*., chlorophyll content, plant height, grain yield, stover yield and biological yield was obtained under control treatments.

Keywords: Chlorophyll content, plant height, yield, physico-chemical properties

Introduction

To optimize zinc doses and to enhance maize growth and yield, the present investigation was carried out to know the effects of combined application of different sources and levels of zinc. Maize (*Zea mays* L.) ranks third in global cereal importance, following wheat and rice and holds significant prominence in India. Renowned for its versatility, maize thrives across varied environmental conditions and serves multiple purposes in human diets, animal feed and as raw materials for numerous industrial products (Ayyar *et al.*, 2019) [5]. Maize is cultivated across 10.8 million hectares, yielding 37.25 million tonnes with an average productivity of 3.65 tonnes ha^{-1}. The primary contributors to this production are Andhra Pradesh, Karnataka, Rajasthan and Maharashtra (FAOSTAT, 2024-25). In Rajasthan, maize is extensively grown under rainfed conditions during the Kharif season, particularly in the Mewar, Wagad, and Hadoti regions. It is grown over an area of 0.949 million ha with a production of 2.34 million tonnes and productivity of 2.46 tonnes ha^{-1} (Commissionerate of Agriculture, Rajasthan, 2024-25). Maize serves as a primary source of calories and minerals for many rural populations. However, it is inherently deficient in protein and minerals, notably zinc (Ayyar and Apavoo, 2017) [4]. It is a crop with high nutrient demands particularly sensitive to micronutrient deficiencies, particularly zinc. It is recognized as an indicator plant for assessing zinc deficiency in soil (Ayyar and Appavoo, 2017) [4]. Zinc regulates auxin synthesis in plants. Therefore, zinc deficiency causes leaf distortion and shortening of internodes, ultimately leading to inadequate plant protein synthesis (Begum *et al.*, 2016) [6]. Zinc primarily stimulates the production of the growth hormone indole acetic acid, leading to higher auxin content and consequently enhancing the growth and yield of maize (Fajudar *et al.*, 2014) [10]. It is alarming to discover in the 21st century that approximately 2 billion people worldwide are deficient in zinc. This deficiency is particularly widespread in developing countries (Gibbson, 2006) [11]. In the current global context, it's important to recognize that zinc deficiency can contribute to increased susceptibility to and progression of COVID 19 (Skalny *et al.*, 2020) [14]. The deficiency of zinc in soils has risen from 44% to 48%, with an anticipated increase to 63% by 2025 in

India (Preetha and Stalin, 2014) [13]. Plant physiologists have extensively documented the significant influence of zinc on fundamental plant processes including nitrogen uptake and metabolism, protein quality, photosynthetic activity, chlorophyll synthesis, carbonic anhydrase activity, resistance to biotic and abiotic stresses and protection from oxidative damage (Alloway, 2004; Cakmak, 2008) [1, 8]. So, this experiment was carried out to know the combined effect of zinc application on growth and yield of maize.

Materials and Methods

The present investigation was carried out during *Kharif*, 2024 at Instructional Farm, Rajasthan College of Agriculture, Udaipur. The experimental site is located in the south-eastern region of Rajasthan, at an elevation of 579.5 meters above mean sea level, situated at 24°35′ N latitude and 74°42′ E longitude. The area falls within Agro-Climatic Zone IVA, classified as the Sub-Humid Southern Plain and Aravalli Hills of Rajasthan. The region experiences typical subtropical weather with moderate summer temperature and mild winters. The rainfall occurs with south-west monsoon with 637 mm of yearly average annual precipitation. The experimental soil was clayey in texture. The 9 treatments combination which was carried out in randomised plot design are existing in table 1. The cultivar PHM-6 was used for the experiment. The treatments were applied according to treatment details at the time of sowing. The crop was sown on 26th June, 2024 with seed rate of 25 kg and harvested on October 17, 2024. The critical difference for the comparison of treatments was worked out, wherever, the ‘F’ test was found significant at 5 percent level of significance.

Table 1: Treatment details

T_1	:	Control
T_2	:	100% $ZnSO_4$
T_3	:	100% $ZnSO_4$ + 0.25% Functional Zinc Sulphate
T_4	:	100% $ZnSO_4$ + 0.5% Functional Zinc Sulphate
T_5	:	75% $ZnSO_4$ + 0.50% Functional Zinc Sulphate
T_6	:	50% $ZnSO_4$ + 0.75% Functional Zinc Sulphate
T_7	:	100% $ZnSO_4$ + Two sprays of 0.25% Functional Zinc Sulphate
T_8	:	75% $ZnSO_4$ + Two sprays of 0.50% Functional Zinc Sulphate
T_9	:	50% $ZnSO_4$ + Two sprays of 0.75% Functional Zinc Sulphate

Note: Functional Zinc sulphate:-Chitosan Formulation

Zinc sulphate used for soil application:-Zinc sulphate heptahydrate ($ZnSO_4.7H_2O$)

RDF = Recommended dose of fertilizer (90 kg N; 60 kg P_2O_5; 40 kg K_2O)

Results

Chlorophyll content at 60 DAS

The chlorophyll content of maize leaves was significantly affected with the application of various sources and levels of zinc and data in summed up in Table 2. The significantly higher chlorophyll content (48.12) of maize at 60 DAS was registered with the application of 100% $ZnSO_4$ + two sprays of 0.25% functional zinc sulphate (T_7) which was being at par with 75% $ZnSO_4$ + two sprays of 0.50% functional zinc sulphate (T_8), 50% $ZnSO_4$ + two sprays of 0.75% functional zinc sulphate (T_9), 100% $ZnSO_4$ + 0.5% functional zinc sulphate (T_4), 75% $ZnSO_4$ + 0.50% functional zinc sulphate (T_5) and 100% $ZnSO_4$ + 0.25% functional zinc sulphate (T_3) than rest of the treatments. While, the lowest chlorophyll content (39.87) was obtained under control (T_1) treatment. Moreover, the chlorophyll content was obtained 20.69% higher under T_7 than the T_1 treatment.

Plant height at harvest

A perusal of data (Table 2) that the application of different sources and levels of zinc had a synergistic effect on plant height in maize. The maximum plant height (280.23 cm) was recorded with the application of 100% $ZnSO_4$ combined with two foliar sprays of 0.25% functional zinc sulphate (T_7). This treatment was statistically at par with both 75% $ZnSO_4$ plus two sprays of 0.50% functional zinc sulphate (T_8) and 100% $ZnSO_4$ plus 0.5% functional zinc sulphate (T_4) and all three outperformed the remaining treatments in terms of plant height. In contrast, the minimum plant height (218.90 cm) was observed under the control treatment (T_1), which received no zinc supplementation. Notably, the plant height under T_7 was 26.67% greater than that observed in the control, highlighting the pronounced effect of optimal zinc fertilization on maize growth.

Grain yield

As presented in Table 3, grain yield in maize responded significantly to the application of zinc from different sources and at varying levels. The highest grain yield (5,675 kg ha^{-1}) was obtained with 100% $ZnSO_4$ plus two sprays of 0.25% functional zinc sulphate (T_7), which was statistically at par with T_8, T_4, T_9 and T_5. These treatments resulted in significantly higher yields than the other treatments. The lowest grain yield (4,623 kg ha^{-1}) was recorded under the control (T_1). The yield improvement under T_7 represented a 22.73% increase compared to the control.

Stover yield

Maize stover yield was significantly affected by the application of zinc from different sources and at varying levels, as indicated in Table 3. The greatest stover yield (8,912 kg ha^{-1}) was observed with 100% $ZnSO_4$ and two foliar sprays of 0.25% functional zinc sulphate (T_7), which was statistically at par with T_8, T_4, T_9 and T_5 all of which produced significantly higher yields than the other treatments. The control (T_1) produced the lowest stover yield (7,486 kg ha^{-1}). Notably, T_7 resulted in a 19.05% higher stover yield compared to the control, demonstrating the effectiveness of zinc application in enhancing maize biomass production.

Biological yield

As presented in Table 3, biological yield in maize responded significantly to different zinc fertilization strategies. The highest yield (14,587 kg ha^{-1}) was observed with 100% $ZnSO_4$ and two foliar sprays of 0.25% functional zinc sulphate (T_7), which was statistically at par with T_8, T_4, T_9 and T_5. These treatments resulted in significantly higher biological yields than the remaining treatments. The minimum biological yield (12,109 kg ha^{-1}) was recorded under the control (T_1). The biological yield in T_7 was 20.46% higher than in the control, highlighting the substantial benefit of zinc application.

Harvest index

The harvest index of maize didn’t influence significantly with the application of various sources and levels of zinc and data summarized in Table 3. The highest harvest index (39.93%) was obtained with the application of 50% $ZnSO_4$

+ 0.75% functional zinc sulphate (T_6) and the lowest harvest index (38.18%) was obtained under cont (T_1).

Physico-chemical properties of soil
The physico-chemical properties after harvest of maize didn't influence significantly, while DTPA-extractable zinc in soil influenced significantly with the application of various sources and levels of zinc and data summarized in Table 4 and 5.

Soil pH
Soil pH at the time of maize harvest was not significantly impacted by zinc fertilization treatments, as presented in Table 4. The pH values across all treatments ranged from 8.2 to 8.4.

Electrical conductivity
No significant effect on soil electrical conductivity at harvest was observed with the application of different sources and levels of zinc, as per Table 4. The EC values across treatments ranged from 0.33 to 0.36 dS m^{-1}.

Organic carbon
As indicated in Table 4, soil organic carbon at harvest did not show significant variation in response to the application of various zinc sources and rates. The observed organic carbon values were between 0.63% and 0.69%.

Available nitrogen
The available nitrogen in soil at harvest of maize didn't influence significantly with the application of various sources and levels of zinc and data summarized in Table 5. And also, the highest available nitrogen (198.4 kg ha^{-1}) in soil was obtained under 50% $ZnSO_4$ + 0.75% functional zinc sulphate (T_5) and lowest was registered under 100% $ZnSO_4$ + 0.5% functional zinc sulphate (T_4).

Available phosphorus
The results summarized in Table 5 show that the application of various zinc sources and levels had no significant effect on available phosphorus in soil at maize harvest. The greatest available phosphorus (23.74 kg ha^{-1}) was found under T_5 (50% $ZnSO_4$ + 0.75% functional zinc sulphate), while the control (T_1) had the lowest value.

Available potassium
As indicated in Table 5, the application of various zinc sources and concentrations did not significantly influence the available potassium levels in the soil at maize harvest. The maximum available potassium (356.34 kg ha^{-1}) was found in T_5 (50% $ZnSO_4$ + 0.75% functional zinc sulphate), whereas the control (T_1) had the lowest value.

DTPA-extractable zinc
The DTPA-extractable zinc in soil at harvest of maize significantly influenced with the application of various sources and levels of zinc as presented in Table 5. The significantly higher DTPA-extractable zinc (0.84 mg kg^{-1}) at harvest of maize was obtained with the application of 100% $ZnSO_4$ + two sprays of 0.25% functional zinc sulphate (T_7) which being at par with 100% $ZnSO_4$ + 0.5% functional zinc sulphate (T_4), 100% $ZnSO_4$ + 0.25% functional zinc sulphate (T_3) and 75% $ZnSO_4$ + two sprays of 0.50% functional zinc sulphate (T_8) than rest of the treatments. While, the lowest DTPA-extractable zinc (0.71 mg kg^{-1}) was registered under control (T_1) treatment. Therefore, the DTPA-extractable zinc by maize at harvest was registered 17.29% higher under T_7 than the T_1 treatment.

Table 2: Effect of zinc application on growth parameters of maize

Treatments	Chlorophyll content (SPADE value)	Plant height (cm) at harvest
T_1: Control	39.87	218.9
T_2: 100% $ZnSO_4$	43.79	241.0
T_3: 100% $ZnSO_4$ + 0.25% functional zinc sulphate	44.69	243.1
T_4: 100% $ZnSO_4$ + 0.5% functional zinc sulphate	47.32	273.6
T_5: 75% $ZnSO_4$ + 0.50% functional zinc sulphate	45.69	250.1
T_6: 50% $ZnSO_4$ + 0.75% functional zinc sulphate	43.61	247.1
T_7: 100% $ZnSO_4$ + two sprays of 0.25% functional zinc sulphate	48.12	280.2
T_8: 75% $ZnSO_4$ + two sprays of 0.50% functional zinc sulphate	47.57	277.3
T_9: 50% $ZnSO_4$ + two sprays of 0.75% functional zinc sulphate	46.78	251.4
SEm±	1.36	9.29
CD (P =0.05)	4.07	27.86

Table 3: Effect of zinc application on yield of maize

Treatments	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	HI (%)
T_1: Control	4623	7486	12109	38.18
T_2: 100% $ZnSO_4$	5132	7969	13101	39.16
T_3: 100% $ZnSO_4$ + 0.25% functional zinc sulphate	5220	7974	13194	39.58
T_4: 100% $ZnSO_4$ + 0.5% functional zinc sulphate	5567	8760	14327	38.87
T_5: 75% $ZnSO_4$ + 0.50% functional zinc sulphate	5418	8412	13830	39.19
T_6: 50% $ZnSO_4$ + 0.75% functional zinc sulphate	5243	7894	13137	39.93
T_7: 100% $ZnSO_4$ + two sprays of 0.25% functional zinc sulphate	5675	8912	14587	38.89
T_8: 75% $ZnSO_4$ + two sprays of 0.50% functional zinc sulphate	5580	8834	14413	38.73
T_9: 50% $ZnSO_4$ + two sprays of 0.75% functional zinc sulphate	5518	8434	13951	39.57
SEm±	140.79	200.04	272.12	0.71
CD (P =0.05)	422.07	599.73	815.81	NS

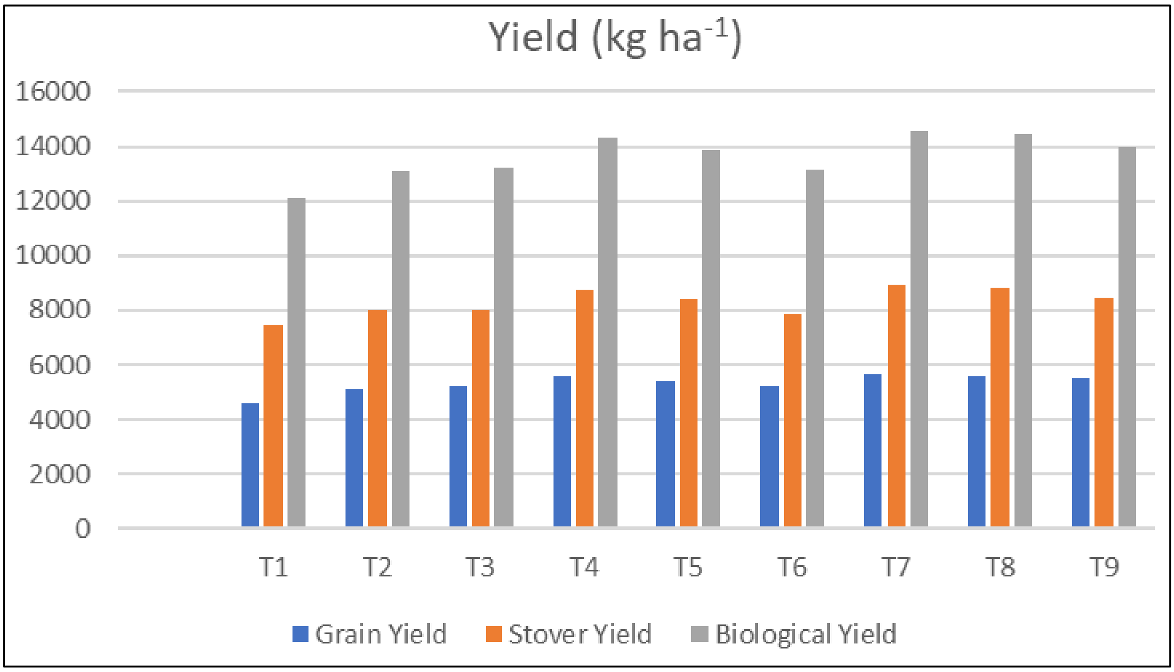

Fig 1: Effect of zinc application on yield of maize

Table 4: Effect of zinc application on physico-chemical properties of soil after harvest

Treatments	pH	EC (dS m^{-1})	Organic carbon (%)
T_1: Control	8.3	0.33	0.69
T_2: 100% $ZnSO_4$	8.2	0.35	0.66
T_3: 100% $ZnSO_4$ + 0.25% functional zinc sulphate	8.3	0.36	0.65
T_4: 100% $ZnSO_4$ + 0.5% functional zinc sulphate	8.3	0.34	0.63
T_5: 75% $ZnSO_4$ + 0.50% functional zinc sulphate	8.6	0.34	0.67
T_6: 50% $ZnSO_4$ + 0.75% functional zinc sulphate	8.4	0.35	0.65
T_7: 100% $ZnSO_4$ + two sprays of 0.25% functional zinc sulphate	8.3	0.34	0.65
T_8: 75% $ZnSO_4$ + two sprays of 0.50% functional zinc sulphate	8.4	0.33	0.64
T_9: 50% $ZnSO_4$ + two sprays of 0.75% functional zinc sulphate	8.2	0.36	0.67
SEm±	0.25	0.01	0.02
CD (P =0.05)	NS	NS	NS

Table 5: Effect of zinc application on available nutrients in soil

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Zinc (mg kg^{-1})
T_1: Control	191.54	18.95	286.06	0.71
T_2: 100% $ZnSO_4$	190.28	21.02	315.46	0.75
T_3: 100% $ZnSO_4$ + 0.25% functional zinc sulphate	192.75	22.33	335.17	0.82
T_4: 100% $ZnSO_4$ + 0.5% functional zinc sulphate	191.05	23.42	348.20	0.83
T_5: 75% $ZnSO_4$ + 0.50% functional zinc sulphate	198.45	23.74	356.34	0.77
T_6: 50% $ZnSO_4$ + 0.75% functional zinc sulphate	194.21	22.17	332.82	0.74
T_7: 100% $ZnSO_4$ + two sprays of 0.25% functional zinc sulphate	192.52	23.39	351.03	0.84
T_8: 75% $ZnSO_4$ + two sprays of 0.50% functional zinc sulphate	194.21	23.71	355.89	0.81
T_9: 50% $ZnSO_4$ + two sprays of 0.75% functional zinc sulphate	195.74	22.25	334.02	0.76
SEm±	4.74	1.05	14.94	0.02
CD (P =0.05)	NS	NS	NS	0.06

Discussion

Chlorophyll, being the primary pigment involved in photosynthesis, directly influences plant productivity. The present data reveals a significant positive response of maize chlorophyll content to zinc fertilization. The highest chlorophyll content (48.12) at 60 days after sowing (DAS) was recorded in treatment T_7 which included soil application of 100% recommended dose of zinc as zinc sulphate ($ZnSO_4$.) along with two foliar sprays of 0.25% functional zinc sulphate over control which is in line with the findings of (Naveena *et al.*, 2018) [12] of foliar application of zinc sulphate ($ZnSO_4$.). This indicates that the synergistic effect of both soil and foliar zinc applications contributes to enhanced chlorophyll synthesis. This suggests that foliar applications can effectively supplement soil-applied zinc, potentially allowing for lower basal zinc inputs without compromising chlorophyll levels. Such strategies could enhance nutrient use efficiency while reducing input costs. Zinc deficiency is known to impair the formation of chlorophyll and reduce the activity of enzymes such as carbonic anhydrase which is essential for photosynthetic carbon fixation.

Similarly, foliar functional zinc application with soil application of zinc sulphate heptahydrate also showed a significant effect on the vegetative growth of maize particularly plant height at harvest. The availability of required nutrients at critical stages and the foliar application of micronutrients facilitates increased Indole Acetic Acid (IAA) production which in turn promotes plant height (Bhaumik *et al.*, 2024) [7]. Since functional zinc sulphate has slow release of zinc ions which might be corelated with (Choudhary *et al.*, 2019) [9] slow release of zinc 93.22 percent zinc release in 7 days and foliar nutrition at early vegetative stages lead to a higher photosynthetic rate than at later stages likely due to increased photosynthetic enzyme activity and better photosystem II function (Naveena *et al.*, 2018) [12] and applying $ZnSO_4$ may have promoted plant height by improving nitrogen availability in the soil (Yadav *et al.*, 2022) [16]. The present investigation resulted the tallest plants (280.23 cm) were observed in T_7 the same treatment that also produced the highest chlorophyll content. This strong correlation further reinforces the importance of zinc in promoting photosynthesis and vegetative vigor. The performance of T_7 was statistically similar to that of T_8 and T_4 which included either reduced soil-applied zinc with higher foliar spray concentrations or sole soil application with a moderate foliar dose. These findings underscore the complementary role of foliar and soil-applied zinc. The results of the present investigation corroborate the findings of several researchers (Amutham *et al.*, 2019; Yadav *et al.*, 2022) [2, 16].

Grain yield is the most important parameter in evaluating the effectiveness of agronomic practices whereas stover yield refers to the total vegetative biomass (leaves, stalks and husks) left after harvesting grain which is critical for livestock fodder and soil organic matter recycling and biological yield is the combined total of grain and stover yield representing the crop's overall biomass productivity. The results clearly show that grain yield, stover yield and biological yield in maize was significantly enhanced by zinc application. The highest grain yield (5675 kg ha^{-1}), stover yield (8912 kg ha^{-1}) and biological yield (14,587 kg ha^{-1}) was recorded under T_7 (100% $ZnSO_4$ + two foliar sprays of 0.25% functional zinc sulphate). This treatment was statistically at par with T_8, T_4, T_9 and T_5 suggesting that even reduced soil application (50-75%) when coupled with targeted foliar sprays could achieve yield levels similar to full basal application. The control treatment (T_1) which did not receive any zinc recorded the lowest grain yield (4623 kg ha^{-1}), stover yield (7486 kg ha^{-1}) and biological yield (12,109 kg ha^{-1}). A 22.73% increase in grain yield, 19.05% increase in stover yield and 20.46% increase in biological yield under T_7 over T_1 indicates the significant role of zinc in promoting grain production, positive effect on vegetative growth and influence on both vegetative and reproductive biomass production. Enhancing chlorophyll content and photosynthetic efficiency. Supporting reproductive development leading to better grain formation. Improving nutrient metabolism and hormone balance for grain filling. The consistent superiority of T_7 reinforces the value of combining soil and foliar applications of zinc for maximizing total productivity. The results of present study corroborate finding by several researchers (Tamil *et al.*, 2021; Yadav *et al.*, 2022) [15, 16] who recorded that combined methods of zinc application gave maximum yield.

Harvest Index (HI) represents the ratio of economic yield (grain) to biological yield. It is a measure of how efficiently the plant converts total biomass into harvestable produce. Unlike other yield attributes, the harvest index in this study was not significantly influenced by zinc treatments. The highest HI (39.93%) was recorded under T_6 (50% $ZnSO_4$ + 0.75% functional zinc sulphate). The lowest HI (38.18%) occurred under T_2 (100% $ZnSO_4$ alone). Although the differences were not statistically significant, the numerical variation shows a tendency toward slightly better grain partitioning under balanced zinc treatments involving foliar supplementation. Zinc boosts both grain and stover yields proportionally. There's no major shift in source-sink partitioning but rather an overall enhancement in biomass accumulation and grain filling. This further suggests that while zinc significantly enhances productivity, the grain-to-total biomass ratio remains largely unaffected which is a desirable trait in modern maize breeding and agronomic strategies.

The soil pH ranged from 8.2 to 8.4 across all treatments. The application of zinc, whether as 100% $ZnSO_4$ alone or in combination with foliar sprays of functional zinc sulphate at various concentrations did not significantly affect the soil pH at harvest. This outcome suggests that the zinc treatments used in the study were not acidic or alkaline enough to alter the natural pH of the soil. Since soil pH is a relatively stable characteristic especially in alkaline soils like those in this study (pH > 8.0) the result aligns with established agronomic principles. Moreover, zinc sulphate typically has a neutral to slightly acidic reaction in soil, which might have contributed marginally but insufficiently to cause statistical significance.

Soil EC values ranged from 0.33 to 0.36 dS m^{-1} across treatments, indicating non-saline conditions. Zinc applications in various forms and combinations, had no significant effect on EC, suggesting no salt accumulation. This stability confirms the salinity safety of the zinc fertilization strategy, particularly given the minimal impact of foliar sprays on soil EC. Maintaining optimal EC supports root function and nutrient uptake, underscoring the agronomic relevance of this finding.

Soil organic carbon ranged from 0.63% to 0.69%, with no significant variation across zinc treatments. This is expected, as the non-organic nature of $ZnSO_4$ and foliar sprays does not directly influence OC levels. Organic carbon typically responds to organic amendments rather than mineral inputs. While enhanced growth (e.g., in T_7) may contribute to OC buildup over time, no significant change is expected in a single-season study.

Available soil nitrogen ranged from the lowest in T_4 to a maximum of 198.4 kg ha^{-1} in T_5, with no significant effect of zinc treatments. While zinc may enhance plant metabolism and N assimilation, its influence on residual soil N was minimal. The higher N in T_5 may reflect improved root biomass and microbial activity but was not statistically significant.

Available phosphorus ranged from the lowest in the control (T_1) to a maximum of 23.74 kg ha^{-1} in T_5 (50% $ZnSO_4$ + 0.75% foliar spray), with no significant effect of zinc treatments. Despite potential Zn-P antagonism, the applied zinc levels did not alter soil P availability, likely due to soil buffering capacity and the short duration of the study.

Available potassium ranged from the lowest in T_1 to a maximum of 356.34 kg ha^{-1} in T_5, with no significant differences across treatments. Zinc applications did not affect soil K levels, as expected, given the lack of K inputs and limited interaction between K and Zn pathways.

Observed variation may reflect plant uptake or moisture differences. In contrast, DTPA-extractable Zn was significantly influenced by treatments.

The highest zinc availability (0.84 mg kg^{-1}) was recorded under T_7 (100% $ZnSO_4$ + two foliar sprays of 0.25%) which was statistically at par with T_4, T_3 and T_8. The lowest availability (0.71 mg kg^{-1}) was recorded under control (T_1). Zinc availability was 17.29% higher under T_7 compared to control. This significant improvement is due to the direct contribution of applied $ZnSO_4$ and foliar sprays, especially in forms readily available to plants (functional zinc sulphate). The sustained availability observed at harvest suggests that the zinc application not only met crop demand but also improved the residual pool of plant-available zinc, enhancing soil fertility for succeeding crops.

Conclusion

The comprehensive findings of the present study clearly reveal that the combined application of 100% $ZnSO_4$ along with two foliar sprays of 0.25% functional zinc sulphate (T_7) significantly improved all major agronomic traits of maize. This treatment notably enhanced chlorophyll content, plant height, grain yield, stover yield and biological yield compared to control. In contrast, control treatments recorded the lowest values for these parameters. However, soil physico-chemical properties such as pH, EC, organic carbon available N, P, K remained unaffected by the treatments. However, 75% $ZnSO_4$ along with two foliar sprays of 0.50% functional zinc sulphate (T_8) is the better option for saving 25% application of zinc fertilizers to maize crop with enhanced growth parameters and yield.

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