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Enhancing maize yield and zinc uptake through foliar application of zinc sulfate in calcareous soil of Peshawar, Pakistan

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Abstract

Zinc deficiency in maize plants is a common problem, particularly in calcareous soils with pH above 7. This study aimed to investigate the impact of zinc sulfate ($ZnSO_4$) applied in different forms (foliar and soil application) and concentrations on maize yield, zinc uptake, and nutrient use efficiency (NUE) in calcareous soil. The results demonstrated that zinc application significantly increased maize yield, zinc uptake, NUE, and the uptake of Nitrogen, Phosphorus, and Potassium. Foliar application of $ZnSO_4$ was more effective than soil application in enhancing zinc uptake, with the highest uptake observed in plants treated with 1.5% $ZnSO_4$ foliar spray. Additionally, zinc application increased zinc content in grains and surface soil, with the highest zinc content in grains found in plants treated with 1.5% $ZnSO_4$ foliar spray and the highest zinc content in surface soil observed in plants treated with 10 kg ha-1 $ZnSO_4$ soil application. These findings suggested that foliar application of $ZnSO_4$ is an effective strategy for improving zinc uptake and grain zinc content in maize plants grown in calcareous soils.

Keywords: Zinc Uptake; NUE; Foliar Application; Calcareous Soil

1. Introduction

Maize (*Zea mays* L.) is ranked as the third most significant cereal globally and in India, following wheat and rice. It is a highly versatile crop that finds applications in human nutrition, animal feed, and various industrial sectors [1] (Ayyar et al., 2019). Due to its immense potential, this grain, known as the "Queen of cereals" & "Miracle Crop" is cultivated in nearly 130 countries [2] (Suganya 2015). In addition to being used as food and animal feed, maize is highly prized for its capacity to generate starch, resins, syrups, ethanol, and other valuable products [3] (Ayyar and Appavoo, 2016). Maize, being a C4 plant, effectively utilizes bio-elements for its nutrition. The significance of maize grains in providing sustenance to three billion individuals is widely acknowledged. The increasing adoption of nonvegetarian diets and the growth of the poultry industry in the state are leading to a surge in the demand for maize grain as a feed for chickens. This nutrient-rich crop is susceptible to micronutrient deficits, particularly zinc (Zn) deficiencies. The introduction of high-yielding agricultural cultivars/hybrids, known as the green revolution, has exacerbated this problem [4] (Ayyar and Appavoo 2017). Zinc is essential for the development of the human immune system and brain, as well as for the enzymatic processes and metabolic activities in plants. Zinc is required in moderate quantities to sustain many plants physiological processes. Zinc serves as a fundamental component or controlling agent for numerous enzymes and proteins involved in crucial biochemical processes in plants. These processes include carbohydrate metabolism, encompassing both photosynthesis and the transformation of sugars into starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, maintenance of biological membrane integrity, and defense against specific pathogens. The prevalence of micronutrient malnutrition, particularly zinc deficiency, affects around three billion people, primarily in impoverished countries [5] (Balakrishnan and Subramanian 2012).

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Soil zinc shortage affects 49% of crop productivity globally. The zinc utilization efficiency (ZUE) is only 3.5% because of the variation in the soil's ability to adsorb zinc, as stated by [2] Suganya in 2015. ZUE is further diminished by physico-chemical factors. Around 50% of soils in India exhibit zinc deficiency, necessitating the use of various forms of zinc fertilizers such as conventional fertilizers, chelated zinc, and naturally occurring organic complexes like polymer coated zinc. When water-soluble Zn is applied in the form of $ZnSO_4$, it undergoes a transformation into Zn (OH) and Zn (OH)2 at pH levels of 7.7 and 9.0 respectively. In calcium-rich alkali soils, it becomes zinc carbonate, while in near neutral to alkali soils with sufficient phosphorus, it forms zinc phosphate. Under reduced circumstances, it turns into zinc sulphide. Zinc is primarily found in soils as a result of hydrous iron and aluminum oxides, as well as clay minerals [6] (Hafeez, Khanif, and Saleem 2013). Fertilizer Zn has limited downward movement in cultivated soils and undergoes insolubility upon application, resulting in Zn deficiency. A deficiency in zinc leads to an 80% decrease in grain output and a decrease in the zinc levels in the grains [7] (Cakmak 2008).

Zinc deficiency can occur in various types of soils, especially neutral and calcareous soils. Furthermore, studies have shown that zinc deficiency is observed in many types of soil. The minimum soil levels required to prevent zinc insufficiency range from 0.6 parts per million (ppm) to 2.0 milligrams of zinc per kilogram (mg zinc kg–1), depending on the method of extraction. Calcareous soils with a pH greater than 7 and a moderate to high concentration of organic matter (more than 1.5% organic carbon) are prone to have zinc deficiency due to the presence of high soil solution HCO3. This study aimed to determine the impact of various Zinc concentration applied in various forms on calcareous soil and its uptake by maize plant in Peshawar, Pakistan.

2. Materials and Methods

A Randomized Complete Block Design for the current research was used for to assess the impact of various Zinc (Zn) concentration applied in various forms on calcareous soil and its uptake by maize plant in Peshawar during 2022 at “Agricultural Research Farm (ARF)” at The University of Agriculture, Peshawar. “Azam” variety was used in the current research. N, P_2O_5, and K_2O wa applied in 20:60:60 20 kg ha^{-1}.

In order to apply Zn, zinc sulphate ($ZnSO_4$) was applied in different form i.e., foliar and in soil during various stages of growth. Soil applied was applied in 0, 5, 10, 15, and 20 kgha^{-1} while in case of foliar applied 0.25, 0.50, 1.0, and 1.5% was applied.

2.1. Volume of spray per treatment plot

Volume of spray applied per treatment plot are 6.2 g/L (0.25%), 12.38 g/L (0.5%), 18.6 g/L (1.0%), 24.8 g/L (1.5%).

2.2. Soil Physico-chemical Analysis

In order to examine various soil physico-chemical characteristics, field soil was collected in composite ratio. All the procedure was followed as per [8] Salam et al., 2022.

For Soil pH and Electrical Conductivity, 1: 5 (Soil: Water, V/V) was used in which 10 g of soil extract was made in 50 mL of distilled water. The clear soil extract was subjected for pH and EC analysis using digital pH meter and EC meter respectively.

Hydrometer methodology was followed in order to find out the soil texture of the field. The method included addition of sodium bicarbonate to the soil samples followed by shaking. An initial reading with temperature at this point is recorded. A final reading is recorded after 2 hours when all the clay is settled.

The equations for determining soil texture are as:

$$\%(silt + clay) = \frac{40\,\text{sec} * Hydrometer\ reading\ \pm Temperature\ correction}{weight\ of\ soil(g)} \times 100$$

$$\%\ clay = \frac{2\ hrs\ Hydrometer\ reading \pm Temperature\ correction}{weight\ of\ soil(g)} \times 100$$

$$\%\ Sand = 100 - \%(silt + clay)$$

$$\%Silt = 100 - sand - clay$$

To determine the Soil Organic Matter (SOM), the methodology of Sommer & Nelson (1982) was followed. The equation used is given as:

$$O.M\ (\%) = \frac{[(mL\ Fe2SO4.7H20) \times N] - (mL\ K2Cr2O7 \times N) \times 0.69}{Weight\ of\ Soil\ (g)}$$

The methodology of [9] (Soltanpour and Schwab, 1977) was followed for AB DTPA extractable Soil Phosphorus & Potassium Contents which used spectrophotometer at 880 nm and flame photometer 766.5 nm.

To determine the total nitrogen the procedure of [10] Bremner, 1996 was followed who determined the nitrogen content using acid-digestion methodology. All the necessary calculations were put at the end of all recordings.

$$Nirtogen\ (\%) = \frac{(S - B) \times 0.005N \times 0.014 \times 10000}{Sample\ Weight\ \times ml\ of\ extract\ used}$$

2.3. AB-DTPA Extractable Zinc content

The standard protocol for determination of Zinc was carried out in order to find the zinc content in the soil. 1:2 Soil-Water extract was prepared in which the AB-DTPA reagent was mixed the suspension was subjected to shaking for 15-20 mins following filtration via Whatman 42 filter paper. In the end, the extract was subjected to atomic absorption spectrophotometer for zinc determination. Calculation for Zinc is given below.

$$\text{Zinc (mg/kg)} = \frac{\text{Device readings} \times V}{\text{Ws}}$$

Where “V” is the volume and W_s is the weight of soil sample

2.4. Plant Zinc Concentrations in leaves and grains

Wet digestion was carried out to determine the zinc concentration in plants’ leaves and grains as per [11] (Rashid and Ryan, 2004).

$$\text{Zn (\%)} = \frac{\text{Instrumental reading} \times \text{volume made}}{\text{wegiht of sample} \times \text{Vol taken} \times 10000}$$

2.5. Plant Zinc Uptake

Zinc uptake in the plants was determined using the following equation

$$Zinc\ Uptake = \frac{Amount\ of\ Zn\ in\ plant\ \times Dry\ mass}{1000}$$

2.6. Nutrient Use Efficiency (NUE):

Nutrients use efficiency refers to the measure of how efficiently plants take up and use nutrients from the soil. It was determined by the followed equation

$$\text{NUE} = \frac{\text{Total uptake} - \text{control}}{\text{Applied fertilizer}} \times 100$$

2.7. Statistical Analysis

All the necessary statistical analysis were carried using ANOVA. For F-values, significance was kept at 5% level of probability while doing LSD test the means were compared.

3. Results and Discussions

3.1. Soil Physico-chemical Analysis

Before carrying out the experiment, soil physico-chemical analysis was carried. All the readings are listed in Table 1. The soil texture was "Silty Loam", pH (8.40), EC (0.21 (dSm^{-1}), SOM (0.67%), P (3.20 $mgkg^{-1}$), K (103 $mgkg^{-1}$), Zn (0.9 $mgkg^{-1}$).

Table 1 Physico-chemical properties of experimental site

Soil Texture	**Sand (%)**	**Silt (%)**	**Clay (%)**	**pH**	**EC ($dSm^{-1)}$**	**SOM (%)**	**TN (%)**	**P ($mgkg^{-1}$)**	**K ($mgkg^{-1}$)**	**Zn ($mgkg^{-1}$)**
Silt loam	12.51	76	11.49	8.40	0.21	0.67	0.09	3.20	103	0.9

3.2. Zinc Concentration in Leaves

All the findings of Zinc concentration in leaves are presented in Table 2. Treatments were applied in various concentrations via soil and foliar application. The findings listed in Table 2. depicts how different concentrations significantly affect the plants in plants.

In case of soil application, Zn was present in highest concentration (28.4%) compared to control (24.7%) @ 20 $kgha^{-1}$. For foliar application, highest concentration was found to be 41.9% @ 1.5 % foliar volume applied. It was found that foliar Zn application is significantly higher than soil applications [12] and [13] Ozkutlu et al. (2006) and **Ziaeian** and **Malakouti** (2001) both demonstrated that increasing zinc levels in the soil, either through direct application or spraying, can significantly enhance zinc concentrations in maize plants.

3.3. Zinc Concentration in Grains

The impact of a treatment on zinc content in grains at various soil and foliar levels is given in Table 2. The soil application of zinc resulted in the highest concentration at a rate of 20 kg per hectare, which was 44.5%. The lowest concentration was observed in the control group, which was 36%. The maximum concentration of Zn (56.5%) was seen when Zn was applied at a level of 1.5%. This was followed by a concentration of 54.1% when Zn was treated at a level of 1%. Applying a 5% level of significance, it was determined that all treatments were very significant with the use of Zn. Compared to the control group, the application of zinc to the leaves and soil led to a significantly higher concentration of zinc. Compared to soil applications, foliar Zn applications resulted in a higher concentration of Zn.

The results were compared with literature. It was found out that zinc have been found significantly in high amount if the grains were treated with zinc either directly or via soil [14] (Lungu et al., 2011).

3.4. Zinc Uptake by Plant

Table 2. presents data on the plant's absorption of Zn, demonstrating that all treatments were very significant when Zn was administered to the soil or to the crop's leaves, with a 5% level of significance. The highest zinc uptake of 426.6 g/ha was observed when 20 g/ha of zinc was applied through soil application. In contrast, the lowest uptake of 298 g/ha was observed in the control group, which did not receive any zinc. The highest uptake of Zn (568.5 g ha-1) was seen when treated at a concentration of 1.5%. This was followed by a Zn uptake of 521.7 g ha-1 when applied at a concentration of 1%. Compared to the control group, the application of Zn to the soil and leaves led to a considerably higher uptake of Zn by the maize plant. Compared to soil applications, foliar sprays of Zn resulted in greater Zn uptake. The results matched with the ones reported by [15] Fageria et al. (2008) who reported highest zinc uptake in plants treated with zinc compared to control.

3.5. Zinc Content in Surface Soil

The table 2. presents the analysis of zinc concentration in surface soil. The data acquired demonstrated significant results regarding the content of Zn in the soil during the post-harvest stage. All treatments after harvested showed a high level of of zinc in the soil soil. The "soil application" of Zn resulted in the greatest Zn concentration of 0.7 mg/kg at a rate of 10 kg ha-1, while a lower concentration of zinc (0.2 mg/kg) was recorded in the control group. The foliar application of zinc resulted in the maximum concentration of zinc observed at a level of 1.5, with a concentration of 0.8 mg kg-1. This was followed by a concentration of 0.7 mg kg-1 observed at a level of 1% zinc application. Compared to the control group, the application of Zn to the soil and leaves led to a significantly higher concentration of Zn in the top layer of soil. Compared to soil applications, foliar Zn applications led to higher Zn content in the surface soil. The presence of "root secretions" led to an elevation in zinc levels throughout post-harvest phase, leading to a limited conversion of total Zn to accessible Zn [16] (Aref, 2007).

Table 2 Impact of Various Zinc Concentration by Different Methods in leaves, Zn content in corn grains, Zn uptake by plant and Soil Zn concentration

Treatments, Zn (kg/ha)		**Zinc Conc leaves (%)**	**Zinc Conc grains (%)**	**Zinc uptake (g ha^{-1})**	**Soil Zinc Conc (mg kg^{-1})**
Control		24.7i	36.0f	298.1h	0.2
Soil treatments	5 kg	26.2h	38.7ef	354.5g	0.4
	10 kg	27.0gh	41de	380.7f	0.7
	15 kg	27.7fg	42.7d	404.6e	0.6
	20 kg	28.4f	44.5d	426.6de	0.5
Foliar treatments	0.25%	35.1d	49.1c	428.0d	0.6
	0.50%	36.9c	52.1bc	478.1c	0.7
	1%	39.1b	54.1ab	521.7b	0.7
	1.50%	41.9a	56.5a	568.5a	0.8
CV %		1.77	4.15	3.13	4.69
LSD Value		0.97	3.87	22.6	0.04

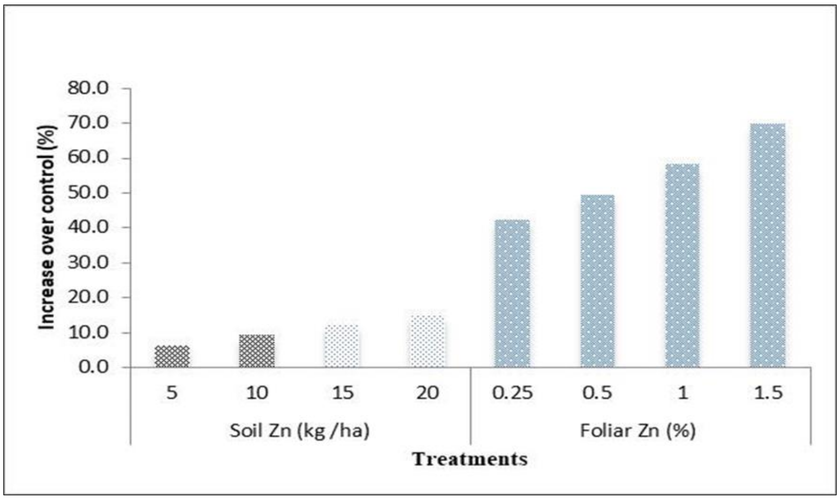

Figure 1 Percentage Increase (%) in Zinc concentrations in leaves for different treatments of maize crop

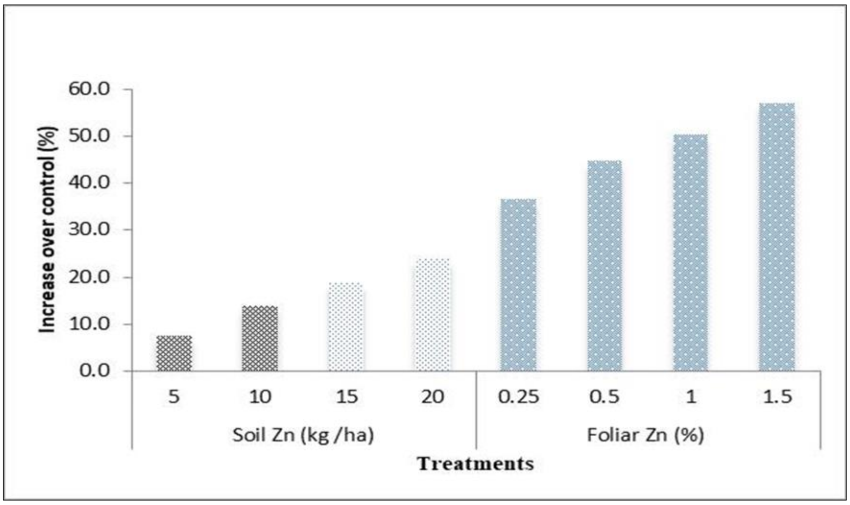

Figure 2 Percent Increase in Zn concentrations in grains over control for different treatments in maize crop

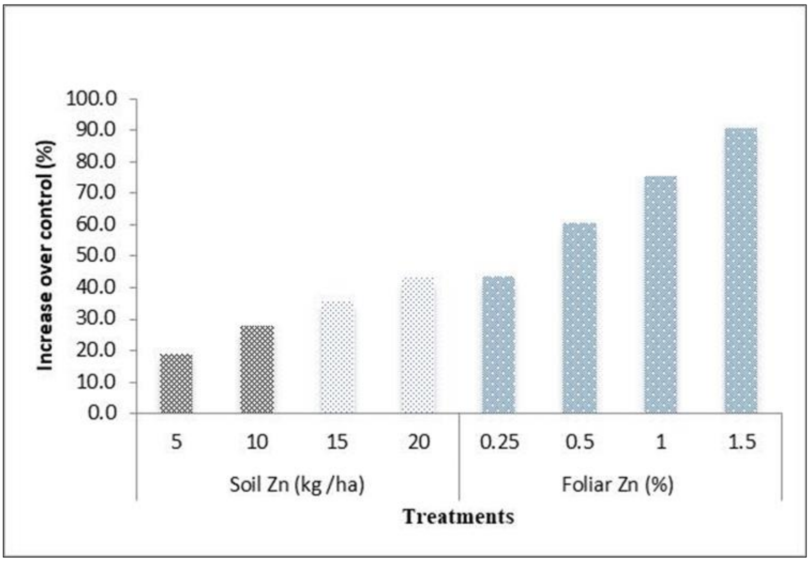

Figure 3 Percent Upsurge in Zinc Concentration for different treatments on maize crop

4. Conclusion

- Zinc uptake and zinc concentration exhibited a significant response to zinc application.
- The findings of this study reinforce the conclusion that soil application of zinc is superior to foliar application.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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