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RESPONSE OF GROWTH AND YIELD PARAMETERS OF MAIZE TO THE EXOGENOUS APPLICATION OF ZINC UNDER DIFFERENT IRRIGATION REGIMES

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Abstract

Zinc (Zn) is a vital micronutrient necessary for enhancing the growth and productivity of crops, particularly under conditions of limited water availability. This study examines the effects of externally supplied zinc on the growth and yield characteristics of maize, conducted through a field experiment at the Agriculture Research Institute's Oilseeds Section in Tandojam. The research explores how varying irrigation practices interact with zinc supplementation to influence maize growth and yield. In this study, three different irrigation schedules (2, 3, and 4 irrigations) and four levels of zinc supplementation (0, 5, 10, and 15 kg ha-1 using ZnSO4) were employed. The growth and yield metrics experienced a notable decline when there was no external application of zinc, particularly under the condition of two irrigations. The introduction of zinc through external application alleviated this stress, as indicated by a statistically significant ($P < 0.05$) interaction observed between zinc and irrigation regimes. Under four irrigation cycles, the highest values for plant height (192.66 cm), number of seeds per cob (165.0), seed weight per cob (41.25 g), seed index (239.75 g), and grain yield (2012 kg ha-1) were observed with the application of 15 kg Zn ha-1. The positive impact of zinc was evident as the seed yield increased from 1535 kg ha-1 under no zinc application and two irrigations (control) to 2012.00 kg ha-1 with the application of 15 kg Zn ha-1 and four irrigations. In summary, the external application of zinc significantly enhances the growth and yield parameters of maize across different irrigation regimes.

1. Introduction

Zinc (Zn) is a crucial micronutrient essential for numerous metabolic processes, particularly the synthesis of proteins and carbohydrates (Sahito *et al*., 2014; Yadavi *et al*., 2014). Zinc deficiency causes damage to plant cells, primarily impacting the cell membrane, as noted by (Candan*et al*., 2018). The external administration of zinc substantially enhances the growth and productivity of diverse crops under both optimal conditions and situations of water scarcity, as evidenced by research from (Zafar *et al*., 2014; Zeb *et al*. 2018;Hussain *et al*.. 2020;Rehmani *et al.*, 2025; and Nazir*et al*., 2021). Zinc is crucial for regulating solute potential and the opening and closing of stomata during periods of drought stress, as demonstrated by (Moghadam *et al*., 2013) and (Monjezi *et al*., 2013) and (Rajput *et al.*, 2023). To achieve optimal growth and yield, maize necessitates an ideal provision of both macro- and micronutrients. Nevertheless, the consistent supply of these nutrients, particularly micronutrients, may be disrupted by a decrease in water availability during drought stress. Moreover, due to the limited supply of canal water enriched with micronutrients and the limited or no exogenous application of micronutrients, especially Zn, Zn deficiency has been well observed. This implies that an exogenous application of optimum doses of Zn is essential for the growth and productivity of maize.Under abiotic stress conditions like drought stress, Zn plays an important role in optimizing various metabolic activities in crop plants. The enhancement of various physiological processes like photosynthesis and chlorophyll contents has been reported in various crop plants with the exogenous application of Zn under drought or limited water supply. Ultimately, the exogenous application results in enhanced growth and yield parameters like the harvest index of crops under drought stress. Based on the above discussion, Zn enhances the growth and yield parameters of various crops under drought stress. However, limited research work under field conditions has been conducted to elucidate the role of zinc in improving the growth and yield of crops. Based on this hypothesis, the present study was conducted to elucidate the effect of different application rates of Zn and irrigation regimes on the growth and yield parameters of maize grown under field conditions.

2. Materials and Methods

2.1 Soil analysis

Before sowing maize, the soil samples were collected using random composite sampling from 0–15 cm depth, removed from stones and other materials, thoroughly ground, sieved (2 mm), and stored until analyzed. The soil was analyzed regarding various physicochemical properties such as texture, pH, and electrical conductivity (US Salinity Laboratory Staff, 1954), organic matter (Moodie *et al.*, 1959), NPK, and Zn contents (Jackson, 1962; Watanabe and Olsen, 1965). The soil was clay loam in texture with a pH of 7.4 and EC of 0.80 dS m^{-1}. The soil contained organic matter = 0.88%, total nitrogen = 0.072%, Olsen P = 4.93 mg kg^{-1}, potassium = 112.18 mg kg^{-1} and DPTA-extractable Zn = 0.65 mg kg^{-1}.

2.2 Field Experiment

A field experiment was carried out at the Oil Seed Section, ARI Tandojam, Sindh, Pakistan, to find out the effect of Zn under different irrigation regimes on maize growth and productivity during 2021. Zinc was applied at 0, 5, 10, and 15 kg Zn ha^{-1} using $ZnSO_4$ under 2, 3, and 4 irrigations. The net plot size was 5m x 3m = 15 m2,and the three replicates of each treatment were arranged in a randomized complete block design. Two dry plowings, followed by laser leveling of the field, were performed for land preparation. After that, the land was soaked with irrigation water. When proper moisture conditions were achieved, the land was plowed again two times with a crosswise cultivator, followed by planking to achieve a fine seedbed. In the case of fertilizers, NPK was applied using urea, single superphosphate, and muriate of potash at the recommended rates (120–60 kg ha^{-1}), respectively. A single coulter hand drill was used to sow maize (var. Akbar) seeds at a rate of 30 kg ha^{-1}. During the early growth stages, the plant-to-plant (25 cm) and row-to-row distance (75 cm) distances were maintained via thinning. At the time of sowing, the whole amount of P, K, and Zn, together with half of N, was side-dressed. The remaining half of N was divided into two portions and applied, respectively, at the first and second irrigations. In all the plots, recommended agronomic practices were carried out. After maturity, samples from an area of 1 m^{2}were randomly selected, and the data regarding various growth and yield parameters were recorded using ten plants selected randomly in each treatment. The details about the measurement of each parameter are given below.

2.3 Growth and Yield Parameters

Plant height (cm) was recorded at maturity using a measuring tape from the base to the top of ten randomly selected plants from a square meter. The number of days from seeding to physiological maturity of the plants, number of seeds cob^{-1}, seed index as 1000 grains weight (g), and the weight of the grain cob^{-1} were recorded manually. The following equation was used to calculate the grains yield (kg ha^{-1}):

$$\text{Grain yield (kg ha}^{-1}) = \frac{\text{Grain yield plot}^{-1}\text{ (kg)}}{\text{Plot size (m}^2)} \times 10000$$

2.4 Statistical Analysis

Analysis of variance (ANOVA) technique was employed for the statistical analysis of collected data, using Statistix v. 8.1 (Analytical Software, USA). The difference among treatment means was calculated using the least significant design (LSD) test at α = 0.05 (Steel *et al.*, 1997).

3. Results

3.1 Growth Parameters

Table 1: Effect of different Zn levels and irrigation regimes on growth parameters (plant height and number of days to maturity) of maize

Zn levels	Irrigation regimes 2 irrigations	3 irrigations	4 irrigations	Mean
	Plant height (cm)			
0 kg ha-1 (Control)	166.00	171.00	174.00	170.33 d
05 kg ha-1	171.33	176.33	179.00	175.55 c
10 kg ha-1	173.33	181.66	187.66	180.89 b
15 kg ha-1	175.33	186.33	192.66	184.78 a
Mean	171.50 c	178.83 b	183.33 a	-
LSD α = 0.05	Zn levels (a) = 3.312	Irrigation regimes (b) = 3.439		a × b = 3.083
	Number of days to maturity			
0 kg ha-1 (Control)	101.33	104.66	105.00	103.66 ab

05 kg ha-1	102.00	105.00	105.66	104.22 a
10 kg ha-1	102.33	105.33	106.33	104.66 a
15 kg ha-1	101.66	106.00	107.00	104.88 a
Mean	101.83 b	105.25 a	106.00 a	
LSD α = 0.05	Zn levels (a) = 1.091	Irrigation regimes (b) = 1.133		a × b = 1.014

The mean values followed by the same letters either in a row or column are statistically non-significant at α = 0.05

Plant height is generally influenced by the genetic makeup of parental materials as well as by soil fertility status. As is clear from the data in Table 1, a significant interaction effect between application rates of Zn and irrigation regimes was noted regarding the plant height of the maize. In comparison to the control, the maximum plant height (184.78 cm) was recorded in the plots fertilized with Zn at a rate of 15 kg ha^{-1}. The rise in plant height with increased Zn levels was largely attributed to increased soil fertility status and the elimination of Zn deficiency from the experimental soil in particular. In the case of irrigation regimes, the plant height was remarkably highest, i.e., 183.33 cm on average, in plots given four irrigations, while the plant height was considerably reduced to 178.83 cm on average when the maize crop was irrigated three times. Moreover, the smallest plant height of 171.50 cm was recorded in plots given two irrigations. It was observed that the interaction of 15 kg Zn + 4 irrigations resulted in the highest maize plant height of 192.66 cm, while the lowest (166 cm) was under 0 kg Zn (control) + 2 irrigations. The results further showed that zinc compensated well for the maize plant height, and under irrigation deficit stress (2 irrigations), the plant height increased to 175.33 cm as compared to the 166 cm plant height under control.The maturity period may vary between varieties, but this character is mostly associated with the amount of nutrients added and irrigation. Table 1 provides the findings of the number of days to maturity of the maize influenced by various levels of Zn and the irrigation regimes. Regarding the number of days taken to maturity under different levels of Zn, irrigation regimes, and their interaction, a statistically significant effect (*P < 0.05*) was recorded. The maize field, when receiving the maximum Zn application, i.e., 15 kg ha^{-1}, took the maximum number of days to mature, while the plots that received zero Zn (control) took the minimum number of days (103.66) to maturity. This indicates that the application of Zn resulted in a minor delay in the maturity of the maize. The results further disclosed that an upsurge in the number of irrigations markedly delayed the maturity, and the maize receiving 4 and 3 irrigations showed physiological maturity averagely in 106.00 and 105.25 days, respectively, while reduced irrigation (2 irrigations) resulted in early crop maturity in 101.83 days. Treatment interaction of 15 kg Zn + 4 irrigations resulted in maturity in 107 days, while 0 kg Zn (control) + 2 irrigations resulted in maturity in 101.33 days.

3.2 Yield Parameter

Table 2: Effect of different Zn levels and irrigation regimes on yield parameters

Zn levels	**Irrigation regimes**			**Mean**
	2 irrigations	**3 irrigations**	**4 irrigations**	
		Number of seeds cob^{-1}		

0 kg ha^{-1} (Control)	133.00	144.00	147.66	141.55 b
05 kg ha^{-1}	138.33	150.00	152.00	146.77 b
10 kg ha^{-1}	141.33	152.00	157.00	150.11 ab
15 kg ha^{-1}	148.00	159.00	165.00	157.33 a
Mean	140.16 b	151.25 a	155.41 a	-
LSD α = 0.05	Zn levels (a) = 6.470	Irrigation regimes (b) = 6.717		a × b = 6.022
		Weight of seeds cob^{-1} (g)		
0 kg ha^{-1} (Control)	33.25	36.00	36.95	35.40 b
05 kg ha^{-1}	34.58	37.50	37.93	36.67 b
10 kg ha^{-1}	35.33	38.00	39.25	37.52 ab
15 kg ha^{-1}	37.16	39.75	41.25	39.39
Mean	35.08 b	37.81 a	38.84 a	-
LSD α = 0.05	Zn levels (a) = 1.616	Irrigation regimes (b) = 1.678		a × b = 1.504
		Seed index		
0 kg ha^{-1} (Control)	199.75	214.66	225.08	213.16 b
05 kg ha^{-1}	203.75	219.16	230.16	217.69 b
10 kg ha^{-1}	206.00	226.33	231.08	221.14 ab
15 kg ha^{-1}	211.00	234.25	239.75	228.33 a
Mean	205.12 c	223.60 b	231.52 a	-
LSD α = 0.05	Zn levels (a) = 5.689	Irrigation regimes (b) = 5.907		a × b = 5.296
		Grain yield (kg ha^{-1})		
0 kg ha^{-1} (Control)	1535.00	1661.33	1718.00	1638.11 b
5 kg ha^{-1}	1580.33	1753.00	1796.66	1710.00 b
10 kg ha^{-1}	1629.33	1788.33	1899.66	1772.44 ab
15 kg ha^{-1}	1723.00	1887.00	2012.00	1874.00 a
Mean	1616.92 b	1772.42 a	1856.58 a	-
LSD α = 0.05	Zn levels (a) = 85.17	Irrigation regimes (b) = 88.43		a × b = 79.28

The mean values followed by the same letters either in a row or column are statistically non-significant at α = 0.05

Seed-bearing capacity is directly proportional to the genetic makeup of the variety being used. However, the number of seed cob^{-1} is associated with the application of inputs, particularly soil nutrients and irrigation water. The maximum number of seeds cob^{-1} (157.33) was observed with the application of Zn at 15 kg ha^{-1} while the minimum (141.55) was observed in control without Zn application (Table 2). This increase under higher Zn levels was mainly associated with improved plant growth, which had a stimulatory impact. In the case of irrigation regimes, the number of seeds cob^{-1} was the highest (155.41) in plots given four irrigations, while it was reduced to 151.25 under three irrigations. However, the lowest numbers of seeds (cob-1) (140.16) were recorded in plots given two irrigations. The results further showed that the interaction of 15 kg of Zn with 4 irrigations caused the maximum number of seeds, i.e., 165 cob^{-1}. In contrast, the lowest numbers of seeds (133) cob-1 were recorded under the interaction of 0 kg Zn (control) with 2 irrigations.The weight of the seed is influenced by the quality of the seed and the amount of input applied to the crop. Seed weight cob^{-1} was the highest (39.39 g) with the application of 15 kg Zn ha-1, while that of the lowest (35.40 g cob^{-1}) was recorded in control plots without Zn application (Table 2). The increase in the weight of the seeds cob^{-1} under higher Zn levels was primarily associated with an enhanced number of seeds cob^{-1} due to better growth when Zn was applied in higher quantities. In the case of irrigation regimes, the maximum weight of the seeds cob^{-1} was 38.84 g in plots given four irrigations, and the lowest seed weight cob^{-1} (35.08 g) was recorded in plots given two irrigations. The data further suggested that the interaction of 15 kg Zn + 4 irrigations resulted from the maximum seeds weight, i.e., 41.25 g cob-1. In comparison, the lowest weight of corn seed (33.25 g) cob-1 was attained under the interface of 0 kg Zn (control) + 2 irrigations. The Zn impact on water-stressed maize plants was remarkable, and in control, 33.25 g seed weight cob^{-1} was obtained, while under the same irrigation regimes with 15 kg Zn, the weight increased to 37.16 g cob^{-1}.Seed index is considered the quality measurement trait of seed, and this character has a linear relationship with the grain yield per unit area. The statistical analysis demonstrated that seed index was positively ($P<0.01$) influenced by increasing Zn levels, irrigation regimes, and their interaction (Table 2). The Zn application at a rate of 15 kg ha^{-1} resulted in the maximum seed index (228.33 g) and the minimum (213.16 g) in control plots without Zn application. The increase in the seed index under higher Zn levels was mainly associated with healthy-growing plants, which resulted in the formation of healthy grains. In the case of irrigation regimes, the seed index was maximum (231.52 g) in plots given four irrigations and minimum (205.12 g) in plots given two irrigations. Regarding the interaction effect, the application of 15 kg Zn ha^{-1} + 4 irrigations resulted in the maximum seed index value (239.75 g). However, the application of 0 kg Zn ha^{-1} (control) + 2 irrigations resulted in the lowest seed index (205.12 g). The Zn impact on seed index under water-stressed maize plants was considerable, and in control, a seed index of 199.75 g was obtained, while under the same irrigation regimes with 15 kg of Zn, the weight increased to 211 g. Grain yield ha^{-1} is mainly composed of the number and weight of grains cob^{-1}, and these traits could be under the genetic influence of a variety or could be affected by the application of essential nutrients and water (Table 2). The grain yield ha^{-1} was significantly enhanced under different levels of Zn, irrigation regimes, and interactions between Zn levels and irrigation regimes. The maximum grain yield (1874 kg ha^{-1}) was recorded with the application of 15 kg Zn ha^{-1}. In the case of individual irrigation regimes, four irrigations resulted in the maximum grain yield (1856.58 kg ha^{-1}) and the minimum (1616.92 kg ha-1) observed in plots given two irrigations. Regarding the interaction effect between Zn levels and irrigation regimes, the maximum grain yield (2012 kg ha^{-1}) was recorded with the application of 15 kg Zn ha^{-1} + 4 irrigations compared to the control.

4. Discussion

Zinc, being an essential trace nutrient for plants, plays a crucial role in carbohydrate and protein synthesis and contributes to the metabolism of nucleic acids, lipids, and polysaccharides (Mengel *et al.,* 2001; Sahito *et al.,* 2014; and Dayo *et al*. 2025). In addition to its role in improving the quality of various crops, it also plays an important role in causing resistance against various abiotic stresses, such as drought, through various mechanisms (Zeb *et al.,* 2018; Hussain *et al.,* 2020; Nazir *et al.,* 2021). Usually, the farmers grow maize without considering the significance of micronutrients. The soils of Pakistan have become zinc-deficient, and it is essential to analyze the soil before cultivating crops. This premise is supported by the results obtained through pre-soil analysis of the experimental field, which showed that it contained 0.65 mg kg^{-1} soil DPTA-extractable Zn. As was clear from the soil analysis, the soil in the experimental field was Zn deficient, i.e., < 2.4 mg kg^{-1}. Therefore, it is necessary to add Zn through the exogenous application of Zn-containing fertilizers. It has been well known that drought stress significantly decreases the productivity of cereals, including corn, via decreasing growth and yield parameters. In the present study, a decrease in growth and yield parameters was observed with a smaller number of irrigations. However, this effect was alleviated via the application of Zn and resulted in improved growth and yield parameters of maize, as observed in the present study. The increase in growth parameters might be due to its role in enhancing chlorophyll contents through photosynthesis, ultimately resulting in enhanced growth and biomass. Various researchers around the world have confirmed the increase in growth parameters of red cabbage, tomato, sunflower, winter wheat, and tea (Hajiboland and Amirazad, 2010; Eslami and Dehghanzadeh, 2014; Sadoogh *et al.*, 2014). In the absence of Zn application and reduced irrigations, minimum plant height was recorded, which might be due to the deleterious effect of drought stress on various metabolic activities in crop pants. There was a linear relationship between the growth parameters, Zn levels, and irrigation regimes. This demonstrates that both factors exert a stimulating effect on the growth parameters of maize. The results of the current study indicate a positive impact of zinc on the growth and yield parameters of water-stressed maize, as demonstrated by the observed values under control conditions and various zinc levels. The seed yield under control conditions without zinc supplementation and two irrigations was 1535 kg ha-1, while it significantly increased to 1723 kg ha-1 with the combined application of 15 kg ha-1 of zinc and two irrigations. This suggests that the influence of soil-applied zinc on maize was not only positive but also significant. Particularly, when 15 kg of zinc per hectare was applied alongside four irrigation cycles, the highest increase in plant height and other yield parameters was observed. The findings are consistent with those of previous researchers who noted a notable improvement in growth parameters through the external application of zinc, as observed by (Movahhedy-Dehnavy *et al*., 2009; and Wu *et al*., 2015; Likewise, Takkar *et al*., 1976) demonstrated that exogenous application of zinc could alleviate zinc deficiency. In a relevant investigation, (Dwivedi *et al*., 2002) examined the impacts of zinc on maize production and the quality of nutrient absorption, identifying an optimal zinc dosage of 7.1 kg ha-1, resulting in peak maize crop yields. In a separate study, (Subedi and Ma, 2009) and (Kaleri *et al.*,2024) noted that the grain yield responses to external application of potassium, zinc, and manganese in maize were contingent upon site-specific and/or seasonal factors. The findings from the current study suggest that maize, under conditions of water deficit, could mitigate losses in growth and yield parameters with an adequate supply of zinc.

5. Conclusions

The present research found that the Zn application significantly enhances the growth and yield attributes of maize under different irrigation regimes. In the absence of Zn supply, the growth and yield parameters were severely deteriorated under limited water supply, i.e. 2 irrigations. However, the exogenous application of Zn alleviated this stress. The application of Zn at 15 kg ha^{-1} with 4 irrigations resulted in the maximum increase in various growth and yield parameters of maize. Moreover, the role of Zn was significant as the seed yield under Zn 0 (control) with 2 irrigations was 1535 kg ha^{-1} and it was remarkably improved to 2012.00 kg ha^{-1} under 15 kg ha^{-1} Zn with 4 irrigations. In conclusion, Zn improves growth and yield parameters of maize under normal as well as limited water supply conditions.

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