



Phenology and Productivity of Maize (*Zea mays* L.) as Influenced by Different Methods of Zinc Application

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ABSTRACT

Background: Maize is the most sensitive crop to zinc deficiency and enhancement of grain yield due to zinc application was well-known in the diverse agroclimatic conditions of the globe.

Methods: A field experiment was conducted at Uttar Banga Krishi Viswavidyalaya, West Bengal, during the *Rabi* seasons of 2018 and 2019 to study the effects of different zinc application methods on maize phenology and productivity. The experiment was laid out in a randomized block design with three replications and eight treatments, including control, soil applications (@ 5 and 10 kg Zn ha⁻¹), seed priming (SP) with 2% Zn solution, SP of 1% Zn solution along with foliar applications (FA) of 0.5% Zn at tasseling and silking stage and FA of 1% Zn solely at silking and 0.5% each at tasseling and silking.

Result: Results indicated that zinc application significantly advanced tassel initiation and silking, particularly with a soil application of 10 kg Zn ha⁻¹. On average, the maize variety Kaveri-2018 took 5 to 6 days to transition from tasseling to silking. Maize matured earlier with zinc treatments, especially with soil-applied zinc (10 kg ha⁻¹), took 111 and 116 days in 2018 and 2019 respectively as compared to control treatment, which took 115 and 119 days to mature in 2018 and 2019 respectively. Grain yield was highest with soil-applied zinc @10 kg ha⁻¹ (10.03 and 11.25 t ha⁻¹ in 2018 and 2019, respectively), followed by 5 kg Zn ha⁻¹ and seed priming with a 2% zinc solution. Foliar applications of 0.5% Zn both at tasseling and silking stages and 1% Zn at silking stage increased yield by 15.45% and 13.62%, respectively, over the control. Among the growth stages, uptake of nitrogen (221.37 kg ha⁻¹), phosphorus (6.91 kg ha⁻¹) and potassium (84.90 kg ha⁻¹) was found highest at silking stage with the soil application of zinc @5-10 kg ha⁻¹.

Key words: Maize, Priming, Silking, Tasseling, Zinc.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop in the agricultural economy after wheat and rice, in the world as well as in India. Maize area is increasing day by day in the Northern part of West Bengal. Aziz *et al.* (2021) reported that application of nitrogen @ 40 kg ha⁻¹ in three equal splits of nitrogen helped in production of more than 10 t/ha of grain in the *terai* climatic zone of West Bengal. Ideal sowing time for maximum yield of maize during *rabi* season under North Bengal condition is 15th November as reported by Patra *et al.* (2022). Maize is recognized as the "golden food" because of its higher potentiality of grain yield and higher nutritional value. Several million people, particularly in developing countries, derive their protein and calorie requirements from maize (Prasanna *et al.*, 2001). Maize is considered as leading cereals in the world as far as its production per unit area is concerned (FAO, 2010). Its production is growing at double the annual rate of that of rice and thrice that of wheat (Fischer *et al.*, 2014). Maize is a flexible crop that can be grown in various agroclimatic conditions and is suitable for growing alongside legumes to improve fodder quality, Prasanna *et al.*, (2025). According to an estimation it was reported that, world human population will reach 9 billion by the year 2050, (Girgis *et al.*, 2010). In this context, increase in the grain productivity may cause decreased content of minerals in grains in the future (Zhao and Shewry, 2011). A challenge for global food and nutrition security is to feed the world population with nourishing

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food (Quasem *et al.*, 2009). Therefore, in the future, emphasis should be given on production of high-quality food with the required level of nutritive elements (Ghaly and Alkoik, 2010). The deficiency of micronutrients is directly related with food security (Meenakshi *et al.*, 2010). Among different micronutrients zinc deficiency is the most widespread nutritional disorder next to Iron, Vitamin A and Iodine and its deficiency is a major public health threat worldwide. WHO reported Zn deficiency stands at the fifth risk factor for causing diseases among children in developing countries. Based on analysis of diet composition and nutritional needs, it has been estimated that 49% of

the world's population (equivalent to three billion) are at risk of suffering from Zn deficiency. Zinc deficiency in crops directly correlates to zinc deficiency in humans, a critical issue with significant impacts on food security and health. Adding zinc to soils and crops can make a key contribution towards the global food production and nutritional value problem with significant social, health and economic benefits. Zinc plays a crucial role in chlorophyll formation, carbohydrate metabolism, auxin metabolism and maximizing the biosynthesis of carotenoids, chlorophyll and eventually helpful for the photosynthetic mechanism of the plant (Aravind and Prasad, 2003).

Nearly half of the world's cereal-growing area is affected by soil Zn deficiency (Manzeke *et al.*, 2012). Zinc deficiency is rated as the most widespread micronutrient problem in Indian soils as it is deficient in 50 per cent soils of 14 Indian states (Shukla *et al.*, 2021).

Maize is the most susceptible crop to zinc deficiency (Mattiello *et al.*, 2015). In the last decades Zn deficiency in the soil crop system has been widely reported (Fageria *et al.*, 2002). Improvement of grain yield due to zinc application was established worldwide (Harris *et al.*, 2007; Hossain *et al.*, 2008; Potarzycki and Grzebisz, 2009). With the intention to overcome Zn deficiency, several strategies like fortification, supplementation, diversification and bio-fortification are being employed. Among these strategies Zn bio-fortification of food crops is considered to be sustainable, because it is simple, relatively inexpensive and enhancement can be achieved very rapidly. Keeping the above cited facts into consideration, a field study entitled "Performance of maize (*Zea mays* L.) under different methods of zinc application" was under taken during the *Rabi* seasons of 2018 and 2019.

MATERIALS AND METHODS

This research was conducted at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India. The farm is situated at 26°19'86" N latitude and 89°23'53" E longitude at an elevation of 43 meters above mean sea level. The soil at the experimental site was sandy loam (62.51% sand, 19.74% silt and 17.39% clay) in texture and acidic in nature having pH of 5.57. The initial organic carbon 0.67%, available nitrogen 182.76 kg ha⁻¹, available phosphorus 21.56 kg ha⁻¹, available potash 172.45 kg ha⁻¹ and available zinc 0.26 ppm were recorded before initiation of experiment in 2018. The amount of rainfall received during the experimental period was 555.71 mm and 443.3 mm in the year 2018 and 2019, respectively. During the period of experimentation (January to May) average maximum and minimum temperature was 30.92°C and 9.25°C and 30.92 and 9.0°C, respectively during 2018 and 2019.

Experimental details

Maize (Hybrid: Kaveri-218) was sown during *rabi* season (January-May) with a spacing of 60 × 30 cm. The experiment was laid out in randomized block design with three

replications having 8 treatments viz. T₁: Control (no zinc); T₂: Soil application of 10 kg Zn ha⁻¹; T₃: Soil application of 5 kg Zn ha⁻¹; T₄: Seed priming with 2% Zn solution; T₅: Seed priming with 1% Zn solution + foliar application of 0.5% Zn at tasseling stage; T₆: Seed priming with 1% Zn solution + foliar application of 0.5% Zn at silking stage; T₇: Foliar application of 1% Zn at silking stage and T₈: Foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage. NPK was applied @ 140:70:70 kg ha⁻¹ in all the treatments. Full amount of phosphorus, 75% of potassium and 40% nitrogen was applied at the time of final land preparation. Remaining 60% nitrogen was applied in three equal splits at 4th leaf, 8th leaf and tasseling stage while rest of potassium was applied at tasseling stage. ZnSO₄ (24% Zn) was used for seed priming as well as for soil application, while Zn-EDTA (14%) was used for foliar application.

Crop husbandry

Crop management practices were similar during both years. Field preparation was done by tractor followed by power tiller 3-4 times. Thereafter individual plots of equal size (28 m²) were prepared and separated by bunds. The plots were leveled using a wooden plank. Seeds were treated with bavistin @ 2.5 g kg⁻¹ of seed. Maize was sown during 24th January and 15th January 2018 and 2019, respectively. Two hand weeding were done, 1st at 20 DAS and 2nd at 40 DAS and simultaneously earthing up was done. Irrigations was given after every weeding. Harvesting (19th and 14th May in 2018 and 2019, respectively) was done when the shells of cobs were dried and the kernel color turned yellow.

Data collection and analysis

Days to 50 and 100% tasseling and silking were recorded treatment wise by counting number of days taken from sowing. 10 plants from each plot were selected randomly and harvested to measure cob length, cob width, No. of grain rows cob⁻¹, number of grains cob⁻¹ and 100 grain weight for maize. At maturity all the plants from net plot area (28 m²) were harvested at physiological maturity and data on grain and stover yield for maize crop were recorded and expressed in t ha⁻¹.

Plant samples were analyzed for N, P and K contents at tasseling, silking and at harvest as per following standard analytical protocols. Plant samples from each plot were collected for the purpose of the determination of zinc content using atomic absorption spectrophotometer (AAS). Nitrogen, phosphorus, potassium and zinc uptake was assessed by multiplying stage wise content and dry matter. Statistical analysis was done using SPSS software version 20. Treatment differences were found significant based on results of F test, critical differences were calculated at 5% level of probability.

RESULTS AND DISCUSSION

Phenology of maize

Days to 50 and 100% emergence, tasseling, silking and maturity were recorded treatment wise and presented in

the Fig 1, 2 and 3. There was very little variation among treatments in terms of days to emergence, tasseling and silking. Irrespective of methods of zinc application, on an average Kaveri-218 was taken 9 to 11 days during 2018 and 11 to 13 days during 2019 to 50% germination. Pooled data clearly represented that variety took 13.50 to 15.50 days to achieve 100% germination. Days taken to 50% and 100% tasseling were varied from 68 to 70 and 72 to 74 based on pooled data. 50 and 100% tassel initiation were earlier whenever zinc was applied as basal @ 10 kg ha⁻¹. Silking stages was coming earlier in the treatment receiving soil application of zinc @ 10 kg ha⁻¹. On an average kaveri-2018 took 5 to 6 days to complete silking from tasseling. The variety mature earlier whenever zinc was applied as basal @ 10 kg ha⁻¹ and took 111.33 and 116 days in 2018 and 2019 respectively. Maturity was delayed by 1 to 3.67 days during 2018 and 2019 in control plot over other treatments.

Yield attributes and yields of maize

During both the years of experiment, among different yield attributes the longest cob (18.32 and 19.86 cm), significantly highest cob diameter (16.89 and 18.03 cm), significantly highest number of grains cob⁻¹ (519.93 and 608.03) and highest seed index value (36.70 and 37.97) were recorded

upon application of 10 kg Zn ha⁻¹ over control, closely followed by T₃ (cob length: 18.22 and 19.41 cm) (cob diameter: 16.77 and 17.98 cm), (number of grains cob⁻¹: 505.64 and 602.05), (seed index: 35.97 and 36.53 g) and T₄ (cob length-18.08 and 19.29 cm), (cob diameter-16.57 and 17.95 cm), (number of grains cob⁻¹-501.52 and 599.87), (seed index-35.57 and 36.13 g). Treatment receiving no zinc (T₁) produced statistically shortest cob (15.36 and 16.05 cm), least cob diameter (15.07 and 16.05 cm), lowest grains cob⁻¹ (434.52 and 518.77) and seed index (33.20 and 33.30 g) during both the year of experimentation, as mentioned in Table 1.

Soil application of 10 kg Zn ha⁻¹ recorded significantly higher grain yield (10.03 and 11.25 t ha⁻¹ during 2018 and 2019 respectively) over control which was followed by application of 5 kg Zn ha⁻¹ (9.81 and 11.18 t ha⁻¹) and seed priming with 2% zinc solution (9.55 and 11.02 t ha⁻¹). The lowest grain yield of 8.09 and 9.39 t ha⁻¹ recorded under control during 2018 and 2019, respectively. Among the methods of zinc application, soil application was performed best followed by seed priming, seed priming + foliar and sole foliar application. Foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage (T₈) and 1% Zn at silking stage (T₇) produced 15.45 and 13.62% higher

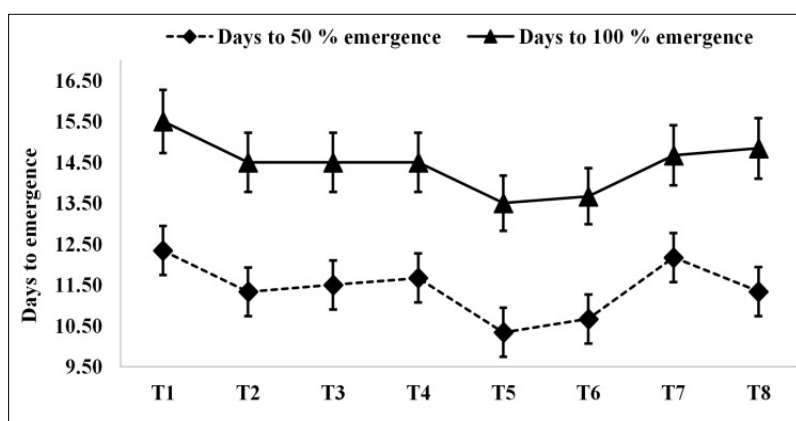


Fig 1: Days to 50 and 100% emergence as influenced by methods of zinc application.

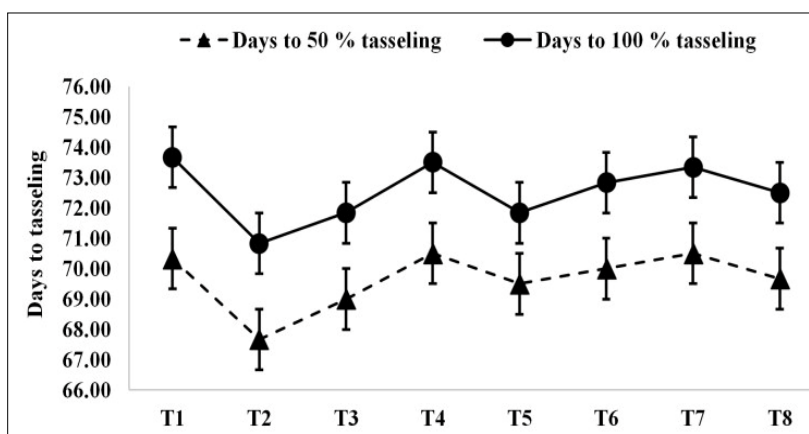


Fig 2: Days to tasselling as influenced by methods of zinc application.

yield over control. Splitting of zinc at tasseling and silking resulted in 1.61% higher yield advantage over single application at silking (Table 1).

Highest stover yield (10.42 and 11.12 t ha⁻¹) of maize was obtained in control plot (T₁) and while lowest stover yield of 9.28 and 9.25 t ha⁻¹ was observed in T₂ (soil application of 10 kg Zn ha⁻¹) during 2018 and 2019 respectively. Highest value of harvest index (52.00 and 55.03%) and shelling percentage (74.24 and 74.78) was found in T₂ (soil application of zinc 10 kg ha⁻¹) while control plot registered lowest value of harvest index and shelling percentage (43.69 and 45.79%) and (71.46 and 72.17) followed by T₃ (50.83 and 53.10) (74.03 and 73.70) and T₄ (49.96 and 52.08) (73.79 and 73.39) respectively, as mentioned in Table 1.

Nutrient uptake (kg ha⁻¹)

Application of zinc to maize results in higher uptake of nitrogen over control and it could be attributed to synergistic effect between N and zinc. Pooled data revealed that at silking, application of Zn @ 10 kg ha⁻¹ (T₂) recorded highest nitrogen uptake of 221.37 kg ha⁻¹ followed by application of

Zn @ 5 kg ha⁻¹ (214.07 kg ha⁻¹) while control plot recorded lowest values (107.91, 143.03 and 122.62 kg ha⁻¹ at tasseling, silking and harvest respectively) of nitrogen uptake.

Soil application of 5 kg zinc ha⁻¹ recorded significantly highest phosphorus uptake (4.65, 6.91 and 7.30 kg ha⁻¹ at tasseling, silking and harvest, respectively) values over control (T₁) and closely followed soil application of 10 kg zinc ha⁻¹ with the values of 4.33, 6.21 and 6.65 kg ha⁻¹ respectively at tasseling, silking and harvest.

It was clearly seen from Table 2 that potassium uptake increased continuously with the progression of growth stages and reached maximum at the silking stage thereafter, declined was noticed sharply. At silking, treatment receiving 10 kg Zn ha⁻¹ (T₂) recorded significantly highest potassium uptake (84.90 kg ha⁻¹) compared to the rest of treatments. Pooled data revealed that the control plot (no zinc) recorded significantly lowest potassium uptake (31.11, 49.54 and 46.30 kg ha⁻¹) in all the stages. Among the methods of zinc application, foliar application of 1% Zn at silking stage (T₇) recorded lowest potassium uptake values (36.58, 56.17 and 49.92 kg ha⁻¹ at tasseling, silking and harvest, stages respectively).

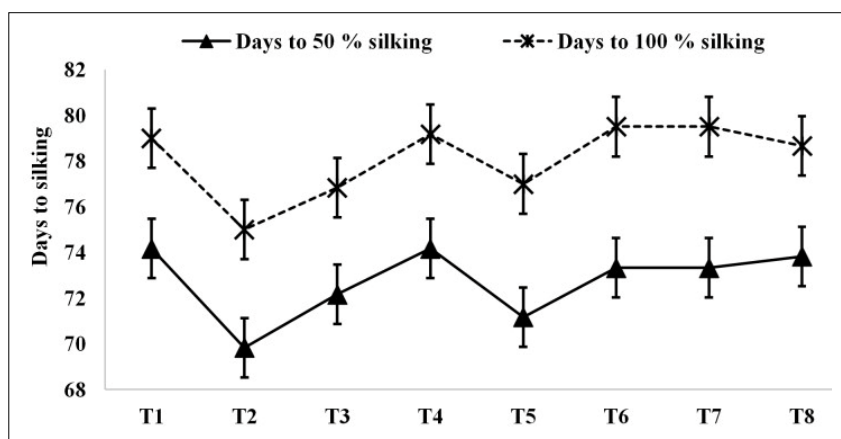


Fig 3: Days to 50 and 100% silking as influenced by methods of zinc application.

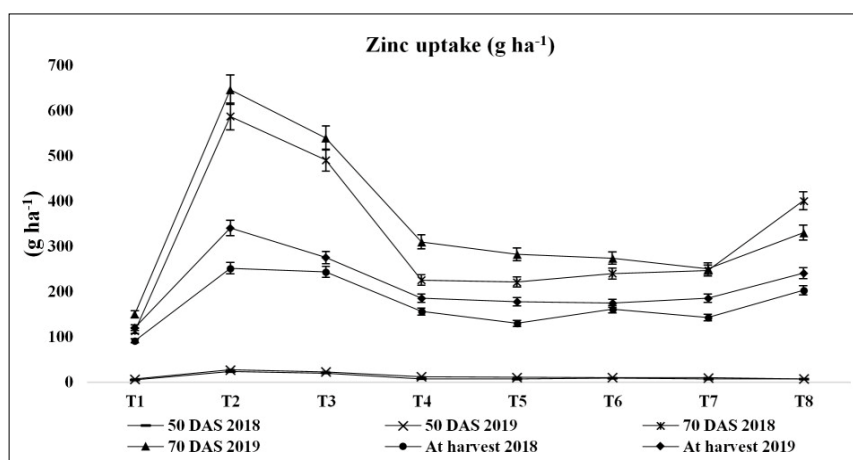


Fig 4: Zinc uptake of maize as influenced by methods of zinc application.

Table 1: Yield attributes and yields of maize as influenced by different methods of zinc application.

Treatments	Cob length (cm)		Cob diameter (cm)		No. of grains cob ⁻¹		Seed index (gm)		Grain yield (t ha ⁻¹)		Stover yield (t ha ⁻¹)		Harvest index (%)		Shelling percentage (%)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
T ₁	15.36	16.05	15.07	16.05	434.52	518.77	33.20	33.30	8.09	9.39	10.42	11.12	43.69	45.79	71.46	72.17
T ₂	18.32	19.86	16.89	18.03	519.93	608.03	36.70	37.97	10.03	11.25	9.28	9.25	52.00	55.03	74.24	74.78
T ₃	18.22	19.41	16.77	17.98	505.64	602.05	35.57	36.53	9.81	11.18	9.49	9.89	50.83	53.10	74.03	73.70
T ₄	18.08	19.29	16.57	17.95	501.52	599.87	35.97	36.13	9.55	11.02	9.58	10.15	49.96	52.08	73.79	73.39
T ₅	17.62	19.07	16.25	17.74	500.05	593.61	34.00	35.53	9.43	10.80	9.69	10.21	49.32	51.39	73.50	73.61
T ₆	17.93	19.21	16.15	17.14	500.80	595.73	34.77	35.33	9.47	11.00	10.17	10.53	48.09	50.59	72.60	73.19
T ₇	16.83	18.71	16.56	17.87	488.15	575.47	34.03	35.07	9.39	10.48	10.06	10.42	48.61	51.40	72.44	73.19
T ₈	17.29	18.87	16.15	17.14	496.93	584.27	33.63	34.30	9.41	10.76	10.36	10.86	47.54	49.14	72.42	72.85
SEM (±)	0.63	0.57	0.32	0.25	19.55	22.55	0.58	0.90	0.19	0.15	0.39	0.47	1.31	1.26	0.93	0.62
CD	1.92	1.72	0.97	0.77	59.30	68.41	1.76	2.74	0.57	0.46	NS	NS	3.98	3.82	NS	1.88

(P=0.05%)

Uptake of zinc differed among treatments due to application of zinc through different methods. Zinc uptake was increased at a rapid rate and reached its peak value at 70 days after sowing, thereafter declining towards maturity due to lower availability of zinc content irrespective of treatments and year of experimentation. Soil application of zinc was found superior over seed priming and foliar application. Application of 10 kg Zn ha⁻¹ recorded significantly highest values of zinc uptake (23.04 and 27.02, 587.35 and 646.85, 251.84 and 340.86 g ha⁻¹) at 50, 70 DAS and at harvest respectively during both the year of experimentation (Fig 4).

The positive effect of zinc application on maize phenology and yield can be attributed to the role of zinc in various physiological processes, including carbohydrate metabolism, chlorophyll formation and auxin synthesis. Soil application of zinc @10 kg ha⁻¹ was the most efficient in improving phenological stages and enhancing maize yield and nutrient uptake. The soil application method proved superior as it provided a steady supply of zinc, improving the plant's physiological efficiency, which resulted in better grain development and earlier maturity. Higher grain yield of maize with soil application of 10 kg Zn ha⁻¹ was also noticed by Ahmed *et al.* (2021). Lower yield attributes and yield in the control plot might be due to inadequate availability of nutrients, particularly nitrogen and zinc at vital growth stages of maize and also due to poor translocation of photosynthates towards grain as compared to zinc treated plots. Insufficient quantity of zinc leads to physiological anxiety in plants due to the malfunction of metabolic processes and thereby reduced yield (Ramanjineyulu *et al.*, 2018; Shahab *et al.*, 2016 and Ehsanullah *et al.*, 2015).

Seed priming and foliar applications were also beneficial but less effective than soil application. Seed priming with zinc solution helps in reducing the time by 1 to 2 days for germination as it helps in stimulating pre-germination metabolic changes thereby reducing the environmental challenges that a plant can encounter. Foliar treatments, particularly those applied at tasseling and silking stages, improved yield but did not match the sustained nutrient availability provided by soil application. The enhanced uptake of nutrients in zinc-applied plots further confirms zinc's synergistic effect on nutrient absorption, particularly nitrogen, resulting in improved plant growth and productivity. Arabhanvi and Hulihalli, (2018), Paramasivan *et al.* (2010), Wahengbam *et al.*, (2025) and Shen *et al.* (2006) concluded higher zinc uptake with the external application of zinc.

Zinc application significantly improved yield attributes and yield of maize. Enhanced cob length and diameter, number of grains per cob⁻¹, seed index and grain yield in T₂ were attributed to crucial role zinc in cell division, auxin synthesis and enzyme activation, which support reproductive development, grain filling and assimilate partitioning (Marschner, 2012). Treatments like T₃, T₅ and T₆ also showed substantial improvements, indicating the benefits of partial or stage-specific zinc supplementation, particularly when applied at tasseling and silking stages. Although stover yield differences were statistically non-significant, higher values in T₂, T₃ and

Table 2: Nitrogen, phosphorus and potassium uptake (kg ha⁻¹) by maize in different growth stages as affected by different methods of zinc application. (Pooled data of two years).

Treatments	Nitrogen uptake (kg ha ⁻¹)			Phosphorus uptake (kg ha ⁻¹)			Potassium uptake (kg ha ⁻¹)		
	Tasseling	Silking	At harvest	Tasseling	Silking	At harvest	Tasseling	Silking	At harvest
T ₁	107.91	143.03	122.62	3.17	5.15	5.59	31.11	49.54	46.30
T ₂	158.68	221.37	210.61	4.33	6.21	6.65	57.68	84.90	73.92
T ₃	141.25	214.07	189.05	4.65	6.91	7.30	51.24	74.20	70.00
T ₄	137.81	183.97	175.35	3.93	6.03	6.42	48.20	72.15	66.67
T ₅	118.89	184.84	152.35	3.84	5.93	6.31	44.92	68.53	61.23
T ₆	133.65	175.01	154.45	3.79	5.89	6.23	40.61	59.86	54.22
T ₇	128.04	148.06	152.37	3.46	5.31	6.00	36.58	56.17	49.92
T ₈	124.90	155.29	151.49	3.55	5.78	6.07	39.39	56.90	51.98
SEm.(±)	11.18	11.03	14.19	0.23	0.30	0.30	2.73	2.71	2.72
CD (P = 0.05)	33.56	31.95	41.12	0.68	0.87	0.87	7.90	7.85	7.88

T₆ reflected better vegetative growth and biomass accumulation. The highest harvest index in T₂ indicated efficient source-sink translocation, while higher shelling percentages in T₂ and T₅ pointed to improved kernel development under adequate zinc availability. Conversely, the control plot (T₁) exhibited the poorest performance across traits due to zinc deficiency, which hampers metabolic function and nutrient uptake, leading to reduced yields (Shukla *et al.*, 2021).

Zinc application not only improved yield components but also significantly enhanced the uptake of nitrogen, phosphorus and potassium, Shanmugasundaram and Savithri, (2006). This effect is attributed to the role of zinc in increasing membrane permeability, root surface area and promoting root growth, which together facilitate more efficient nutrient absorption (Zhang *et al.*, 2013). Additionally, zinc stimulates microbial activity and the expression of nutrient assimilation enzymes, further supporting macronutrient uptake (Mehdi *et al.*, 2012). Studies have shown that zinc boosts nitrogen metabolism by enhancing nitrate reductase activity and amino acid synthesis, contributing to greater dry matter accumulation and better grain development (Mona and Azab, 2015).

The role of zinc in boosting maize yields and improving nutrient efficiency was noticed earlier by Zhang *et al.* (2013), Leach and Hameleers, (2011), Mehdi *et al.* (2012), Shen *et al.* (2006) and Mona and Azab, (2015).

CONCLUSION

The study concluded that zinc application significantly influences the phenology and productivity of maize. Soil application of zinc @ 10 kg ha⁻¹ was found to be the most effective method, advancing tasseling, silking as well as maturity. This method also recorded the highest grain yield, outperforming other zinc treatments, including seed priming and foliar applications. In comparison to the control (no zinc), treatments involving zinc application consistently produced higher yields, with foliar applications at tasseling and silking stages also showing notable improvements. The application of zinc, particularly through the soil,

enhanced nutrient uptake, especially nitrogen and zinc. Thus, the study recommends soil application of zinc @ 10 kg ha⁻¹ as the most effective method to improve maize productivity and ensure timely maturity, followed by seed priming and combined foliar applications.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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