

Evaluation of zinc sources and concentrations for urea coating to increase soil fertility and productivity in spring maize (*Zea mays*)

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ABSTARCT

In order to determine the effectiveness of zinc oxide and zinc sulfate for urea coating to increase maize (*Zea mays* L.) production, an experiment was carried out in 2021 and 2022 at the ICAR-Indian Institute of Maize Research research farm in Ludhiana, Punjab. Eleven treatments, including no zinc, 0.05% zinc through ZnO, 0.12% zinc through ZnO, 0.24% zinc through ZnO, 0.47% zinc through ZnO, 0.95% zinc through ZnO, 0.26% zinc through ZnSO₄, 0.52% zinc through ZnSO₄, 1.03% zinc through ZnSO₄, 2.07% zinc through ZnSO₄, were replicated three times. Zn at 2.07% (5.68 and 6.36) and 4.15% (5.71 and 6.37) through ZnSO₄ recorded higher grain yield, followed by 0.95% of Zn (5.50 and 6.23) through ZnO and 1.03% (5.42 and 6.25) through ZnSO₄ in 2021 and 2022. With 4.15% (27.70 and 27.87 mg/kg) and 2.07% (26.33 and 27.67 mg/kg) of Zn by ZnSO₄, grain had a greater Zn content. In spring maize, Zn at 2.07% via ZnSO₄ was shown to be appropriate for urea coating to improve productivity, soil enzymatic activities, and residual soil fertility.

Keywords: urea coating, zinc oxide, zinc sulfate, zinc absorption, spring maize

With 9.2 Mha of area and a production of 27.3 Mt, maize (*Zea mays* L.) is the third most important crop in India, after wheat and rice (FAO 2023). An extra 17 million tons will be needed by 2025 because to the recent increase in demand in the poultry industry and the manufacture of bioethanol from maize (GOI 2022). Spring maize has grown significantly in Punjab and Haryana due to its high yield and low weed, insect, and disease infestation, making it a desirable crop for silage production. Appropriate agronomic production methods and sufficient micronutrient administration may improve spring maize productivity (Sepat et al. 2019). Zinc (Zn) is an essential element that maize needs in tiny amounts for optimal development (White and Broadley 2005). Zn levels in maize grains are low, especially in areas with poor zinc soils. Numerous studies have shown that applying zinc to Zn-deficient soils significantly boosts maize grain production (Prasad et al. 2013).

Zn levels in cereal grains may be as low as 5–12 mg/kg in almost 50% of cereal-growing countries (Kutman et al. 2012). Over 90% of the zinc in soil is insoluble and cannot be absorbed by plants.

ICAR: Indian Institute of Maize Research, Ludhiana, Punjab. *Corresponding author email: seemasepat12@gmail.com The range of exchangeable zinc in soil is 0.1-2 mg/kg (Cakmak 2008). For various soils and crops, the critical limits of DTPA extractable zinc range from 0.38 to 2 mg/kg (Martens and Lindsay 1990). One major barrier to meeting maize's zinc requirements is low and insufficient zinc availability in the soil. Compared to other crops, maize has a high Zn requirement (42 g Zn/mg grain), making it very vulnerable to Zn shortage (Martens and Lindsay 1990). It is important to note that zinc oxides (ZnO) and zinc sulfates (ZnSO₄·H₂O) or (ZnSO₄·7H₂O) are often used zinc fertilizers in India to repair zinc deficiencies in soil and plants. The existing technique of adding ZnSO₄·7H₂O to soil is difficult due to the low quality of fertilizers that farmers may purchase. To provide a high-quality Zn supply, Zn coated urea (ZCU) is being produced. According to many research, applying ZCU enhanced the grain yield of wheat and rice by 0.5–2%, or 1.3–5.2 kg Zn/ha. Additionally, 2% ZCU raised wheat and rice grain yields by 19.1% and 29.4%, respectively (Shivay and Prasad 2014). One of the key markers of soil quality is soil biological activity. Furthermore, soil enzyme activities show a strong responsiveness to management approaches and are used as a possible indication of fertility management and nutrient cycle processes (Sepat et al. 2015). Different effects on soil enzymatic activity may result from Zn-urea coating via ZnO and ZnSO₄. A deeper comprehension of these

The choice of suitable fertilizer management techniques with an efficient supply of zinc for urea coating may result from these interactions. In order to increase maize production, an experiment was carried out to

investigate the effectiveness of zinc oxide and zinc sulfate for urea coating.

METHODS AND MATERIALS

The experiment was carried out in 2021 and 2022 at the ICAR-Indian Institute of Maize Research research farm in Ludhiana, Punjab (30.59° N, 75.44° E, and 247 msl). The location is in the Indo Gangetic Plains agroclimatic zone, which has warm summers and chilly winters due to its subtropical and semi-arid environment. In 2021 and 2022, the average yearly maximum (43.2–44.8) and minimum (20.8–24.2) temperatures were noted. The three months of July through September accounted for around 70–80% of the average annual rainfall of 876 mm. In 2021 and 2022, the total amount of rainfall from February to June was 168 mm and 142 mm, respectively. The sandy clay loam soil had a pH of 7.7, an electrical conductivity of 0.45 dS/m, and a cation exchange capacity of 12.8 cmol/kg at a depth of 0–15 cm. It contains 0.48% soil organic carbon and 212 kg/ha, 11.5 kg/ha, 340 kg/ha, and 0.52 mg/kg of accessible N, P, K, and Zn. Eleven treatments—no zinc, 0.05% zinc through ZnO, 0.12% zinc through ZnO, 0.24% zinc through ZnO, 0.47% zinc through ZnO, 0.95% zinc through ZnO, 0.26% zinc through ZnSO₄, 0.52% zinc through ZnSO₄, 1.03% zinc through ZnSO₄, 2.07% zinc through ZnSO₄, were replicated three times. Imidachloropid 70 ws @10 g/kg of seed was applied to the seed to reduce the incidence of stem borer. On a ridge, 20 kg/ha of maize (variety DKC 9164) was seeded at a spacing of 67.5 cm (row × row) and 20 cm (plant × plant). Spring maize received a total of 12 irrigations in accordance with specifications. Spring maize received the recommended doses of 180 kg N, 60 kg P₂O₅, and 40 kg K₂O via urea, di-ammonium phosphate, and muriate of potash, respectively. While N was provided in three equal splits at sowing, 35 days after sowing (DAS), and the tasseling stage (45 DAS), P₂O₅ and K₂O were treated in whole at the time of planting. For efficient weed control, pendimethalin PE was used, followed by manual weeding at 35 DAS. Chlorantraniliprole 18.5 sc was sprayed at 15 and 25 DAS to reduce the prevalence of fall armyworms. Grain yield per plot was weighted and recorded at 12.5% moisture content. Harvesting was done by hand during the first week of June each year.

Statistical analysis and data observation: Before harvesting, ten tagged plants from each plot were used to collect data on plant height and cobs per plant. Similarly, after harvest, yield characteristics like as cob length, kernel rows/cob, kernels/row, and prolificacy were noted. Grain yield was measured in t/ha at a grain moisture level of 14%. For nutrient analysis, soil samples were collected from each plot.

Table 1 Effects of urea coating with zinc oxide and zinc sulphate on growth parameters of maize during 2021 and 2022

Treatment	Plant height at		Number of cobs/		Number		of Cob		1000-grain	
	maturity (cm)		plant		grains/ cob		weight/plant (g)		weight (g)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Absolute control	146	145	1.00	0.67	379	382	213	212	225	220
0.05% of through ZnO	Zn153	161	1.00	1.00	381	384	215	214	227	223
0.12% of through ZnO	Zn159	166	1.00	1.00	393	395	217	216	230	224
0.24% of through ZnO	Zn163	174	1.00	1.00	405	410	220	220	232	226
0.47% of through ZnO	Zn165	178	1.00	1.00	412	430	225	228	234	228
0.95% of through ZnO	Zn177	180	1.00	1.00	427	445	236	239	235	230
0.26% of through ZnSO ₄	Zn164	174	1.00	1.00	418	416	220	220	234	230
0.52% of through ZnSO ₄	Zn167	180	1.00	1.00	429	438	229	230	236	232
1.03% of through ZnSO ₄	Zn176	182	1.00	1.00	431	442	240	240	238	235
2.07% of through ZnSO ₄	Zn179	184	1.33	1.33	438	456	251	248	240	236

4.15% of Zn	182	186	1.33	1.33	440	458	253	250	242	237
through ZnSO ₄										
SEm+	3.60	4.47	0.04	0.04	3.33	3.11	2.79	2.47	2.43	2.12
LSD (P=0.05)	11.80	14.3	0.12	0.13	10.4	9.70	8.71	7.70	7.80	6.79

uptake analysis after the harvest of maize. Before biological analyzes, soil samples were held at 5°C and equilibrated at 22–25°C. The fumigation approach was used to measure soil microbial biomass C (Vance et al. 1987) and soil dehydrogenase activity (Cassida et al. 1964). SAS version 9.4 software was used to calculate the analysis of variance. The 95% confidence interval was used to get the least significant difference values for the treatment mean comparison.

OUTCOMES AND TALK

Growth and yield characteristics: During 2021–2022, ZnO and ZnSO₄ for urea coating had a substantial impact on a variety of growth metrics, including plant height at maturity, number of cobs/plant, number of grains/cob, and cob weight/plant of spring maize (Table 1). Generally speaking, maize plants varied in height from 146 to 182 cm. Plants with 4.15 and 2.07% Zn via ZnSO₄ had greater plant heights, while those without Zn had the lowest. 0.95% of ZnO and 1.03% of Zn via ZnSO₄ were found at plant height. In 2021 and 2022, Zn treatment with 0.95% Zn via ZnO, 2.07% Zn through ZnSO₄, and 4.15% Zn through ZnSO₄ considerably increased the cobs/plant in maize compared to no Zn in maize because Zn application greatly improved pollen viability during the tasseling stage (Edreira et al. 2011).

Similarly, higher Zn concentrations via ZnO or ZnSO₄ improved grains/cob and cob weight.

in contrast to having no Zn. In comparison to no Zn, greater grains/cob and cob weight/plant were seen with 1.03%, 2.07%, and 4.15% of Zn by ZnSO₄. In 2021 and 2022, the ZnO levels with the highest grains/cob and cob weight/plant were 0.95% and 0.47%, respectively. Higher test weight values were achieved by Zn at 2.07% and 4.15% via ZnSO₄, followed by Zn at 0.95% through ZnO (Table 2). Zn deficiency reduces pollen viability and causes pollen sterility, which results in reduced grain weight in maize (Imran and Rehim 2016). Therefore, low Zn concentrations in ZnO or ZnSO₄ showed reduced test weight values, but they were still better than no Zn in both years.

Yield: During 2021–2022, Zn via ZnO and ZnSO₄ had a considerable impact on grain, stover yield, and the harvest index of maize (Table 2). Grain yield was greater for Zn at 2.07% (5.68 and 6.36) and 4.15% (5.71 and 6.37) via ZnSO₄ in 2021 and 2022, followed by Zn at 0.95% (5.50 and 6.23) through ZnO and Zn at 1.03% (5.42 and 6.25) through ZnSO₄. According to Shivay and Prasad (2014), incremental Zn enrichment of urea from 0.5–2% (or 1.3–5.2 kg Zn/ha) boosted rice and wheat grain production. The administration of ZnSO₄ in spring maize showed a similar pattern in our investigation. In comparison to no Zn (5.23) in 2021 and 2022, grain yield increased by 9.2 and 8.6% with Zn application at 4.15% (equal to 5.6 kilogram Zn/ha) and 2.07% via ZnSO₄ (equivalent to 2.8 kg Zn/ha). ZnSO₄ is soluble in water, while ZnO

Table 2 Effects of urea coating with zinc oxide and zinc sulphate on yield parameters of maize during 2021 and 2022

Treatment	Grain yield		Stover yield		Harvest index		N uptake	P uptake		K uptake		
	(t/ha)		(t/ha)		(%)			(kg/ha)		(kg/ha)		
	2021	2022	2021	2022	2021	2022	Grain	Total	Grain	Total	Grain	Total
Absolute control	5.23	5.83	6.31	6.94	45.3	45.7	88.5	133.5	19.9	26.5	19.4	117.4
0.05% of Zn through ZnO	5.25	5.88	6.37	6.98	45.2	45.7	91.3	136.7	20.0	27.4	20.0	119.5
0.12% of Zn through ZnO	5.26	5.91	6.40	7.04	45.1	45.6	92.2	138.5	20.7	28.1	20.1	120.9
0.24% of Zn through ZnO	5.28	5.93	6.43	7.07	45.1	45.6	93.0	139.6	21.3	29.1	20.7	123.3
0.47% of Zn through ZnO	5.31	6.05	6.49	7.17	45.0	45.8	94.9	141.3	21.6	29.8	21.0	127.6
0.95% of Zn through ZnO	5.50	6.23	6.54	7.30	45.7	46.0	98.5	146.3	22.9	31.2	21.7	130.3

0.26% of Zn	5.30	6.02	6.38	7.13	45.4	45.8	94.5	141.1	20.9	28.4	20.4	124.4
through ZnSO ₄												
0.52% of Zn	5.38	6.12	6.41	7.19	45.6	46.0	97.2	144.8	21.9	29.3	21.3	126.7
through ZnSO ₄												
1.03% of Zn	5.42	6.25	6.61	7.37	45.1	45.9	98.6	148.2	22.8	31.1	22.2	133.3
through ZnSO ₄												
2.07% of Zn	5.68	6.36	6.87	7.40	45.3	46.2	102.9	154.3	24.1	32.6	23.5	137.6
through ZnSO ₄												
4.15% of Zn	5.71	6.37	6.80	7.44	45.6	46.1	103.9	156.6	24.8	33.3	23.6	137.5
through ZnSO ₄												
SEm ⁺	0.06	0.05	0.12	0.13	0.08	0.09	0.89	1.00	0.44	0.49	0.59	1.19
LSD (P=0.05)	0.18	0.17	0.37	0.40	0.24	0.28	2.87	3.19	1.42	1.58	1.89	3.80

performs better than ZnO for Zn enrichment of urea in spring maize because it is not water soluble (Prasad et al. 2013). In 2021 and 2022, Zn at 2.07% (6.80 and 7.40) and 4.15% (6.87 and 7.44) via ZnSO₄ recorded greater stover output, followed by Zn at 0.95% (6.54 and 7.30) through ZnO and Zn at 1.03% (6.61 and 7.37) through ZnSO₄. In comparison to no Zn (6.31 and 6.94), stover output increased by 7.77–6.63% at higher Zn concentrations of 2.07% and 4.15% via ZnSO₄. The harvest index (45.3 and 46.2) was greater for the 2.07% Zn via ZnSO₄.

Nutrient intake: During 2021–2022, urea coating with ZnO and ZnSO₄ at different concentrations had a substantial impact on the uptake of N, P, K, and Zn (Table 3). The nutrient intake in spring maize was often greatly enhanced by a progressive rise in Zn levels, either using ZnSO₄ or ZnO. No Zn showed poor N absorption in grain (88.5) and total (133.5), but ZnSO₄ (102.8 and 155) showed greater N uptake with 2.07% and 4.15%, respectively. Applying 2.07% Zn via ZnSO₄ resulted in a 4.47% increase in N in grain when compared to ZnO. Because of the negative P × Zn interaction in plant metabolism, it is well known that excessive P usage reduces Zn absorption capability (White and Broadley 2005). In this instance, P absorption in grain and total was greater with 2.07% and 4.15% Zn via ZnSO₄ than with 0.95% Zn through ZnO. With 2.07% of Zn via ZnSO₄, there was an increase of 21.2 and 25.2% in grain and total compared to no Zn (19.9 and 26.5). P absorption in maize has not been hampered by low Zn levels via ZnSO₄ for urea coating or less soluble ZnO (Imran and Rehim 2016).

In comparison to no Zn, K absorption in grain (21.1%) and total (16.7%) was shown to be greater with 2.07% and 4.15% of Zn via ZnSO₄. For the purpose of feeding humans and animals, it is crucial to biofortify maize grain to increase its zinc content (Cakmak 2008). With 4.15% of Zn by ZnSO₄, Zn absorption in the current research rose from 19.36 to 23.56 mg/kg. Compared to no Zn (19.4 in grain), an increase of 18.18% in Zn absorption was seen with 2.07% of Zn by ZnSO₄ treatment. In contrast to the progressive decline in Zn levels with ZnO and ZnSO₄, a greater Zn absorption in grain and total was discovered with 2.07% of Zn (equal to 2.8 kilogram Zn/ha) and 4.15% of Zn (equivalent to 5.6 kg Zn/ha) via ZnSO₄.

Post-soil fertility: ZnSO₄ at 4.15% for urea coating produced greater soil microbial biomass carbon (MBC) and dehydrogenase activity (DHA) than ZnSO₄ and ZnO application at 2.07% (Supplementary Table 1). Zn is crucial to the creation of DHA's structure. Since Zn is necessary for cells to produce energy, Zn

Table 3 Effects of urea coating with zinc oxide and zinc sulphate on nutrient uptake of maize during 2021 and 2022 (mean of two years)

Treatment	Zn uptake (g/ha)		Microbial biomass		Organic soil C (%)	N C	P (kg/ha)	K (kg/ha)	Zn (mg/kg)
	Grain	Total	C (mg/kg)	e activity (μg TPF/g/day)					
Absolute control	19.36	31.94	277.3	20.8	0.48	180.5	10.9	320.8	0.53
0.05% of Zn through ZnO	19.48	32.16	279.9	22.5	0.48	189.8	11.0	328.5	0.53
0.12% of Zn through ZnO	19.55	32.99	280.4	24.3	0.48	192.5	11.8	338.4	0.53

0.24% of Zn	19.62	33.79	292.6	26.8	0.49	198.7	12.0	340.5	0.53
through ZnO									
0.47% of Zn	20.45	35.47	310.2	27.2	0.49	200.8	12.5	342.5	0.54
through ZnO									
0.95% of Zn	21.70	36.92	323.7	28.4	0.49	205.3	12.9	344.5	0.54
through ZnO									
0.26% of Zn	19.81	33.32	320.4	27.9	0.48	200.5	11.5	349.5	0.53
through ZnSO ₄									
0.52% of Zn	20.70	36.34	370.3	28.5	0.49	208.8	12.9	355.4	0.54
through ZnSO ₄									
1.03% of Zn	21.59	37.67	382.8	29.6	0.51	212.5	13.2	368.5	0.55
through ZnSO ₄									
2.07% of Zn	22.88	40.00	400.2	30.1	0.52	224.5	14.8	372.2	0.56
through ZnSO ₄									
4.15% of Zn	23.56	41.36	420.8	32.8	0.52	230.2	14.2	380.2	0.57
through ZnSO ₄									
SEm+	0.35	0.66	5.72	0.78	0.05	2.66	0.67	3.09	0.002
LSD (P=0.05)	1.12	2.10	18.29	2.48	0.16	8.52	2.14	9.89	NS

ZnSO₄ increases soil DHA activity (Sepat et al. 2019). However, over the course of two years, Zn coating with urea had little effect on soil organic C, but it had a considerable impact on soil N, P, and K (Supplementary Table 1). It is important to note that exchangeable zinc varies between 0.1–2 mg/kg in soil, but more than 90% of zinc in soil is insoluble and inaccessible to plants (Kutman et al. 2012). Thus, there was no discernible increase in soil zinc (0.57 mg/kg) when zinc was applied using ZnSO₄ (up to 4.15%) or ZnO (up to 0.95%). With 4.15% of Zn via ZnSO₄, soil levels of N, P, and K remained higher. In comparison to no Zn (180.5, 10.9, and 320.8) during the two years, spring maize with high biomass production and sufficient fertilization showed increases of 27.5, 30.3, and 18.5% in N, P, and K with 2.07% of Zn via ZnSO₄.

The research demonstrates the significance of Zn coating on urea using ZnSO₄ and ZnO for increased maize crop production. ZnSO₄ outperformed ZnO for Zn coating on urea in maize, according to the results. According to the results, ZnSO₄ at 2.07% is appropriate for Zn coating on urea in order to increase maize production. To fully use the production potential of the maize crop, ZnO at 0.95% is an option to urea coating that has to be tested at greater concentrations.

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