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Assessment of zinc sources and levels for urea coating to achieve higher productivity and soil fertility in spring maize (*Zea mays*)

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ABSTARCT

An experiment was conducted during 2021 and 2022 at the research farm of ICAR-Indian Institute of Maize Research, Ludhiana, Punjab to study the efficacy of zinc oxide and zinc sulphate for urea coating to achieve higher productivity in maize (*Zea mays* L.). Experiment was laid out in a randomized block design (RBD) comprised of 11 treatments, viz. no Zn; 0.05% of Zn through ZnO; 0.12% of Zn through ZnO; 0.24% of Zn through ZnO; 0.47% of Zn through ZnO; 0.95% of Zn through ZnO; 0.26% of Zn through $ZnSO_4$; 0.52% of Zn through $ZnSO_4$; 1.03% of Zn through $ZnSO_4$; 2.07% of Zn through $ZnSO_4$; and 4.15% of Zn through $ZnSO_4$ replicated thrice. Results indicated that grains/cob and cob weight/plant recorded higher with 1.03%, 2.07% and 4.15% of Zn through $ZnSO_4$ compared to no Zn. Zn at 2.07% (5.68 and 6.36) and 4.15% (5.71 and 6.37) through $ZnSO_4$ 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) of Zn through $ZnSO_4$ in 2021 and 2022. A higher Zn content in grain was registered with 4.15% (27.70 and 27.87 mg/kg) and 2.07% (26.33 and 27.67 mg/kg) of Zn through $ZnSO_4$. Overall, Zn at 2.07% through $ZnSO_4$ was found suitable for urea coating to enhance productivity, soil enzymatic activities and residual soil fertility in spring maize.

Keywords: Spring maize, Urea coating, Zinc sulphate, Zinc oxide, Zinc uptake

In India, maize (*Zea mays* L.) is the third most important cereals after rice and wheat, having 9.2 Mha acreage with a production of 27.3 Mt (FAO 2023). The recent rise of demand in poultry sector and bioethanol production for maize has generated an additional demand of 17 million tonnes by 2025 (GOI 2022). Maize has become an attractive crop for silage production, being high yield with less infestation of weed-pest and diseases; therefore, area under spring maize has expanded considerably in Punjab and Haryana. The production of spring maize may be enhanced through appropriate agronomic production techniques and adequate application of micronutrients (Sepat *et al*. 2019). Zinc (Zn) is a necessary micronutrient required in small amount for ideal growth in maize (White and Broadley 2005). Maize grains have low Zn, particularly in regions where soils are low in Zn. Many studies have indicated that maize grain yield increases considerably with the Zn application in Zn deficient soils (Prasad *et al*. 2013).

Nearly 50% of cereal growing regions have low Zn, resulting in as little as 5–12 mg/kg Zn content in cereal grains (Kutman *et al*. 2012). More than 90% of Zn in soil occurs as insoluble Zn and remain unavailable to plant, while exchangeable Zn ranges from 0.1–2 mg/kg in soil (Cakmak 2008). The critical limits of DTPA extractable Zn vary from 0.38–2 mg/kg for different soils and crops (Martens and Lindsay 1990). Low and inadequate Zn availability in soil is a main constraint to meet Zn requirement of maize. Maize has a high Zn requirement (42 g Zn/mg grain) compared to other crops and it is therefore very sensitive to Zn deficiency (Martens and Lindsay 1990). It is worth to mention that in India, commonly used Zn fertilizers are zinc oxides (ZnO) and zinc sulfates ($ZnSO_4 \cdot H_2O$) or ($ZnSO_4 \cdot 7H_2O$) for Zn deficiency corrections in soil and plant. The current practice of applying $ZnSO_4 \cdot 7H_2O$ to soil is problematic because of the poor quality of the nutrients available in the market to the farmers. Zn coated urea (ZCU) is therefore being manufactured to guarantee a good quality Zn source. Several studies indicate that grain yield of rice and wheat increased from 0.5–2% which is 1.3–5.2 kg Zn/ha with ZCU application. Further, 2% ZCU increased the grain yield of rice by 29.4% and wheat by 19.1% (Shivay and Prasad 2014). Soil biological activities are one of the important indicators of soil quality. In addition, soil enzyme activities used as potential indicator of nutrient cycling processes and fertility management, and have high response to management practices (Sepat *et al*. 2015). Zn-urea coating through ZnO and $ZnSO_4$ may act differentially on soil enzymatic activities. A better understanding of these

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interactions may lead to the selection of appropriate fertilizer management practices with effective source of Zn for urea coating. Therefore, an experiment was conducted to study the efficacy of zinc oxide and zinc sulphate for urea coating to achieve higher productivity in maize.

MATERIALS AND METHODS

The experiment was conducted during 2021 and 2022 at the research farm of ICAR-Indian Institute of Maize Research, Ludhiana (30.59° N and 75.44° E and 247 msl), Punjab. The site falls in Indo Gangetic Plains agro-climatic zone, with subtropical and semi-arid climate, having warm summers and cold winters. The mean annual maximum (43.2–44.8) and minimum (20.8–24.2) temperatures were recorded in 2021 and 2022. The mean annual rainfall was 876 mm and approximately 70–80% occurred during 3 months (July–September). The total rainfall (February–June) received in 2021 and 2022 was 168 and 142 mm, respectively. Soil was sandy clay loam having *p*H 7.7, electrical conductivity 0.45 dS/m and cation exchange capacity 12.8 cmol/kg at 0–15 cm depth. It has soil organic carbon of 0.48%, available N, P, K and Zn of 212 kg/ha, 11.5 kg/ha, 340 kg/ha and 0.52 mg/kg. Experiment was laid out in a randomized block design (RBD) comprised of 11 treatments, viz. no Zn; 0.05% of Zn through ZnO; 0.12% of Zn through ZnO; 0.24% of Zn through ZnO; 0.47% of Zn through ZnO; 0.95% of Zn through ZnO; 0.26% of Zn through $ZnSO_4$; 0.52% of Zn through $ZnSO_4$; 1.03% of Zn through $ZnSO_4$; 2.07% of Zn through $ZnSO_4$; and 4.15% of Zn through $ZnSO_4$, replicated thrice. Seed treatment was done with imidachloropid 70 ws @10 g/kg of seed to control stem borer incidence. Maize (variety DKC 9164) was sown on ridge with distance of 67.5 cm (row × row) and 20 cm (plant × plant) with 20 kg/ha seed rate. A total 12 irrigations were applied in spring maize as per requirements. Recommended dose of 180 kg N, 60 kg P_2O_5 and 40 kg K_2O through urea, di-ammonium phosphate and muriate of potash, respectively was applied in spring maize. A full amount P_2O_5 and K_2O was applied at sowing time while N was given in three equal splits at sowing, 35 days after sowing (DAS) and tasseling stage (45 DAS). Pendimethalin PE followed by hand weeding at 35 DAS was done for effective weed control. Fall armyworm incidence was controlled by spray of chlorantraniliprole 18.5 SC at 15 and 25 DAS. In each year, harvesting was done manually in first week of June, and grain yield as per plot was weighted and reported at 12.5% moisture content.

Data observation and statistical analysis: Data pretending to plant height and cobs/plant were taken prior to harvesting from 10 tagged plants from each plot. Likewise, yield attributes, viz. cob length, kernel rows/cob, kernels/row and prolificacy were recorded after harvest. The grain yield was recorded at 14% grain moisture content and expressed as t/ha. Soil samples were taken from each plot for nutrient

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 maturity (cm)		Number of cobs/ plant		Number of grains/ cob		Cob weight/plant (g)		1000-grain 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 Zn through ZnO	153	161	1.00	1.00	381	384	215	214	227	223
0.12% of Zn through ZnO	159	166	1.00	1.00	393	395	217	216	230	224
0.24% of Zn through ZnO	163	174	1.00	1.00	405	410	220	220	232	226
0.47% of Zn through ZnO	165	178	1.00	1.00	412	430	225	228	234	228
0.95% of Zn through ZnO	177	180	1.00	1.00	427	445	236	239	235	230
0.26% of Zn through $ZnSO_4$	164	174	1.00	1.00	418	416	220	220	234	230
0.52% of Zn through $ZnSO_4$	167	180	1.00	1.00	429	438	229	230	236	232
1.03% of Zn through $ZnSO_4$	176	182	1.00	1.00	431	442	240	240	238	235
2.07% of Zn through $ZnSO_4$	179	184	1.33	1.33	438	456	251	248	240	236
4.15% of Zn through $ZnSO_4$	182	186	1.33	1.33	440	458	253	250	242	237
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 maize harvest. Soil samples were stored at 5°C, and prior to biological analyses equilibrated at 22–25°C. Soil dehydrogenase activity (Cassida *et al*. 1964) and soil microbial biomass C was determined by fumigation method (Vance *et al*. 1987). Analysis of variance was computed by using SAS version 9.4 software. For treatment mean comparison, least significant difference values were obtained at 95% confidence interval.

RESULTS AND DISCUSSION

Growth and yield attributes: ZnO and $ZnSO_4$ for urea coating significantly influenced the various growth parameters such as plant height at maturity, number of cobs/plant, number of grains/cob and cob weight/plant of spring maize during 2021–22 (Table 1). In general, plant height of maize ranged from 146–182 cm and a higher plant height was recorded with 4.15 and 2.07% of Zn through $ZnSO_4$ while no Zn had lowest plant height. Among ZnO levels, 0.95% of Zn recorded at par plant height with 1.03% of Zn through $ZnSO_4$. Zn application significantly enhanced pollen viability at the tasseling stage (Edreira *et al*. 2011), and therefore Zn application with 0.95% Zn through ZnO, 2.07% and 4.15% of Zn through $ZnSO_4$ significantly increased the cobs/plant in maize over no Zn in maize during 2021 and 2022.

Likewise, with the increased concentration of Zn through ZnO or $ZnSO_4$ enhanced grains/cob and cob weight compared to no Zn. A higher grains/cob and cob weight/plant were recorded with 1.03%, 2.07% and 4.15% of Zn through $ZnSO_4$ compared to no Zn. Among the ZnO levels, 0.95% of Zn recorded higher grains/cob and cob weight/plant followed by 0.47% of Zn in 2021 and 2022. Zn at 2.07% and 4.15% through $ZnSO_4$ recorded higher values of test weight followed by 0.95% Zn through ZnO (Table 2). Zn deficiency decreases pollen viability and led to pollen sterility and consequently low weight of grains in maize (Imran and Rehim 2016). So, low concentration of Zn either in ZnO or $ZnSO_4$ recorded lower values of test weight but remained superior over no Zn in both the years.

Yield: Zn through ZnO and $ZnSO_4$ significantly influenced grain, stover yield and harvest index of maize during 2021–22 (Table 2). Zn at 2.07% (5.68 and 6.36) and 4.15% (5.71 and 6.37) through $ZnSO_4$ 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) of Zn through $ZnSO_4$ in 2021 and 2022. Shivay and Prasad (2014) reported that grain yield of rice and wheat increased with gradual Zn enrichment of urea from 0.5–2% (equivalent to 1.3–5.2 kg Zn/ha). In this study, we also found more or less same trend with $ZnSO_4$ application in spring maize. An increase of 9.2 and 8.6% was registered in grain yield with Zn application at 4.15% (equivalent to 5.6 kg Zn/ha) and 2.07% through $ZnSO_4$ (equivalent to 2.8 kg Zn/ha) as compared to no Zn (5.23) in 2021 and 2022. $ZnSO_4$ being water soluble, 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 (t/ha)		Stover yield (t/ha)		Harvest index (%)		N uptake (kg/ha)		P uptake (kg/ha)		K uptake (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 through $ZnSO_4$	5.30	6.02	6.38	7.13	45.4	45.8	94.5	141.1	20.9	28.4	20.4	124.4
0.52% of Zn through $ZnSO_4$	5.38	6.12	6.41	7.19	45.6	46.0	97.2	144.8	21.9	29.3	21.3	126.7
1.03% of Zn through $ZnSO_4$	5.42	6.25	6.61	7.37	45.1	45.9	98.6	148.2	22.8	31.1	22.2	133.3
2.07% of Zn through $ZnSO_4$	5.68	6.36	6.87	7.40	45.3	46.2	102.9	154.3	24.1	32.6	23.5	137.6
4.15% of Zn through $ZnSO_4$	5.71	6.37	6.80	7.44	45.6	46.1	103.9	156.6	24.8	33.3	23.6	137.5
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

is not water soluble and therefore performed superior over ZnO for Zn enrichment of urea in spring maize (Prasad *et al.* 2013). Zn at 2.07% (6.80 and 7.40) and 4.15% (6.87 and 7.44) through ZnSO4 recorded higher stover yield followed by 0.95% of Zn (6.54 and 7.30) through ZnO and 1.03% (6.61 and 7.37) of Zn through ZnSO4 in 2021 and 2022. A higher concentration of Zn of 2.07% and 4.15% through $ZnSO_4$ registered an increase of stover yield by 7.77–6.63% as compared to no Zn (6.31 and 6.94). The 2.07% Zn through $ZnSO_4$ recorded higher harvest index (45.3 and 46.2).

Nutrient uptake: Urea coating with ZnO and $ZnSO_4$ at various levels significantly influenced nutrient uptake of N, P, K and Zn during 2021–22 (Table 3). In general, a gradual increase in Zn levels either with $ZnSO_4$ or ZnO significantly increased the nutrient uptake in spring maize. No Zn recorded low N uptake in grain (88.5) and total (133.5) while the higher was with 2.07% of Zn and 4.15% of Zn through $ZnSO_4$ (102.8 and 155). An increase of 4.47% of N in grain was registered with application of 2.07% Zn through $ZnSO_4$ compared to ZnO. It is well established that Zn absorption capacity is reduced by high P utilization owing to negative P × Zn interaction in plant metabolism (White and Broadley 2005). In this case, 2.07% and 4.15% Zn through $ZnSO_4$ recorded higher P uptake in grain and total compared to 0.95% of Zn through ZnO. An increase of 21.2 and 25.2% in grain and total was registered with 2.07% of Zn through $ZnSO_4$ as compared to no Zn (19.9 and 26.5). The low levels of Zn through $ZnSO_4$ for urea coating and less solubility of ZnO have not interfered with uptake of P in maize (Imran and Rehim 2016).

K uptake in grain (21.1%) and total (16.7%) was recorded higher with 2.07% and 4.15% of Zn through $ZnSO_4$ as compared to no Zn. Increasing the Zn concentration in maize grain through biofortification is important for human and livestock feeding (Cakmak 2008). In the present study, Zn uptake increased from 19.36–23.56 mg/kg with 4.15% of Zn through $ZnSO_4$. An increase of 18.18% in Zn uptake was registered with 2.07% of Zn through $ZnSO_4$ application as compared to no Zn (19.4 in grain). A higher Zn uptake in grain and total was found with 2.07% of Zn (equivalent to 2.8 kg Zn/ha) and 4.15% of Zn (equivalent to 5.6 kg Zn/ha) through $ZnSO_4$ compared to gradual decrease in Zn levels with ZnO and $ZnSO_4$.

Post-soil fertility: $ZnSO_4$ at 4.15% for urea coating gave higher soil microbial biomass carbon (MBC), dehydrogenase activity (DHA) compared to 2.07% of Zn through $ZnSO_4$ and ZnO application (Supplementary Table 1). Zn plays an important role in structure formation of DHA. Zn is required for energy production in cell, and therefore 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 C (mg C/kg)	Dehydrogenase activity (µg TPF/g/day)	Organic soil C (%)	N	P	K	Zn (mg/kg)
	Grain	Total				(kg/ha)			
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 through ZnO	19.62	33.79	292.6	26.8	0.49	198.7	12.0	340.5	0.53
0.47% of Zn through ZnO	20.45	35.47	310.2	27.2	0.49	200.8	12.5	342.5	0.54
0.95% of Zn through ZnO	21.70	36.92	323.7	28.4	0.49	205.3	12.9	344.5	0.54
0.26% of Zn through $ZnSO_4$	19.81	33.32	320.4	27.9	0.48	200.5	11.5	349.5	0.53
0.52% of Zn through $ZnSO_4$	20.70	36.34	370.3	28.5	0.49	208.8	12.9	355.4	0.54
1.03% of Zn through $ZnSO_4$	21.59	37.67	382.8	29.6	0.51	212.5	13.2	368.5	0.55
2.07% of Zn through $ZnSO_4$	22.88	40.00	400.2	30.1	0.52	224.5	14.8	372.2	0.56
4.15% of Zn through $ZnSO_4$	23.56	41.36	420.8	32.8	0.52	230.2	14.2	380.2	0.57
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

through $ZnSO_4$ increase DHA activity in soil (Sepat *et al*. 2019). On the other hand, soil organic C was not influenced with Zn coating with urea in two years while N, P and K in soil was significantly influenced with Zn coating with urea (Supplementary Table 1). It is worth to mention that more than 90% of Zn in soil occurs as insoluble Zn and it remained unavailable to plants while exchangeable Zn ranges from 0.1–2 mg/kg in soil (Kutman *et al.* 2012). Therefore, application of Zn through $ZnSO_4$ (up to 4.15%) or ZnO (up to 0.95%) had no significant increase in soil Zn (0.57 mg/kg). In soil, N, P and K were remained higher with higher levels of Zn with 4.15% of Zn through $ZnSO_4$. In spring maize, high biomass production and adequate fertilization recorded an increase of 27.5, 30.3 and 18.5% in N, P and K with 2.07% of Zn through $ZnSO_4$ as compared to no Zn (180.5, 10.9 and 320.8) over the two years.

The study shows the importance of Zn coating through $ZnSO_4$ and ZnO on urea for higher productivity in maize crop. Results showed that $ZnSO_4$ was superior over ZnO for Zn coating on urea in maize. So, based on the findings it can be recommended that $ZnSO_4$ at 2.07% is suitable for Zn coating on urea to obtain higher yield in maize. However, ZnO at 0.95% is another alternative for urea coating and need to be experimented at higher concentration to harness the full yield potential in maize crop.

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