J. Indian Soc. Coastal Agric. Res. 41(2): 120-127 (2023) https://doi.org/10.54894/JISCAR.41.2.2023.135567

Short Communication

Yield and Zn Uptake of Maize (*Zea mays* L.) as Influenced by Zn-enriched FYM, Zinc Solubilizer and Chemical Fertilizers

Received: 21.04.2023 Accepted: 09.10.2023

In the realm of plant nutrition, primary nutrients tend to receive greater focus compared to secondary and micronutrients. But these nutrients are equally important for attaining maximum yield and better quality. Zinc plays a significant role in plant metabolism like photosynthesis, cell membrane integrity, protein synthesis, pollen formation and disease resistance within plant tissues and with high yielding potential. In addition, Zn is also required to produce phytohormones such as abscisic acid, auxins, gibberellins, cytokine in plants. In the Indian context, more than 50% of the agricultural soils are deficient in zinc. About 62.42% soils of Agricultural College Farm, is deficient in Zn content (Supriya *et al.,* 2019). India is the seventh largest producer of maize in the world with a cultivable area of 9.2 million hectares and a total production of 30 mt (Directorate of Economics and Statistics, 2020-21). In India, maize is sown in an area of 6.17 lakh hectares during *rabi* season. In Andhra Pradesh, maize is grown in about 10% of the total cropped area during both *kharif* and *rabi* seasons (https://www.pjtsau.edu.in/agri-marketing-intelligence.html). In Kurnool district of Andhra Pradesh, maize is the predominant crop cultivated under irrigated conditions due to its high market demand for alcohol production and for poultry feed. Enriching FYM with zinc fertilizers, zinc solubilizing strains and applying to the soil may not only help to increase zinc concentration in grains but also to deal with the problem of malnutrition. Therefore, the current research was undertaken to investigate the impact of Zn-enriched FYM, a zinc solubilizer, and chemical fertilizers on the yield, zinc content, and zinc uptake in maize.

The field experimental was carried out at the Farm of Agricultural College, Acharya N.G. Ranga Agricultural University, Mahanandi, Andhra Pradesh, located at a geographical position of 15°30′36″ N latitude and 78°36′36″ E longitude, at an elevation of 233.48 meters above sea level during *rabi* season of 2021-22. The soil of the experimental site had a sandy loam texture, was neutral in reaction (pH 7.33), low in organic carbon content (0.48%) and available N (248 kg ha^{-1}), medium in available P (49 kg ha^{-1}), high in available K (586 kg ha^{-1}) and low in available Zn (0.54 mg kg^{-1}). The experimental design adopted was a randomized block design with eleven treatments, which were replicated thrice. The treatments involved the combined application of Zn-enriched FYM zinc solubilizer and chemical fertilizers, *viz.*, T_1: Control [Recommended dose of fertilizer (RDF) alone: $N:P_2O_5:K_2O$ @ 240:80:80 kg ha^{-1}]; T_2: FYM @ 10 t ha^{-1}; T_3: $ZnSO_4$ @ 50 kg ha^{-1}; T_4: FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}; T_5: Foliar application of 0.2% $ZnSO_4$; T_6: FYM @ 10 t ha^{-1} enriched with Zn solubilizing bacteria (ZNSB, *Bacillus coagulans*) @ 5 kg ha^{-1}; T_7: T_6 + Foliar application of 0.2% $ZnSO_4$; T_8: Soil application of ZnSB @ 5 kg ha^{-1}; T_9: Seed treatment with ZnSB @ 10 g kg^{-1} of seed; T_{10}: T_8 + foliar application of 0.2 % $ZnSO_4$; T_{11}: T_9 + foliar application of 0.2% $ZnSO_4$. The Advanta PAC-751 maize hybrid seeds were sown using the dibbling technique, with one seed per hill maintaining a spacing of 60 cm x 20 cm. The crop was managed as per the standard agronomic practices. Nitrogen, phosphorus and potassium were supplied through urea, single super phosphate (SSP) and muriate of potash (MOP). The recommended dose of fertilizer *i.e.*, 240 kg N, 80 kg P_2O_5 and 80 kg K_2O ha^{-1} was applied uniformly to all the plots (Treatments T_1-T_{11}) Entire quantity of phosphorus was applied as basal dose whereas nitrogen and potassium were applied in three equal splits (1/3rd each at the time of sowing, knee high and tasseling stages). Zinc sulphate was applied to the soil after two days of application of phosphorus fertilizers. Foliar application of 0.2% $ZnSO_4$ was given at knee high stage as per the treatments. Zinc solubilizer - *Bacillus coagulans* @ 5 kg ha^{-1} was applied 3 days before the application of fertilizers. Harvesting of the crop was done at 120 days

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post-sowing. The kernel and cob yields from each net plot were cleaned and sundried until a constant weight was recorded and grain yields were expressed in kg ha^{-1}.

The concentration of zinc in the soil was assessed according to Lindsay and Norvell (1978). For plant samples, zinc content was measured using a diacid extract (composed of HNO_3 and $HClO_4$ in a ratio of 2:1) and quantified using an atomic absorption spectrophotometer (Varian AA 240 FS) and used to calculate the uptake of zinc. The economics of production for different treatments was worked out on a per hectare basis by considering the prevailing market prices of inputs and outputs. Gross returns (₹ ha^{-1}), net return (₹ ha^{-1}) and benefit: cost ratio was worked out. The data were statistically analysed employing Fisher's method of analysis of variance, following the approach outlined by Panse and Sukhatme (1985) for the randomized block design. The statistical significance was assessed using the F value at a significance level of $p = 0.05$.

The results showed that the dry matter production increased with crop growth from the knee-high stage to harvest in all the treatments (Table 1). The rate of increase was more from tasseling to harvest than from knee-high to tasseling. All the treatments recorded higher dry matter production than control (T_1: RDF alone) at all the stages of crop growth.

Among all the treatments, T_4 (FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) recorded significantly the highest dry matter production which was on par with the treatments T_7 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2% $ZnSO_4$) and T_6 (FYM @10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) at all the stages of crop growth. Increased dry matter production in T_4, T_6 and T_7 treatments might be due to the balanced supply of macro and micronutrients through enriched FYM with $ZnSO_4$ and ZnSB which resulted in better crop growth and photosynthetic activity. This led to a better supply of photosynthates which ultimately resulted in higher dry matter production per plant. Moreover, the application of enriched FYM acts as a soil conditioner, which improves the soil aggregates and thereby enhances soil microbial activity and micronutrient contents which led to more vegetative growth resulting in higher dry matter accumulation. These findings conformed with the findings of Baradhan and Kumar (2018), Hekmat *et al.* (2019), Nandini *et al.* (2020) and Kumar and Salakinkop (2018).

Like dry matter production, the highest stover and kernel yields (Table 1) were obtained in the treatment T_4 (FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) which was on par with the treatments T_7 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2% $ZnSO_4$) and T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (Table 1).

The combined use of chemical zinc fertilizers, FYM and zinc solubilizers showed an encouraging result in improving stover and kernel yield than when applied alone. The yield attributes were also found higher in the same treatments T_4, T_6 and T_7 which resulted in higher stover yield. Integrated application of FYM with zinc sulphate and zinc solubilizers might have increased plant growth hormones and formed organic zinc chelates that promoted better growth. Organic sources, through the release of their nutrients increased nutrient use efficiency, easy translocation of photosynthates and also improved soil physico-chemical and biological properties than the application of chemical zinc fertilizers alone (Ariraman *et al.,* 2022; Augustine and Imayavaramban, 2022; Mishra *et al.,* 2019; Patil *et al.,* 2017; Solanki *et al.,* 2020).

The zinc content was high in the early stage (*i.e.,* knee-high) and gradually declined with the age of the crop and minimum was recorded at harvest. This might be due to the dilution of concentration which occurred as the dry matter accumulated. At harvest, higher zinc content was found in stover when compared to kernel (Table 2). The treatment T_1 (RDF alone) recorded the lowest values of zinc content and uptake at all the stages of crop growth. The higher zinc content and its uptake were observed in T_4, T_6 and T_7 treatments. This was due to the integrated application of enriched FYM with $ZnSO_4$, RDF and foliar spray of the trace elements like $ZnSO_4$ @ 0.2%. This combined application might have led to the formation of organic zinc chelate which plays a major role in plant metabolic processes such as protein synthesis, photosynthesis, respiration, carbohydrate metabolism, gene regulation and phytohormone production. Similar reports have been confirmed by Augustine and Imayavaramban (2022).

The uptake of zinc progressively increased from knee-high to harvest stages. The lowest zinc uptake was

Table 1. *Dry matter production and yield of maize influenced by Zn-enriched FYM, zinc solubilizer and chemical fertilizers*

Treatments	Dry matter production (t ha^{-1})			Yield (t ha^{-1})		
	Knee-high	Tasseling	Harvest	Stover yield	Cob yield with husk	Kernel yield
T_1: Control (RDF alone)	0.79	2.87	8.69	5.79	5.47	4.21
T_2: FYM @ 10 t ha^{-1}	0.93	3.85	9.38	6.33	7.12	5.47
T_3: $ZnSO_4$ @ 50 kg ha^{-1}	0.90	3.67	9.20	6.20	6.78	5.22
T_4: FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}	1.20	4.52	10.39	7.33	8.09	6.23
T_5: Foliar application of 0.2% $ZnSO_4$	0.81	2.98	8.78	6.03	5.62	4.32
T_6: FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	1.11	4.32	10.17	6.91	7.76	5.97
T_7: T_6 + foliar application of 0.2% ZnSO4	1.15	4.42	10.18	7.05	7.91	6.09
T_8: Soil application of ZnSB @ 5 kg ha^{-1}	0.86	3.17	8.92	6.21	5.99	4.61
T_9: Seed treatment with ZnSB @ 10 g kg^{-1} of seed	0.88	3.38	8.98	6.24	6.32	4.86
T_{10}: T_8 + foliar application of 0.2% $ZnSO_4$	0.91	3.42	9.09	6.22	6.47	4.98
T_{11}: T_9 + foliar application of 0.2% $ZnSO_4$	0.92	3.52	9.17	6.39	6.59	5.07
SEm±	0.04	0.16	0.39	0.26	0.34	0.24
CD (p=0.05)	0.12	0.46	1.15	0.77	1.00	0.69
CV (%)	7.3	7.4	7.2	7.1	8.7	7.8

Note: RDF of Maize *i.e.,* 240:80:80 kg N-P_2O_5-K_2O ha^{-1} through urea, SSP and MOP was applied to all the treatments

Table 2. *Zinc content and uptake of maize as influenced by Zn-enriched FYM, zinc solubilizer and chemical fertilizers application at different stages of crop growth.*

Treatments	Zinc content (mg kg^{-1})				Zinc uptake (g ha^{-1})			
	Knee-high	Tasseling	Harvest		Knee-high	Tasseling	Harvest	
			Stover	Kernel			Stover	Kernel
T_1: Control (RDF alone)	31.08	26.13	24.06	20.66	24.55	74.97	139.19	86.88
T_2: FYM @ 10 t ha^{-1}	35.08	33.12	30.13	26.05	32.69	127.41	190.83	142.47
T_3: $ZnSO_4$ @ 50 kg ha^{-1}	38.29	36.18	33.19	29.03	34.42	132.85	205.78	151.48
T_4: FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}	41.51	39.40	36.41	32.04	49.90	178.21	267.01	199.45
T_5: Foliar application of 0.2% $ZnSO_4$	33.32	29.71	26.22	22.63	26.99	88.51	158.19	97.85
T_6: FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	39.84	37.73	34.74	30.91	44.18	163.03	239.98	184.53
T_7: T_6 + foliar application of 0.2% $ZnSO_4$	40.45	38.34	35.35	31.52	46.36	169.35	249.32	191.89
T_8: Soil application of ZnSB @ 5 kg ha^{-1}	34.02	30.91	28.92	26.80	29.33	97.95	179.65	123.41
T_9: Seed treatment with ZnSB @ 10 g kg^{-1} of seed	35.79	33.10	30.01	26.03	31.32	112.01	187.22	126.51
T_{10}: T_8 + foliar application of 0.2% $ZnSO_4$	36.05	34.08	31.09	27.18	32.81	116.66	193.32	135.25
T_{11}: T_9 + foliar application of 0.2% $ZnSO_4$	36.22	34.65	31.68	27.62	33.43	122.11	202.29	140.01
SEm±	1.74	1.57	1.57	1.39	2.09	6.96	10.44	6.89
CD (p=0.05)	5.13	4.62	4.62	4.11	6.16	20.54	30.81	20.31
CV (%)	8.26	8.00	8.73	8.83	10.31	9.59	8.99	8.31

observed in T_1 (RDF alone) when compared to all other treatments. The highest Zn uptake (49.90 g ha^{-1} at knee-high and 178.21 g ha^{-1} at tasseling) was registered in the treatment T_4 (FYM @10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) which was on par with the treatments T_7 (FYM @10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2 % $ZnSO_4$) (46.36 g ha^{-1} at knee-high and 169.35 g ha^{-1} at tasseling) and T_6 (FYM @10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (44.18g ha^{-1} at knee - high and 163.03 g ha^{-1} at tasseling).

At harvest stage (stover and kernels), higher Zn uptake was registered in the treatment T_4 (FYM @10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) (267.01 g ha^{-1} in stover and 199.45 g ha^{-1} in kernels) which was on par with the treatments T_7 (FYM @10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2 % $ZnSO_4$) (249.32 g ha^{-1} in stover and 191.89 g ha^{-1} in kernels) and T_6 (FYM @10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (239.98 g ha^{-1} in stover and 184.53 g ha^{-1} in kernels).

The experimental findings revealed elevated zinc levels and uptake in the treatments T_4, T_6 and T_7. This outcome can be attributed to the synergistic approach of combining enriched farmyard manure (FYM) with zinc sulfate ($ZnSO_4$), recommended dose of fertilizer (RDF), and a foliar spray containing trace elements like $ZnSO_4$. This integrated application fosters the creation of organic zinc chelates, crucial for fundamental plant metabolic processes encompassing protein synthesis, photosynthesis, respiration, carbohydrate metabolism, gene regulation, and phytohormone production. This comprehensive strategy proves to be an efficient means of enhancing zinc concentration in both plant stover and kernels (Augustine and Imayavaramban, 2022).

Data on DTPA extractable Zn (Table 3) revealed that the maximum zinc availability was observed in the treatments T_3, T_4, T_6 and T_7 at different stages of maize. This enhanced availability can be attributed to several factors, including the application of farmyard manure enriched with both $ZnSO_4$ and ZnSB, the sole application of $ZnSO_4$, or the combination of foliar spraying with 0.2% $ZnSO_4$ along with FYM enriched with ZnSB. In contrast, the exclusive use of foliar application did not result in an increase in DTPA content. Instead, a synergistic effect was achieved when combining farmyard manure with both $ZnSO_4$ and ZnSB. This combination facilitates the transformation of insoluble zinc forms into soluble ones by promoting the release of organic acids through microbial activity. The elevated soil zinc availability observed in plots treated with enriched FYM can be attributed to several factors. Firstly, the decomposition of FYM results in the liberation of zinc and the formation of chelating agents. Additionally, they contribute to soil improvement by promoting microbial activity and modifying the chemical environment in a manner conducive to enhanced zinc uptake. Conversely, treatments that did not receive zinc through soil application exhibited lower zinc content due to the absence of zinc replenishment in those treatments. Similar results were earlier observed by Masih *et al.* (2018), Patra *et al.* (2022) and Prusty *et al.* (2022).

The highest cost of cultivation (Table 3) was incurred with T_4 (FYM @10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) (₹45,126 ha^{-1}) while T_1 (RDF alone) recorded the lowest cost of cultivation (₹35,626 ha^{-1}). The highest gross returns (₹97,042 ha^{-1}) were obtained with T_4 (FYM @10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) which was on par with the treatments T_7 (FYM @10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2% $ZnSO_4$) (₹94,847 ha^{-1}), T_6 (FYM @10 t ha^{-1} enriched with ZnSB @5 kg ha^{-1}) (₹93,004 ha^{-1}) and T_2 (FYM @10 t ha^{-1}) (₹ 85,202 ha^{-1}). The control (RDF alone) recorded significantly the lowest gross returns (₹ 65,968 ha^{-1}). Results showed that gross returns are higher in treatments with integrated application of organic manures like enriched FYM, inorganic fertilizers and foliar spraying with 0.2% $ZnSO_4$ than in control. Increased gross returns were due to high kernel and stover yield compared to other treatments. Chand *et al.* (2017), Prusty *et al.* (2022) and Rajendran and Veeramani (2022) also reported similar results. The highest net returns were obtained with T_7 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2% $ZnSO_4$) (₹53,061 ha^{-1}) which was on par with the treatments T_4 (FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @50 kg ha^{-1}) (₹51,916 ha^{-1}) and T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (₹51,378 ha^{-1}). The control (RDF alone) (T_1) recorded significantly the lowest net returns (₹30,342 ha^{-1}). These results are in conformity with those reported by Prusty *et al.* (2022), and Rajendran and Veeramani (2022).

The highest B:C ratio (2.27) was obtained with T_7

Table 3. *DTPA extractable Zn and economics as influenced by Zn-enriched FYM, zinc solubilizer and chemical fertilizers*

Treatments	DTPA extractable Zn (mg kg^{-1})			Economics			
	Knee-high	Tasseling	Harvest	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_1: Control (RDF alone)	0.92	0.77	0.55	35,626	65968	30342	1.85
T_2: FYM @ 10 t ha^{-1}	1.55	1.30	0.87	41,126	85202	44076	2.07
T_3: $ZnSO_4$ @ 50 kg ha^{-1}	1.62	1.49	0.98	39,626	81370	41744	2.05
T_4: FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}	1.76	1.54	1.15	45,126	97042	51916	2.15
T_5: Foliar application of 0.2% $ZnSO_4$	1.23	0.89	0.59	35,786	67877	32091	1.90
T_6: FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	1.65	1.48	1.07	41,626	93004	51378	2.23
T_7: T_6 + foliar application of 0.2% $ZnSO_4$	1.69	1.50	1.10	41,786	94847	53061	2.27
T_8: Soil application of ZnSB @ 5 kg ha^{-1}	1.41	1.04	1.02	36,126	72181	36055	2.00
T_9: Seed treatment with ZnSB @ 10 g kg^{-1} of seed	1.47	1.16	0.69	35,651	76019	40368	2.13
T_{10}: T_8 + foliar application of 0.2% $ZnSO_4$	1.53	1.20	0.72	36,286	77749	41463	2.14
T_{11}: T_9 + foliar application of 0.2% $ZnSO_4$	1.55	1.23	0.78	35,811	79228	43417	2.21
SEm±	0.07	0.06	0.03		4526.02	2437.00	0.09
CD (p=0.05)	0.20	0.19	0.18		13349.73	7188.06	0.26
CV (%)	8.08	8.72	8.52		9.68	9.93	7.21

(FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2% $ZnSO_4$) which was on par with the treatments T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (2.23), T_{11} (seed treatment with ZnSB @ 10 g kg^{-1} of seed+ foliar application of 0.2% $ZnSO_4$) (2.21), T_4 (FYM @10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) (2.15), T_{10} (soil application of ZnSB @ 5 kg ha^{-1} + foliar application of 0.2% $ZnSO_4$) (2.14), T_9 (seed treatment with ZnSB @10 g kg^{-1} of seed) (2.13) and T_2 (FYM @ 10 t ha^{-1}) (2.07), T_3 ($ZnSO_4$ @ 50 kg ha^{-1}) (2.05). The lowest B:C ratio (1.85) was recorded in (T_1) control (RDF alone). The result suggests that the B:C ratio as well as net returns increased with an increase in kernel and stover yield of maize. Treatments involving the integrated application of organic manures and fertilizers gained additional cost for fertilizers and FYM over control. But the kernel and stover yield was significantly higher in these treatments compensating for the extra expenses and resulting in a high benefit-cost ratio. Bandiwaddar *et al.* (2016), Prusty *et al.* (2022), Rajendran and Veeramani (2022) and Yogananda *et al.* (2019) also reported similar results.

In conclusion, the research findings underscore that individual applications of zinc sulfate and farmyard manure (FYM) do not yield noteworthy effects on maize growth and yield when contrasted with the application of zinc-enriched FYM. Hence, after careful consideration, the sole viable approach for achieving sustainable yields in the scare rainfall zone of Andhra Pradesh is through the integrated practice of applying FYM at a rate of 10 t ha^{-1} enriched with ZnSB at 5 kg ha^{-1}, along with a foliar application of 0.2% $ZnSO_4$. This ecologically and economically sound nutrient management strategy stands out as the optimal choice.

ACKNOWLEDGEMENT

The authors are thankful to Acharya NG Ranga Agricultural University for providing scholarship, facilities and financial support to carry out the work.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest

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