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Effect on Soil Properties as Influenced by the Application of FYM Enriched with Zinc Solubilizers and Zinc Sulphate in Maize (*Zea mays* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: Suboptimal dietary zinc intake is widespread in India due to low levels of plant-available zinc in soils and limited food choices. The aim of this study was to enhance the zinc concentration in soil and plant by using farmyard manure (FYM) enriched with zinc fertilizers and zinc solubilizers respectively. Additionally, the response of maize to three forms of zinc fertilizer was determined. Maize crop grown under zinc-deficient soils contain lower zinc concentration, which can cause human illness and a drastic effect on yield can be noticed. Therefore, enhancing zinc content in plants by using FYM enriched with zinc solubilizers and inorganic zinc fertilizers is the best approach to increase zinc content in soil and plants.

Methods: A field experiment was conducted to study the physico chemical properties of soil under maize (*Zea mays* L.) in response to the application of FYM enriched with ZnSB and $ZnSO_4$ on

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sandy loam soils at College Farm, Agricultural College, Mahanandi campus of Acharya N. G. Ranga Agricultural University during *rabi*, 2021-2022. The experiment was laid out in randomized block design with eleven treatments and replicated thrice.

Results: The results revealed that significantly higher and comparable values of available nitrogen (302, 299 and 281 kg ha^{-1} respectively), phosphorous (73.40, 66.53 and 58.40 kg ha^{-1} respectively) and zinc (1.76, 1.54 and 1.15 mg kg^{-1} respectively) at different growth stages of maize were registered with application of FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}. Whereas available potassium, Iron, manganese, copper, soil pH, EC (dS m^{-1}) and OC (%) were not significantly affected by the application of FYM enriched with ZnSB and $ZnSO_4$.

Keywords: Maize; FYM; Enriched; ZnSB and $ZnSO_4$.

1. INTRODUCTION

Maize (*Zea mays* L.) is a cereal grain that was first grown in Central America and belongs to the family Poaceae. It is also known as the "queen of cereals" due to its highest genetic yield potential and wider adaptability under various agro-ecological conditions. Corn is one of the most important cereal crops and is cultivated globally. It was estimated that worldwide maize production would be around 1,161.86 million metric tonnes for the year 2022-2023 (World Agricultural Production.com) [1]. Among the countries, the United States of America ranks first in maize production with 353.83 million metric tonnes, followed by China (274.00 MMT), Brazil (126.00 MMT), Argentina (55.00 MMT), the European Union (54.20 MMT), India (32.00 MMT) and Ukraine (27.00 MMT).

In India, maize is sown in an area of 22.67 lakh hectares during *rabi*. In Andhra Pradesh, maize is grown in 8.03 per cent of total cropped area during both *kharif* and *rabi* seasons (*Maize outlook, February 2023, PJTSAU*). In Kurnool district of Andhra Pradesh, maize is the predominant crop cultivated under irrigated conditions due to its highest market demand for alcohol production and for poultry feeding [2].

In plant nutrition generally more emphasis is given towards primary nutrients than secondary and micronutrients. These secondary and micronutrients are equally important for attaining maximum yield and better quality. Among the micronutrients, zinc has a major role in plant metabolism like photosynthesis, protein synthesis, pollen formation and disease resistance and yielding potential [3]. There are several studies conducted globally to enhance zinc content in plants by using FYM enriched with Zn solubilizers and inorganic zinc fertilizers. It was proved to be a good alternative than alone application of zinc fertilizers for improving the plant zinc content.

Bacillus is one of the most studied zinc solubilizing genera. It possesses strong growth promoting activities like colonizing the rhizosphere and act as biocontrol agents against pathogenic fungi and thus can be used to suppress disease [4]. When Bacillus strains are added to FYM, they solubilize unavailable zinc through production of chelating ligands, secretion of organic acids, amino acids and vitamins through oxido-reductive and proton extrusion mechanisms. In another way FYM enriched with inorganic fertilizers will reduce the leaching losses and fixation by forming organic chelates. It has become an efficient way to increase yield and quality of crops and gives quick compensation of nutrient deficiency. Applying FYM enriched with zinc solubilizing genera and zinc fertilizers to the soil helps in increasing the zinc concentration in grains and problem of malnutrition can be encountered. Therefore, keeping all these facts in view, the present investigation entitled “Effect on soil properties as influenced by the application of FYM enriched with zinc solubilizers and zinc sulphate in maize (*Zea mays* L.) was proposed to study physical and chemical properties of soil.

2. MATERIALS AND METHODS

A field trial was carried out at the Agricultural College Farm, Mahanandi campus of Acharya N. G. Ranga Agricultural University during *rabi*, 2021-2022. The experiment was laid out in randomized block design with eleven treatments and replicated thrice that consists of (T_1) Control (100 % RDF), (T_2) RDF + FYM @ 10 t ha^{-1}, (T_3) RDF + $ZnSO_4$ @ 50 kg ha^{-1}, (T_4) RDF + FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}, (T_5) RDF + Foliar application of 0.2 % $ZnSO_4$ at knee-high stage, (T_6) RDF + FYM @10 t ha^{-1} enriched with ZnSB, (T_7) RDF + FYM @10 t ha^{-1} enriched with ZnSB + foliar application of 0.2 % $ZnSO_4$ at knee-high stage, (T_8) RDF + Soil application of ZnSB @ 5 kg ha^{-1}, (T_9) RDF +

Seed treatment with ZnSB @ 10 g kg^{-1} of seed, (T_{10}) RDF + Soil application of ZnSB @ 5 kg ha^{-1} + foliar application of 0.2 % $ZnSO_4$ at knee-high stage, (T_{11}) RDF + Seed treatment with ZnSB @ 10 g kg^{-1} of seed + foliar application of 0.2 % $ZnSO_4$ at knee-high stage.

The soil of the experimental field was sandy loam in texture, with neutral in reaction (pH 7.33), (EC 0.24 ds m^{-1}) low in organic carbon (0.48 %) and available nitrogen (248 kg ha^{-1}), medium in available phosphorus (49 kg ha^{-1}), high in available potassium (586 kg ha^{-1}), low in available zinc and manganese, medium in Iron and high in available copper. The maize hybrid Advanta – PAC - 751 having duration of 100-120 days was sown with a spacing of 60 cm x 20 cm.

Nitrogen, phosphorus, potassium, and zinc were supplied through urea, single super phosphate (SSP), muriate of potash (MOP) and zinc sulphate respectively. The recommended dose of fertilizer i.e.,240 kg N, 80 kg P_2O_5, 80 kg K_2O ha^{-1} and 50 kg $ZnSO_4$ kg ha^{-1} was applied uniformly to all the plots. Entire quantity of phosphorus was applied as basal dose, whereas nitrogen was applied in three equal splits (1/3 each at the time of sowing, knee-high and tasseling stages). Zinc sulphate @ 50 kg ha^{-1} was applied to the soil after two days of application of phosphorus. 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.

Enrichment of FYM with ZnSB: FYM @ 10 t was collected from Livestock Research Station, Mahanandi and mixed with zinc solubilizing bacteria (ZnSB) @ 5 kg ha^{-1} in the nearby polyhouse. Moisture content was maintained by using wet gunny bags for a period of 30 days and applied to the soil one week prior to the sowing i.e., T_6 (FYM @10 t ha^{-1} enriched with ZnSB basal application) and T_7 (FYM @10 t ha^{-1} enriched with ZnSB basal application + foliar application of 0.2 % $ZnSO_4$) treatments.

Enrichment of FYM with $ZnSO_4$: FYM @ 10 t was mixed with zinc sulphate (heptahydrate) @ 50 kg $ZnSO_4$ ha^{-1} in the nearby polyhouse. Moisture content was maintained by using wet gunny bags for a period of 30 days and applied to the soil one week prior to sowing i.e., T_4 (FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1} basal application) treatment.

Normal FYM application: FYM @ 10 t was collected and applied to the soil 10 days prior to sowing (FYM @ 10 t ha^{-1}) i.e., T_2 (FYM @ 10 t ha^{-1}) treatment.

Seed treatment with ZnSB: Maize seeds were taken in a plastic tray and jaggery mixture was added to the seeds. The seeds were shaken gently so that the mixture spread uniformly over the seeds. The zinc solubilizing bacteria was applied to the seeds and later shade dried for 1-2 days before sowing i.e., T_9 (Seed treatment with ZnSB @ 10 grams per kg of seed) and T_{11} (T9 + foliar application of 0.2 % $ZnSO_4$ at knee-high stage) treatments.

The observations were recorded on various soil parameters such as physical chemical which include pH, EC (%) and OC (%) and chemical properties like available nitrogen, phosphorous, potassium, zinc, at different growth stages of maize crop whereas Iron, manganese, and copper at harvest stag only.

3. RESULTS AND DISCUSSION

3.1 Physico-chemical properties of soil under maize

Soil pH: The data on pH of soil was presented in the Table 1. It indicated that non-significant differences were observed between the treatments from knee high to harvest stages of maize crop.

At knee high, tasseling and harvest stages, pH values were ranged from 7.52 to 7.80, 7.40 to 7.66 and 7.26 to 7.53 respectively. Numerically maximum pH values (7.80, 7.66, 7.53) were recorded in the treatment T_1 (Recommended dose of fertilizers) and minimum pH values (7.52, 7.40,7.26) were recorded in the treatment T_4 (RDF + FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) at knee high, tasseling and harvest stages, respectively.

The decrease in pH in plots treated with FYM enriched with zinc sulphate and FYM enriched with zinc solubilizers might be due to the production of the organic acids by zinc solubilizers and FYM. Similar results were earlier observed by Masih et al. [5].

Electrical conductivity: The data presented in the Table 1, revealed that the electrical conductivity of the soil at different growth stages of maize was not significantly influenced by the application of different treatments. Maximum EC values (0.52, 0.45 and0.32 dSm^{-1}) were observed in T_3 (RDF + soil application of zinc sulphate @ 50 kg ha^{-1}) receiving soil application of zinc sulphate while minimum (0.46, 0.36 and 0.24 dS m^{-1}) was recorded with T_1 (Recommended dose of fertilizers) at knee high, tasseling and harvest stages, respectively.

EC values at harvest stage recorded the lowest values than knee high and tasseling stage. This might be due to irrigation of the field during crop growth which causes movement of salts into deeper layers. These results were corroborated with the findings of Keram et al*.* [6] and Ehsanullah et al*.* [7]. The slight increase of soil EC in zinc sulphate application alone (T_3) might be due to addition of salts and solubilization of native minerals due to slight acidity of soils.

Organic carbon: The data presented in the Table 1, revealed that non-significant differences were observed in organic carbon content of soil between the treatments at all the stages of crop growth. However, the application of FYM enriched with zinc solubilizers slightly increased the organic carbon content in the soil. The organic carbon content at knee high, tasseling and harvest stages of maize crop were ranged from 0.55 to 0.61, 0.51 to 0.56 and 0.45 to 0.51 per cent respectively. The maximum organic carbon content (0.61, 0.56 and 0.51 %) was observed in the treatment T_6 (RDF + FYM @ 10 t ha^{-1} enriched with ZnSB) at all the phenological growth stages of maize. The minimum organic carbon content (0.55, 0.51 and 0.45 % respectively) was observed in the treatment T_1 (Recommended dose of fertilizers) at all the stages of crop growth.

This might be due to the combined application of organic, biofertilizers and inorganic sources of nutrients in T_6 which led to increased humus content in the soil while T_1 doesn't contain any organic and biofertilizers sources of nutrients. The above results were earlier observed by Masih et al. [5].

3.2 Chemical Properties of Soil under Maize

Macronutrients

Available Nitrogen (kg ha^{-1}): The results showed a significant increase in the available nitrogen with the application of FYM enriched with ZnSB and $ZnSO_4$ (Table 2). A declining trend in the available nitrogen was noticed from knee high to harvest stage of maize crop. The lowest available nitrogen was recorded in control T_1 (RDF alone) at all the stages of crop growth. At knee high stage, higher available nitrogen (302.00 kg ha^{-1}) was registered in the treatment T_4 (RDF + FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}) which was on par with the treatments T_2, T_6 and T_7. At tasseling and harvest stages the treatments T_4, T_6 and T_7 significantly increased the available nitrogen content in soil when compared to other treatments.

Application of FYM enriched with ZnSB and $ZnSO_4$ showed more available nitrogen status at harvest stage when compared with initial soil. This might be due to combined application of both organic and inorganic nutrient sources. The above results are in conformity with Wailare and Kesarwani, [8] who reported that application of enriched FYM along with RDF increases overall land productivity than alone application of inorganic fertilizer and concluded that integration of organic and inorganic sources of nutrient improved total soil fertility status.

Available Phosphorus (kg ha^{-1}): Data pertaining to the available phosphorus content at knee high, tasseling and harvest stages presented in Table 2. A declining trend in the available phosphorous was observed from knee high to harvest stage. The lowest available phosphorus was recorded in T_3 when compared to all other treatments. The highest available phosphorus (73.40 kg ha^{-1} at knee high, 66.53 kg ha^{-1} at tasseling and 58.40 kg ha^{-1} at harvest) was registered in the treatment T_4 (RDF + FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) which was on par with the treatments T_7 (RDF + FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of 0.2 % $ZnSO_4$) (68.20 kg ha^{-1} at knee high, 63.20 kg ha^{-1} at tasseling and 57.30 kg ha^{-1} at harvest), T_6 (RDF + FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (67.50 kg ha^{-1} at knee high, 62.00 kg ha^{-1} at tasseling and 57.10 kg ha^{-1} at harvest) and T_2 (RDF + FYM @ 10 t ha^{-1}) (66.80 kg ha^{-1} at knee high, 62.10 kg ha^{-1} at tasseling and 55.40 kg ha^{-1} at harvest).

Application of FYM enriched with ZnSB and $ZnSO_4$ showed more available phosphorous status at harvest stage when compared with initial soil. It might be due to organic acids which were released during microbial decomposition of organic matter which helped in the solubility of

Table 1. Soil pH, electrical conductivity (($dS\ m^{-1}$) and organic carbon (%) as influenced by application of various treatments at different growth stages of maize crop

Treatments	pH			EC ($dS\ m^{-1}$)			OC (%)		
	Knee-high	**Tasseling**	**Harvest**	**Knee-high**	**Tasseling**	**Harvest**	**Knee-high**	**Tasseling**	**Harvest**
T_1 : Control (RDF alone)	7.80	7.66	7.53	0.46	0.36	0.24	0.55	0.51	0.45
T_2 : FYM @ 10 t ha^{-1}	7.70	7.50	7.30	0.47	0.37	0.25	0.59	0.54	0.49
T_3 : $ZnSO_4$ @ 50 kg ha^{-1}	7.70	7.52	7.34	0.52	0.45	0.32	0.57	0.52	0.47
T_4 : FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}	7.52	7.40	7.26	0.49	0.38	0.27	0.59	0.54	0.49
T_5 : Foliar application of 0.2 % $ZnSO_4$	7.66	7.48	7.36	0.47	0.39	0.27	0.57	0.52	0.46
T_6 : FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	7.57	7.41	7.28	0.47	0.40	0.29	0.61	0.56	0.51
T_7 : T_6 + foliar application of 0.2 % $ZnSO_4$	7.56	7.44	7.27	0.49	0.39	0.28	0.60	0.55	0.50
T_8 : Soil application of ZnSB @ 5 kg ha^{-1}	7.65	7.49	7.35	0.48	0.41	0.30	0.56	0.52	0.46
T_9 : Seed treatment with ZnSB @ 10 g kg^{-1} of seed	7.62	7.57	7.32	0.51	0.43	0.31	0.58	0.53	0.47
T_{10} : T_8 + foliar application of 0.2 % $ZnSO_4$	7.67	7.62	7.37	0.49	0.40	0.29	0.57	0.53	0.48
T_{11} : T_9 + foliar application of 0.2 % $ZnSO_4$	7.65	7.60	7.35	0.48	0.39	0.30	0.58	0.54	0.48
SEm±	0.40	0.35	0.35	0.03	0.02	0.02	0.03	0.03	0.02
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.07	8.02	8.22	9.96	9.87	10.63	10.41	8.49	8.51

Table 2. Available nitrogen, phosphorus and potassium (kg ha^{-1}) as influenced by application of various treatments at different growth stages of maize crop

Treatments	Available Nitrogen (kg ha^{-1})			Available Phosphorus (kg ha^{-1})			Available Potassium (kg ha^{-1})		
	Knee-high	Tasseling	Harvest	Knee-high	Tasseling	Harvest	Knee-high	Tasseling	Harvest
T_1: Control (RDF alone)	245.00	230.00	218.00	57.60	52.20	46.30	580.00	576.00	565.00
T_2: FYM @ 10 t ha^{-1}	276.00	262.00	250.00	66.80	62.10	55.40	600.00	593.00	586.00
T_3: $ZnSO_4$ @ 50 kg ha^{-1}	262.00	249.00	236.00	55.90	51.00	44.10	593.00	590.00	584.00
T_4: FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}	302.00	299.00	281.00	73.40	66.53	58.40	610.00	598.00	593.00
T_5: Foliar application of 0.2 % $ZnSO_4$	254.00	242.00	229.00	58.30	52.20	48.30	582.00	579.00	572.00
T_6: FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	285.00	271.00	256.00	67.50	62.00	57.10	604.00	591.00	588.00
T_7: T_6 + foliar application of 0.2 % $ZnSO_4$	290.00	278.00	264.00	68.20	63.20	57.30	607.00	596.00	592.00
T_8: Soil application of ZnSB @ 5 kg ha^{-1}	258.00	245.00	232.00	59.40	55.20	46.80	585.00	581.00	573.00
T_9: Seed treatment with ZnSB @ 10 g kg^{-1} of seed	260.00	248.00	235.00	62.10	56.30	48.50	591.00	587.00	580.00
T_{10}: T_8 + foliar application of 0.2 % $ZnSO_4$	268.00	256.00	240.00	60.30	56.10	48.10	593.00	590.00	580.00
T_{11}: T_9 + foliar application of 0.2 % $ZnSO_4$	270.00	258.00	243.00	64.10	58.50	50.90	588.00	586.00	580.00
SEm±	10.79	10.45	10.44	2.96	2.64	2.44	27.85	30.29	26.11
CD (p=0.05)	31.83	30.81	30.81	8.72	7.78	7.19	NS	NS	NS
CV (%)	7.01	7.04	7.41	8.12	7.91	8.27	8.12	8.92	7.78

native phosphates, thus increasing the available phosphorus in soil. Besides these appreciable quantities of carbon dioxide released during the decomposition of organic matter might have formed carbonic acid, which enhance the solubility of phosphates resulting in higher availability of phosphate in plots treated with organic matter. Similar results were earlier reported by Satish et al. [9].

Available potassium (kg ha^{-1}): Data pertaining to the available potassium content of the soil presented in Table 2. Non - significant differences were observed between the treatments from knee high to harvest stage of maize crop.

The maximum (610, 598 and 593 kg ha^{-1}) available potassium content at knee high, tasseling and harvest stages, respectively, was registered in the treatment T_4 (RDF + FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}) and the increase was 5.17, 3.81 and 4.95 % over T_1 (Recommended dose of fertilizers). The minimum (580.00, 576.00 and 565.00 kg ha^{-1}) available potassium content at knee high, tasseling and harvest stages, respectively was registered in the treatment T_1 (RDF alone). Initial soil status indicates that soil is high in available potassium and upon application of organic and inorganic sources during crop growth period made potassium readily available to the plants. The declining trend of available potassium among all the treatments from knee high to harvest stage of the crop might be due to utilization by plants. Similar results were earlier observed by Goutami et al. [10].

3.3 Micronutrients

DTPA extractable Zn (mg kg^{-1}): The data on available zinc is presented in the Table 3, indicated that significant differences were observed between the treatments regard to available zinc content of soil from knee - high to harvest stage of maize crop. A declining trend in the available zinc was observed from knee - high to harvest stage. The lowest available zinc was recorded in T_1 when compared to all other treatments.

At knee - high stage, higher available zinc content (1.76 mg kg^{-1}) 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 % $ZnSO_4$) (1.69 mg kg^{-1}), T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (1.65 mg kg^{-1}) and T_3 ($ZnSO_4$ @ 50 kg ha^{-1}) (1.62 mg kg^{-1}).

At tasseling stage, maximum available zinc content (1.54 mg kg^{-1}) 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 % $ZnSO_4$) (1.50 mg kg^{-1}), T_3 ($ZnSO_4$ @ 50 kg ha^{-1}) (1.49 mg kg^{-1}) and T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (1.48 mg kg^{-1}).

At harvest stage, higher available zinc content (1.15 mg kg^{-1}) was registered in the treatments 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 % $ZnSO_4$) (1.10 mg kg^{-1}), T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) (1.07 mg kg^{-1}) and T_3 ($ZnSO_4$ @ 50 kg ha^{-1}) (0.98 mg kg^{-1}).

The results of the experiment revealed that maximum zinc availability was observed in the treatments T_3, T_4, T_6 and T_7 at different stages of maize. This might be due to application of FYM enriched with $ZnSO_4$ and ZnSB, foliar spray with 0.2 % $ZnSO_4$ and alone application of $ZnSO_4$. The increase in soil available micronutrient status in plots treated with enriched FYM might be due to the decomposition of FYM leading to the release of micronutrients and formation of chelating agents. This might have prevented micronutrients from precipitation and oxidation there by no reduction was observed in micronutrient content. Treatments which did not receive zinc as soil application recorded lower micronutrient content because there was no replenishment of micronutrients in those treatments. Similar results were earlier observed by Masih et al. [5], Patra et al. [11] and Prusty et al. [12].

DTPA extractable micronutrients (mg kg^{-1}) (Fe, Mn and Cu): DTPA extractable micronutrients (Fe, Mn and Cu) after harvest of the crop were not significantly influenced by application of different treatments (Table 3). The highest content of DTPA extractable Fe, Mn and Cu (8.12, 4.01 and 1.28 mg kg^{-1} respectively) were obtained in the treatment T_4 (FYM @ 10 t ha^{-1} enriched with $ZnSO_4$ @ 50 kg ha^{-1}) while the lowest DTPA extractable Fe, Mn and Cu (7.10, 3.50 and 1.02 mg kg^{-1} respectively) was registered in T_1 (RDF alone). Similar results were observed by Goutami et al. [10].

Table 3. DTPA extractable zinc, Iron, manganese and copper (mg kg^{-1}) as influenced by application of various treatments in maize crop

Treatments	DTPA extractable Zn (mg kg^{-1})			DTPA extractable Fe (mg kg^{-1})	DTPA extractable Mn (mg kg^{-1})	DTPA extractable Cu (mg kg^{-1})
	Knee-high	Tasseling	Harvest		Harvest	
T_1 : Control (RDF alone)	0.92	0.77	0.55	7.10	3.50	1.02
T_2 : FYM @ 10 t ha^{-1}	1.55	1.30	0.87	7.88	3.80	1.22
T_3 : $ZnSO_4$ @ 50 kg ha^{-1}	1.62	1.49	0.98	7.33	3.70	1.14
T_4 : FYM @ 10 t ha^{-1}enriched with $ZnSO_4$ @ 50 kg ha^{-1}	1.76	1.54	1.15	8.12	4.01	1.28
T_5 : Foliar application of 0.2 % $ZnSO_4$	1.23	0.89	0.59	7.24	3.62	1.09
T_6 : FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	1.65	1.48	1.07	7.59	3.90	1.24
T_7 : T_6 + foliar application of 0.2 % $ZnSO_4$	1.69	1.50	1.10	7.86	3.98	1.26
T_8 : Soil application of ZnSB @ 5 kg ha^{-1}	1.41	1.04	1.02	7.39	3.71	1.16
T_9 : Seed treatment with ZnSB @ 10 g kg^{-1} of seed	1.47	1.16	0.69	7.52	3.79	1.12
T_{10} : T_8 + foliar application of 0.2 % $ZnSO_4$	1.53	1.20	0.72	7.68	3.84	1.17
T_{11} : T_9 + foliar application of 0.2 % $ZnSO_4$	1.55	1.23	0.78	7.72	3.87	1.21
SEm±	0.07	0.06	0.03	0.44	0.23	0.05
CD (p=0.05)	0.20	0.19	0.18	NS	NS	NS
CV (%)	8.08	8.72	8.52	9.94	10.34	8.02

4. CONCLUSION

Based on the above investigation, it was concluded that FYM enriched with zinc solubilizers and inorganic zinc fertilizers is the best approach to enhance organic carbon content available nitrogen, phosphorous, potassium and DTPA extractable micronutrients (Zn, Fe, Mn and Cu) in soil and also increases zinc concentration in maize plants. Hence it was the best method to adopt in Scarce Rainfall Zone of Andhra Pradesh.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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