



Effect of zinc-enriched FYM with zinc solubilisers and zinc sulphate on soil microbial population and dehydrogenase activity in maize (*Zea mays* L.)

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Abstract : A widespread deficiency of Zinc in the soil is the major problem associated with crop production in Nandyala district of Andhra Pradesh. Considering this, a field experiment was carried out at Agricultural College Farm, Mahanandi campus, during the *rabi* season of 2021-2022, to study the impact of zinc-enriched FYM with zinc solubilisers and zinc sulphate on soil microbial population and dehydrogenase activity in maize (*Zea mays* L.). FYM enriched with Zn solubilisers (*Bacillus coagulans*), zinc fertilisers were compared with $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (soil and foliar application) in maize (*Zea mays* L.) rhizosphere at various phenological growth stages (knee-high, tasselling and harvesting). The effect of different forms of farmyard manure (FYM) enriched with zinc on soil microbial population and enzymatic activity in Zn-deficient soils (with DTPA-extractable Zn levels at 0.52 mg kg⁻¹) were examined under scarce rainfall zone of Andhra Pradesh. Among all the treatments, the highest microbial population (bacteria, actinomycetes and fungi) and dehydrogenase activity were recorded in T₆ (FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹) (85.5 CFU × 10⁶ g⁻¹ soil) followed by T₁ (FYM @ 10 t ha⁻¹ enriched with ZnSO₄ @ 50 kg ha⁻¹) (84.8 CFU × 10⁶ g⁻¹ soil), T₇ (FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ + foliar application of 0.2 % ZnSO₄) and T₂ (FYM @ 10 t ha⁻¹). FYM enriched with Zn solubilisers (*Bacillus coagulans*) and zinc fertilisers enhanced soil microbes, consequently increasing the soil enzymatic activities and resulted in the release of the insoluble form of Zn to soluble form in the rhizosphere. FYM enriched with zinc solubilisers were proved to be a promising method in increasing Zn use efficiency (94.150%) and microbial biomass in corn rhizosphere.

Key words: Farm yard manure, Zinc solubilising bacteria, Diethylene Triamine Penta Acetic acid, Rhizosphere

Introduction

Maize (*Zea mays* L.) is a cereal grain that was first grown in Central America. It belongs to the family of *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. It was estimated that worldwide maize production would

be around 1,161.86 million metric tons for the year 2022-2023 (USDA 2021-22). It is one of the cosmopolitan essential crops which fulfil the demand of three important sectors as a stable food for human consumption, feed for livestock and poultry and being utilized in many commercial usages. Its grain constitutes about 9.73 % grain protein, 4.85 % grain oil, 9.43 % grain crude fibre, 71.96 % grain starch, 11.77 % embryo while

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fodder contains 22.98 % acid detergent fibre, 51.69 % neutral detergent fibre, 28.79 % fodder cellulose, 40.17 % fodder dry matter, 26.84 % fodder crude fibre, 10.35 % fodder crude protein and 9.09 % fodder moisture. (Shabaz *et al.*, 2015).

In India, the production volume of corn was 31.5 million metric tons for the years 2022-2023 (Statista.com). This was a decrease as compared to the previous year when the production of corn was 32.5 million metric tons (Statistica, 2022-23). This yield gap in maize might be due to imbalanced fertilisation, particularly phosphorus, which causes Zn deficiencies in soils. Several studies were conducted globally to enhance zinc content through microbial culture in plant rhizosphere using FYM enriched with Zn solubilisers and inorganic zinc fertilisers (Nandini *et al.*, 2020). FYM enriched with Zn solubilisers (*Bacillus coagulans*) and zinc fertilisers stimulated the soil microbial population, consequently increasing the soil enzymatic activities and resulting in the release of DTPA-extractable Zn in the maize rhizosphere (Dubey *et al.*, 2021). *Bacillus* is one of the most studied Zinc solubilising genera. It possesses strong growth-promoting activities like colonising the rhizosphere. When *Bacillus* strains are added to FYM for enrichment, they solubilise unavailable zinc through the production of chelating ligands and secretion of organic acids, amino acids, and vitamins through oxido-reductive and proton extrusion mechanisms. Furthermore, enriched FYM proved to be a promising organic fertiliser in increasing Zn use efficiency in corn rhizosphere (Nandini *et al.*, 2020). It proved to be a good alternative to the alone application of zinc fertilisers for improving the plant zinc content.

Therefore, keeping all these facts in view, the present investigation entitled was proposed to study the effect of Zn fertilizer, zinc Solubilizing Bacteria (ZnSB) alone and in combination with Farm Yard Manure (FYM) on the microbial count and dehydrogenase activity at different phenological stages of maize at College Farm, Agricultural College, Mahanandi during *rabi*, 2021.

Materials and Methods

A field trial was carried out at Agricultural College Farm, Mahanandi campus of Acharya N. G. Ranga Agricultural University during *rabi*, 2021-2022. The experiment was laid out in randomised block design with eleven treatments and replicated thrice consisting of (T1) Control (100% RDF), (T2) RDF + FYM @ 10 t ha⁻¹, (T3) RDF + ZnSO₄ @ 50 kg ha⁻¹, (T₄) RDF + FYM @ 10 t ha⁻¹ enriched with ZnSO₄ @ 50 kg ha⁻¹, (T5) RDF + Foliar application of 0.2 % ZnSO₄ at knee high stage, (T6) RDF + FYM @ 10 t ha⁻¹ enriched with ZnSB, (T7) RDF + FYM @ 10 t ha⁻¹ enriched with ZnSB + foliar application of 0.2 % ZnSO₄ at knee high stage, (T8) RDF + Soil application of ZnSB @ 5 kg ha⁻¹, (T9) RDF + Seed treatment with ZnSB @ 10 g kg⁻¹ of seed, (T10) RDF + Soil application of ZnSB @ 5 kg ha⁻¹ + foliar application of 0.2 % ZnSO₄ at knee high stage, (T11) RDF + Seed treatment with ZnSB @ 10 g kg⁻¹ of seed + foliar application of 0.2 % ZnSO₄ at knee high stage.

The soil of the experimental field was sandy loam in texture, with neutral in reaction (pH 7.3), EC of 0.24 ds m⁻¹, low in organic carbon (0.48 %) and available nitrogen (24.8 kg ha⁻¹), medium in available phosphorus (4.9 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 a 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. Recommended dose of fertiliser, *i.e.*, 240 kg N, 80 kg P₂O₅, 80 kg K₂O ha⁻¹ and 50 kg ZnSO₄ kg ha⁻¹, was applied uniformly to all the plots. The entire quantity of phosphorus was applied as a 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 phosphorus application. A foliar application of 0.2 % ZnSO₄ was given at the knee-high stage as per the treatments. Zinc solubilisers—*Bacillus coagulans* @ 5 kg ha⁻¹ were applied 3 days before the application of fertilisers.

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 a 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.*, T₆ (FYM @ 10 t ha⁻¹ enriched with ZnSB basal application) and T₇ (FYM @ 10 t ha⁻¹ enriched with ZnSB basal application + foliar application of 0.2 % ZnSO₄). (ZnSB was purchased from the Department of Microbiology, Rajendranagar, Telangana).

Enrichment of FYM with ZnSO₄

FYM @ 10 t was collected from Livestock Research Station, Mahanandi and mixed with zinc sulphate (heptahydrate) @ 50 kg ZnSO₄ ha⁻¹ in nearby polyhouse. Moisture content was maintained by using

wet gunny bags for a period of 30 days and applied to the soil one week before sowing, *i.e.*, T₄ (FYM @ 10 t ha⁻¹ enriched with ZnSO₄ @ 50 kg ha⁻¹ basal application). The chemical composition of FYM and enriched FYM is given in Table 1.

Normal FYM application

FYM @ 10 t was collected from Livestock Research Station, Mahanandi and applied to the soil 10 days prior to sowing, *i.e.*, T₂ (FYM @ 10 t ha⁻¹).

Seed treatment with ZnSB

Maize seeds (PAC-751) were placed in a plastic tray and gently shaken to coat evenly with a jaggery mixture. Zinc solubilising bacteria (ZnSB) were introduced to the seeds, and they were allowed to dry in the shade for 1-2 days before sowing. This treatment corresponded to T₉ (Seed treatment with ZnSB at a rate of 10 grams per kg of seed) and T₁₁ (T₉ plus foliar application of 0.2% ZnSO₄ at the knee-high stage).

Table 1. Characterization of FYM and enriched FYM (ZnSB & ZnSO₄)

Parameters	FYM	FYM enriched with ZnSB	FYM enriched with ZnSO ₄
	Content		
pH	6.80	6.70	6.90
Electrical conductivity (dS m ⁻¹)	1.20	1.20	1.21
Organic carbon (%)	13.5	12.2	12.8
Total Nitrogen (%)	0.68	0.63	0.65
Total Phosphorus (%)	0.31	0.27	0.28
Total Potassium (%)	0.56	0.51	0.53
Total Zinc (mg kg ⁻¹)	59.23	64.81	1056.42
Total Iron (mg kg ⁻¹)	680.20	675.08	678.93
Total Manganese (mg kg ⁻¹)	86.41	87.26	85.18
Total Copper (mg kg ⁻¹)	19.32	20.61	21.80

The observations were recorded on soil microbial properties like Bacteria (Thornton, 1922), Actinomycetes (Allen, 1959) and Fungi (Martin, 1950)

and enzyme activity like dehydrogenase activity (Casida et al. (1964) at different growth stages of maize crop.

Results and Discussion

Soil microbial population in the rhizosphere of maize Bacteria ($\text{CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$)

Data related to the bacterial population in soil at different stages of the maize crop is represented in Table 2 and depicted in Fig. 1. The bacterial population significantly decreased from the knee-high stage to the harvest stage of the maize crop. The lowest bacterial population was recorded in T_1 (RDF alone). Among all the treatments the highest bacterial population ($85.50 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at knee - high stage, $83.50 \text{ CFU} \times 10^6$

$\text{g}^{-1} \text{ soil}$ at tasseling and $79.00 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at harvest) was registered in T_6 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) which was on par with the treatments T_4 (FYM @ 10 t ha^{-1} enriched with ZnSO_4 @ 50 kg ha^{-1}) ($84.8 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at knee - high stage, $81.00 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at tasseling and $73.00 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at harvest), T_7 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar application of $0.2 \% \text{ ZnSO}_4$) ($84.00 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at knee - high stage, $81.00 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at tasseling and $76.00 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at harvest) and T_2 (FYM @ 10 t ha^{-1}) ($78.20 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at knee - high and $73.50 \text{ CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$ at tasseling).

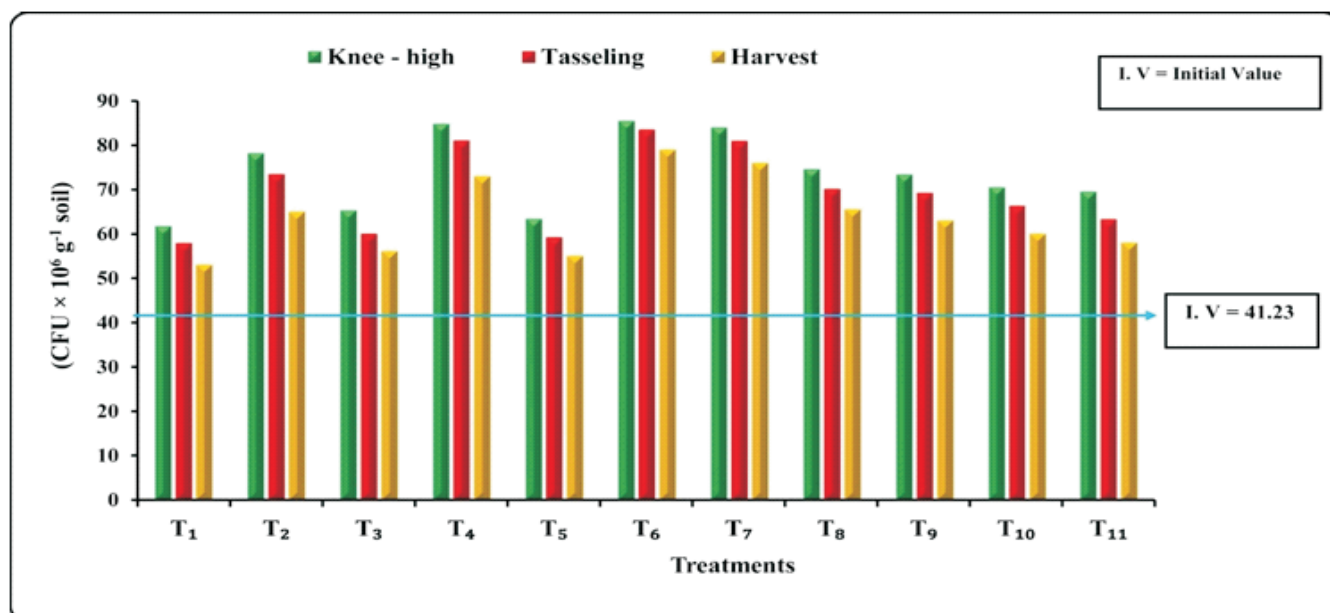


Fig. 1. Bacteria population as influenced by application of zinc-enriched FYM in maize crop

Results of the experiment showed that the increase in microbial population with the incorporation of organics (FYM) might be due to the improvement of the hydrothermal regime and supply of large amounts of carbon, a major food source for several bacteria involved in decomposition. The higher bacterial population may also be due to increased biomass and root exudates, which act as a source for its multiplication. The results agreed with the findings of Krishnakumar *et al.* (2005), Hussain *et al.* (2015), and Goutamiet *et al.* (2015).

Fungi ($\text{CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$)

The results on fungi population in the soil at different stages of maize crop are presented in Table 2 and depicted in Fig. 2. The fungi population significantly decreased from the knee-high stage to the harvest stage of maize crop. The lowest fungi population was recorded in T_1 (RDF alone).

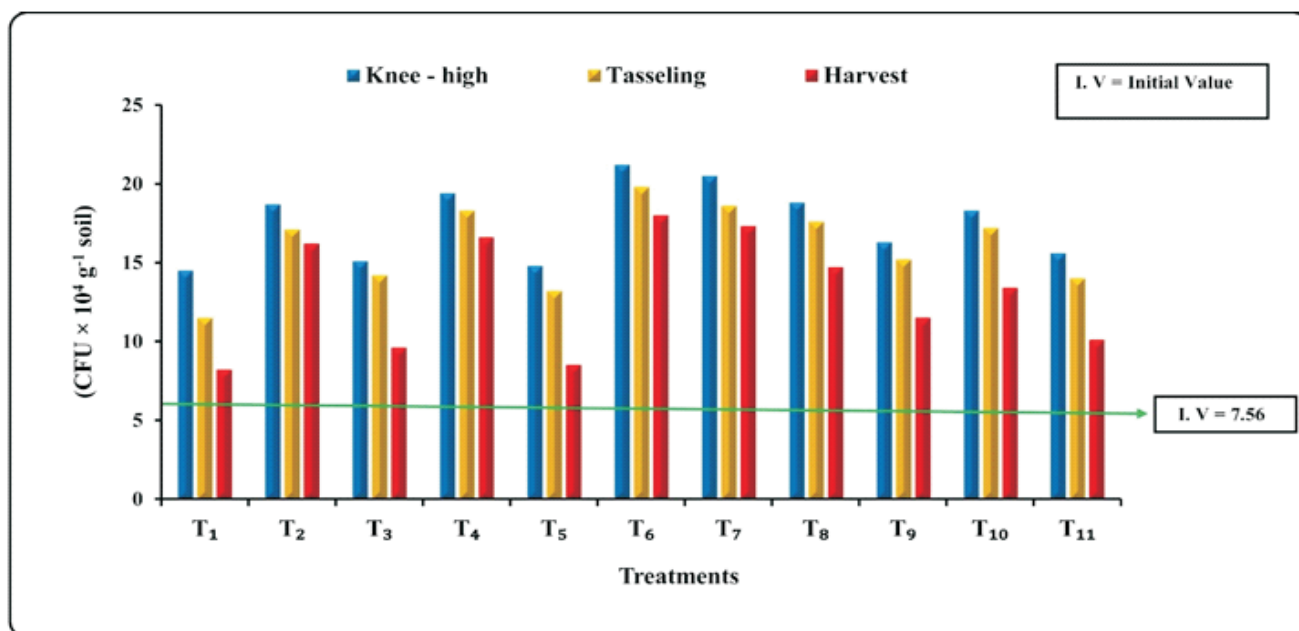


Fig. 2. Fungi population as influenced by application of zinc-enriched FYM in maize crop

The highest fungi population ($21.20 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at knee-high stage, $19.80 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at tasseling and $18.00 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at harvest) was observed in T_6 (FYM@ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}) which was on par with the treatments T_4 (FYM @ 10 t ha^{-1} enriched with ZnSO_4 @ 50 kg ha^{-1}) ($19.40 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at knee - high stage, $18.30 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at tasseling and $16.60 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at harvest), T_7 (FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1} + foliar

application of $0.2\% \text{ ZnSO}_4$) ($20.50 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at knee-high stage, $18.60 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at tasseling and $17.30 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at harvest) and T_2 (FYM @ 10 t ha^{-1}) ($18.70 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at knee - high stage, $17.10 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at tasseling and $16.20 \text{ CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$ at harvest).

Results of the experiment showed that the increased fungal population might be due to the enhanced organic carbon content of the soil as a result of enriched organic manure application.

Table 2. Bacteria, fungi and actinomycetes population (CFU g^{-1} of soil) as influenced by application of various treatments at different growth stages of maize crop

Treatments	Bacteria ($\text{CFU} \times 10^6 \text{ g}^{-1} \text{ soil}$)			Fungi ($\text{CFU} \times 10^4 \text{ g}^{-1} \text{ soil}$)			Actinomycetes ($\text{CFU} \times 10^3 \text{ g}^{-1} \text{ soil}$)		
	Knee-high	Tasselin g	Harvest	Knee-high	Tasselin g	Harvest	Knee-high	Tasselin g	Harvest
T_1 : Control (RDF alone)	61.70	58.02	53.00	14.50	11.50	8.20	7.1	9.2	5.8
T_2 : FYM @ 10 t ha^{-1}	78.20	73.50	65.00	18.70	17.10	16.20	12.9	14.2	10.1
T_3 : ZnSO_4 @ 50 kg ha^{-1}	65.30	60.10	56.10	15.10	14.20	9.60	8.4	10.1	6.2
T_4 : FYM @ 10 t ha^{-1} enriched with ZnSO_4 @ 50 kg ha^{-1}	84.80	81.00	73.00	19.40	18.30	16.60	15.9	19.7	13.5
T_5 : Foliar application of $0.2\% \text{ ZnSO}_4$	63.40	59.30	55.00	14.80	13.20	8.50	7.5	9.6	5.9
T_6 : FYM @ 10 t ha^{-1} enriched with ZnSB @ 5 kg ha^{-1}	85.50	83.50	79.00	21.20	19.80	18.00	17.1	20.1	14.7

T ₇ : T ₆ + foliar application of 0.2 % ZnSO ₄	84.00	81.00	76.00	20.50	18.60	17.30	15.4	18.3	13.3
T ₈ : Soil application of ZnSB @ 5 kg ha ⁻¹	74.60	70.20	65.50	18.80	17.60	14.70	12.2	16.5	10.2
T ₉ : Seed treatment with ZnSB @ 10 g kg ⁻¹ of seed	73.40	69.30	63.00	16.30	15.20	11.50	10.4	13.6	8.8
T ₁₀ : T ₈ + foliar application of 0.2 % ZnSO ₄	70.50	66.41	60.00	18.30	17.20	13.40	9.8	13.1	7.3
T ₁₁ : T ₉ + foliar application of 0.2 % ZnSO ₄	69.50	63.40	58.00	15.60	14.00	10.10	11.3	14.7	9.1
Mean	3.48	3.48	2.70	0.89	0.99	0.70	0.70	0.87	0.5
CD (p=0.05)	10.27	10.27	7.96	2.62	2.93	2.05	2.05	2.01	1.82
CV (%)	8.00	8.27	7.15	8.76	10.70	9.21	10.34	9.42	9.81

Enriched FYM improved the soil's microbial load as it acts as a substrate for decomposition and mineralization of nutrients, thereby creating a favourable condition for fungal proliferation. The results agreed with those of Krishnakumaret *al.* (2005) and Goutamiet *al.* (2015).

Actinomycetes (CFU × 10³ g⁻¹ soil)

Data related to the Actinomycetes population in the soil at different stages of maize crop is represented in Table 2 and Fig 3. The Actinomycetes population was significantly increased from knee-high to tasseling than tasseling to harvest stage of maize crop. The lowest

actinomycetes population was recorded in T₁ (RDF alone). The highest actinomycetes population (17.1 CFU × 10³ g⁻¹ soil at knee-high stage, 20.1 CFU × 10³ g⁻¹ soil at tasseling and 14.7 CFU × 10³ g⁻¹ soil at harvest) was registered in T₆ (FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹) which was on par with the treatments T₄ (FYM @ 10 t ha⁻¹ enriched with ZnSO₄ @ 50 kg ha⁻¹) (15.9 CFU × 10³ g⁻¹ soil at knee-high stage, 19.7 CFU × 10³ g⁻¹ soil at tasseling and 13.5 CFU × 10³ g⁻¹ soil at harvest), T₇ (FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ + foliar application of 0.2 % ZnSO₄) (15.4 CFU × 10³ g⁻¹ soil at knee - high stage, 18.3 CFU × 10³ g⁻¹ soil at tasseling and 13.3 CFU × 10³ g⁻¹ soil at harvest).

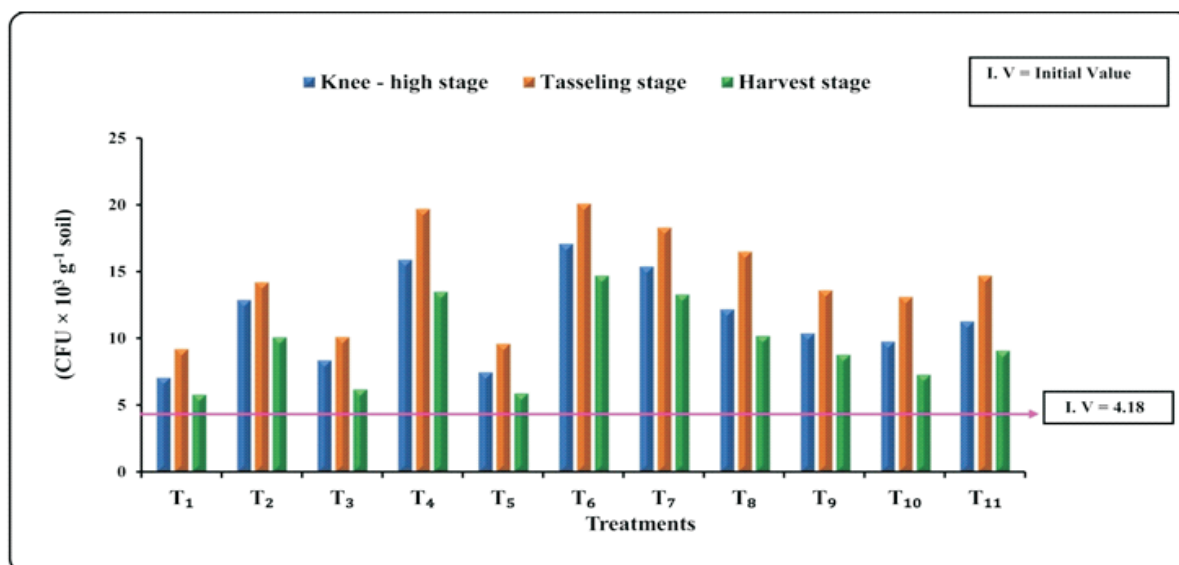


Fig. 3. Actinomycetes population as influenced by application of zinc-enriched FYM in maize crop

The highest actinomycetes population might be due to the increased availability of secondary and micronutrients by successive decomposition of FYM. Moreover, the addition of FYM creates a favourable condition for the improvement of physicochemical properties, thereby increasing the microbial count in the soil. The soil microbial activity was always higher in organic plots than in fertiliser-treated plots. Similar results were earlier reported by Krishnakumar *et al.* (2005), Goutami *et al.* (2015) and Ayyar *et al.* (2019). The results showed that the highest microbial count was recorded with the application of FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ than soil application of ZnSB and seed treatment with ZnSB.

Soil enzyme activity under maize crop

Dehydrogenase Activity ($\mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$)

Data related to dehydrogenase activity in the soil at different stages of crop growth is presented in Table 3 and depicted in Fig. 4. Dehydrogenase activity was significantly increased initially from knee-high to the tasselling stage and then decreased at the harvest stage. The higher dehydrogenase activity values were observed in tasseling followed by harvest and knee-high stage. All the treatments recorded higher dehydrogenase activity than control (T₁) at all the stages of crop growth.

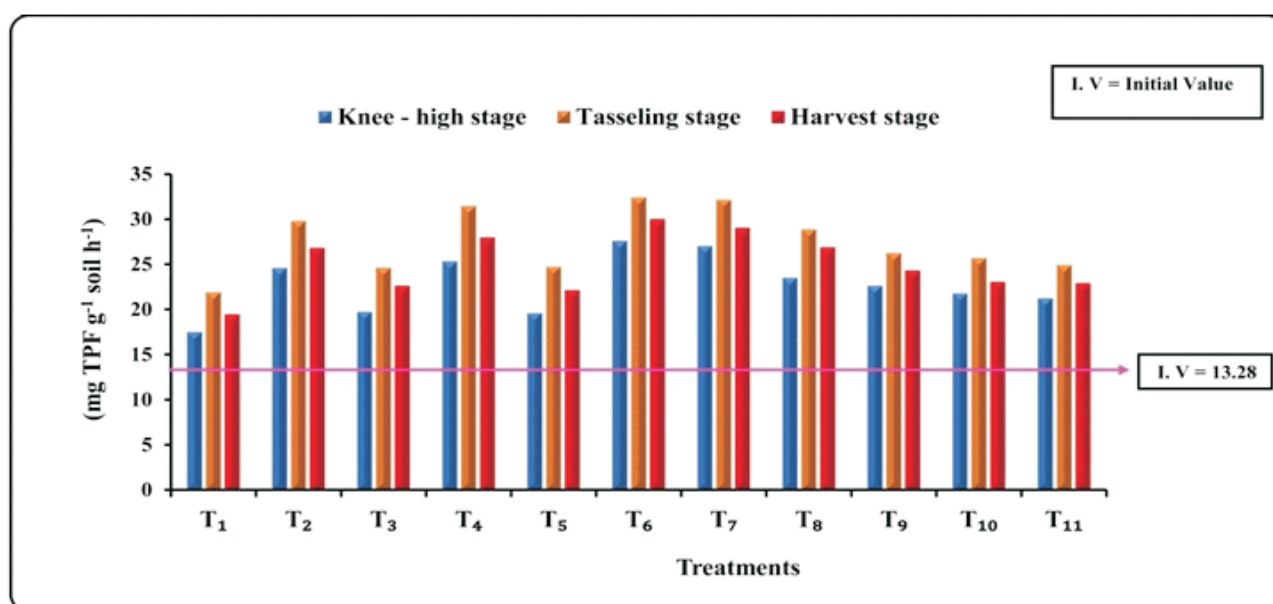


Fig. 4. Dehydrogenase activity as influenced by application of zinc-enriched FYM in maize crop

At knee-high stage, among all the treatments, significantly the highest dehydrogenase activity ($27.60 \mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$) was recorded in T₆ (FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹) which was on par with the treatments T₇ (FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ + foliar application of 0.2 % ZnSO₄), ($27.03 \mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$), T₄ (FYM @ 10 t ha⁻¹ enriched with ZnSO₄ @ 50 kg ha⁻¹) ($25.34 \mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$) and T₂ (FYM @ 10 t ha⁻¹) ($24.60 \mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$).

The dehydrogenase activity at the tasselling and harvest stages also showed the same trend as that of the knee-high. The treatments T₂, T₄, T₆, and T₇ recorded significantly higher dehydrogenase activity. The increase in dehydrogenase activity in T₆ over the control (RDF alone) was 47.9 and 54.0 per cent at the tasselling and harvest stages, respectively.

Maximum dehydrogenase activity was observed in FYM, enriched FYM with ZnSB alone, foliar

application with ZnSO₄ and FYM enriched with ZnSO₄. This might be due to the combined use of organics and inorganics, which improved the organic matter status of soil, thereby enhancing dehydrogenase activity (Mastoet *et al.*, 2006). Zinc, applied as foliar, will release root exudates, which attract more microbes and increase biological enzyme activity. Our experiment results also indicated that the highest total microbial population was observed in the above treatments. Seed treatment with ZnSB and soil application with ZnSB also recorded

significantly higher dehydrogenase activity than 100 % RDF alone because, in these plots, the highest microbial population was observed. Moreover, the addition of organic matter to soil improves microbial proliferation, resulting in increased microbial respiration. Thus, dehydrogenase activity in soil was increased. These results conformed with the findings of Ayyar *et al.* (2019), Vajanthaet *et al.* (2012), Natywaet *et al.* (2011) and Krishnakumar *et al.* (2005).

Table 3. Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$) as influenced by application of various treatments at different growth stages of maize crop

Treatments	Knee-high	Tasseling	Harvest
T ₁ : Control (RDF alone)	17.48	21.91	19.46
T ₂ : FYM @ 10 t ha ⁻¹	24.60	29.82	26.82
T ₃ : ZnSO ₄ @ 50 kg ha ⁻¹	19.72	24.63	22.61
T ₄ : FYM @ 10 t ha ⁻¹ enriched with ZnSO ₄ @ 50 kg ha ⁻¹	25.34	31.46	27.97
T ₅ : Foliar application of 0.2 % ZnSO ₄	19.57	24.73	22.14
T ₆ : FYM @ 10 t ha ⁻¹ enriched with ZnSB @ 5 kg ha ⁻¹	27.60	32.41	29.98
T ₇ : T ₆ + foliar application of 0.2% ZnSO ₄	27.03	32.16	29.03
T ₈ : Soil application of ZnSB @ 5 kg ha ⁻¹	23.51	28.89	26.87
T ₉ : Seed treatment with ZnSB @ 10 g kg ⁻¹ of seed	22.61	26.24	24.31
T ₁₀ : T ₈ + foliar application of 0.2 % ZnSO ₄	21.76	25.70	23.06
T ₁₁ : T ₉ + foliar application of 0.2 % ZnSO ₄	21.23	24.91	22.91
—	1.04	1.39	1.22
CD (p=0.05)	3.08	4.11	3.59
CV (%)	7.95	8.75	8.47

Zinc Use Efficiency

Data related to the zinc use efficiency of the maize crop is presented in Table 4, where the highest zinc use efficiency (94.150 %) was registered in the treatment T₇ (FYM @ 10 t ha⁻¹ enriched with ZnSB

@ 5 kg ha⁻¹ + foliar application of 0.2 % ZnSO₄) followed by T₁₁ (seed treatment with ZnSB @ 10 g kg⁻¹ of seed + foliar application of 0.2 % ZnSO₄) (432.0 %). The lowest zinc use efficiency (20.26 %) was recorded in T₃ (ZnSO₄ @ 50 kg ha⁻¹) as compared to other treatments.

Table 4. Zinc use efficiency (%) as influenced by the application of various treatments in maize crop

Treatments	Zinc use efficiency (%)
T ₁ : Control (RDF alone)	-
T ₂ : FYM @ 10 t ha ⁻¹	-
T ₃ : ZnSO ₄ @ 50 kg ha ⁻¹	20.26
T ₄ : FYM @ 10 t ha ⁻¹ enriched with ZnSO ₄ @ 50 kg ha ⁻¹	40.40
T ₅ : Foliar application of 0.2 % ZnSO ₄	59.50
T ₆ : FYM @ 10 t ha ⁻¹ enriched with ZnSB @ 5 kg ha ⁻¹	-
T ₇ : T ₆ + foliar application of 0.2 % ZnSO ₄	94.50
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	385.50
T ₁₁ : T ₉ + foliar application of 0.2 % ZnSO ₄	432.00

Conclusion

The investigation results concluded that microbial count showed significant differences at knee-high, tasseling and harvest stages in maize crops. The highest count was registered with FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ which was on par with FYM @ 10 t ha⁻¹ enriched with ZnSO₄ @ 50 kg ha⁻¹ and FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ + foliar application of 0.2% ZnSO₄ while the lowest count recorded in control (RDF) whereas zinc use efficiency (T₇) T₆ + foliar application of 0.2 % ZnSO₄ and dehydrogenase activity was recorded highest in FYM @ 10 t ha⁻¹ enriched with ZnSB @ 5 kg ha⁻¹ in Scarce Rainfall Zone of Andhra Pradesh. So, integrating organic and zinc-enriched fertilisers such as FYM combined with ZnSB or ZnSO₄ shows promise to enhance soil microbial activity and improve nutrient use efficiency in maize cultivation. Further research could explore the long-term effects of these treatments on soil health, crop yield, and sustainability in diverse agro-climatic zones. Additionally, studies could investigate the potential for optimising foliar applications of zinc to enhance nutrient uptake and boost resistance to environmental stresses. Expanding trials to other crops and regions, particularly those experiencing rainfall scarcity, could also provide broader insights into the

effectiveness of these practices for improving agricultural resilience and productivity.

Acknowledgement

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

References

- Allen, O. N. (1959). *Experiments in soil bacteriology*. Burgess Publication, Minneapolis.
- Ayyar, S., Appavoo, S., Basker, M., Pandiyarajan, P. and Kavimani, R. (2019). Effect of zinc and microbial inoculation on soil enzyme activities for maize (*Zea mays* L.) in black soil. *International Journal of Current Microbiology and Applied Sciences* **8**(8), 1804-1814.
- Casida Jr, L. E., Klein, D. A. and Santoro, T. (1964). Soil dehydrogenase activity. *Soil Science* **98**(6), 371-376.
- Dubey, A. N., Chattopadhyaya, N. and Mandal, N. (2021). Variation in soil microbial population and soil enzymatic activities under zincated nano clay polymer composites (ZNCPCs), Nano-ZnO, and Zn solubilizers in rice rhizosphere. *Agricultural Research* **10**, 21-31.

- Goutami, N., Rani, P. P., Pathy, R. L. and Babu, P. R. (2015). Soil properties and biological activity as influenced by nutrient management in rice-fallow sorghum. *International Journal of Agricultural Research Innovation and Technology* **5**(1), 10-14.
- Hussain, A., Arshad, M., Zahir, Z. A. and Asghar, M. (2015). Prospects of zinc solubilizing bacteria for enhancing growth of maize. *Pakistan Journal of Agricultural Sciences* **52**(4).
- Krishnakumar, S., Saravanan, A., Natarajan, S. K., Veerabadran, V. and Mani, S. (2005). Microbial population and enzymatic activity as influenced by organic farming. *Research Journal of Agriculture and Biological Sciences* **1**(1), 85-88.
- Martin, J. P. (1950). Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. *Soil Science* **69**, 332-349.
- Masto, R. E., Chhonkar, P. K., Singh, D. and Patra, A. K. (2006). Changes in soil biological and biochemical characteristics in a long-term field trial on a sub-tropical inceptisol. *Soil Biology and Biochemistry* **38**(7) 1577-1582.
- Nandini, P., Laxminarayana, P., Bhanu Rekha, K. and Anjaiah, T. (2020). Growth and yield of maize as influenced by zinc enrichment through agronomic options. *International Journal of Chemical Society* **8**(5), 2087-2091.
- Natywa, M. and Selwet, M. (2011). Respiratory and dehydrogenase activities in the soil under maize growth in the conditions of irrigated and non-irrigated fields. *Acta Scientiarum Polonorum. Agricultura* **10**(3).
- Shabaz, M. K., Ali, H., Sajjad, M., Saif-Ul-Malook, Shah, S. A. N. and Ali, Q. (2015). Effect of seed coating with boron and zinc on *Zea mays* for various yield traits. *American-Eurasian Journal of Agricultural & Environmental Science* **15**(7), 1304-1311.
- Statistica. (2022-23). <https://www.statistica.com>
- Thornton, H. G. (1922). On the development of a standardized agar medium for counting soil bacteria with special reference to the repression of spreading colonies. *Annals of Applied Biology* **9**, 241.
- USDA (2021-22). *World agricultural production*. <http://www.worldagriculturalproduction.com>
- Vajantha, B., Reddy, K. S. and Ramavatharam, N. (2010). Effect of integrated nitrogen management on soil enzyme activities in maize. *Research on Crops* **11**(1), 31-36.