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Zinc solubilizing bacteria effects on the growth and yield of rice in sodic soil

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Abstract
Sodic soils are categorized by high levels of exchangeable sodium, a high pH *i.e* above 8.5, and poor soil structure, leads to reduced infiltration of water. They exhibit a tough, cloddy texture when it is dry and a crusty surface when it is wet, hindering the root growth and seedling emergence. Phosphate ion readily reacts with calcium and magnesium during high pH, to form less soluble compounds. This will lead to less available nutrients and less yield. When the pH increases, the availability of the micronutrients be likely to decrease. For the above said reasons; field experiment was conducted at Arasakulam village, Kariapatti Block during 2024-25. The GR, NR and BCR was significantly high in the treatment receiving Soil test based NPK application + 2.5 kg Zinc lysinate ha^{-1}. T_3 treatment is on par with T_4. Application of zinc solubilizing bacteria in sodic soil increase the availability of zinc as well as uptake of zinc positively in sodic soil. Application of zinc solubilizing bacteria in alkaline soil increase the availability of zinc as well as uptake of zinc positively in alkaline soil.

Keywords: Sodic soil, zinc solubilizing bacteria, rice production, yield, economics

Introduction
Rice is a major crop grown in Virudhunagar District and nearly 550 ha of area in sodic condition in this District. Continuous usage of irrigation water with pH more than 8.5 to the soil leads to sodic condition. The characteristic of sodic soils from the agricultural stand point is that they contain high exchangeable sodium to adversely affect the growth of most crop plants. The experimental soils are sodic and those which have an exchangeable sodium percentage (ESP) of more than 15.8. Excess exchangeable sodium has a severe effect on the physical and nutritional properties of the soil, with subsequent reduction in crop growth. The soils lack of neutral soluble salts but contain measurable to appreciable quantities of salts capable of alkaline hydrolysis, e.g. sodium carbonate. The electrical conductivity of saturation soil extracts is 2.5 dS m^{-1} at 25 °C. The pH of saturated soil is 8.7. Sodic soils are originated mostly from the parent materials and pedogenic processes (soil forming processes). Frequent irrigation with sodic water or without proper drainage, afforestation, and other land management practices that lead to secondary sodification. Soil salinization and alkalization is a important ecological factor that severely limits the functional roles of soil microorganisms in arid and semi-arid regions worldwide (Qadir. 2008, Liu., 2017) [9, 7]. Soil application or foliar spray of zinc sulphate is widely adopted fertilization method to alleviate the Zn deficiency as well as to increase the grain Zn. However, soil applied $ZnSO_4$ with zinc solubilizing bacteria more efficient method. It can increase the soil available Zn up to 10 mg/kg and ensure Zn availability throughout the cropping period. It Enhances the Zn uptake by rice plant. Soil salinity disturbs various plant physiological progressions, leading to oxidative damage and changes in leaf gas exchange, finally resulting in decreased plant growth

Increased salinity levels also interrupt plant metabolism by increasing toxicity of ion, reducing the availability of essential nutrient elements and affecting the protein and lipids synthesis (Houmani *et al*., 2022) [2]. The objectives of the studies are to assess the zinc availability in sodic soils; to know the effect of Zn nutrition and Zn solubilizing bacteria on the growth and yield of rice in sodic soil and to calculate the economics and Zn use efficiency.

Materials and Methods

The field experiment was organized by Krishi Vigyan Kendra, Virudhunagar at Arasakulam village, Kariapatti Block of Virudhunagar District. The experimental soil is clay loamy soil and initial soil (Table 1) and water (Table 2) parameters were analyzed. The soil shows that of ph -8.7; EC – 2.5dS m^{-1} and Exchangeable Sodium Percentage (ESP) – 15.8. Sodicity problem occur due to continuous use of irrigation water without drainage and overfertilization without organic manure application. The treatments were imposed *viz.*, T_1: Soil test based NPK; T_2:Soil test based NPK+ 18.75 kg Zinc sulphate ha^{-1}; T_3: Soil test based NPK+ 2.5 kg Zinc lysinate; T_4: Soil test based NPK + FYM enriched Zinc sulphate at 18.75 kg ha^{-1} (1:10 ratio); T_5: Soil test based NPK+ 18.75 kg Zinc sulphate + 500 ml of ZSB ha^{-1}; T_6: Soil test based NPK+ 1.25 kg Zinc lysinate + 500 ml ZSB ha^{-1}; T_7: Soil test based NPK+ FYM enriched Zinc sulphate at 18.75 kg ha^{-1} + 500 ml ZSB ha^{-1}. Totally seven treatments were taken with three replications. Randomized Block Design (RBD) was followed in this experiment.

Results and Discussion

Impact of different forms of Zn application on plant height and yield attributing characters

Soil test based NPK+ 2.5 kg Zinc lysinate (T_3) treatment having significantly increases plant height (123.9 cm), Number of productive tillers (12.8) and number of filled grains panicle (113.9) compare to the Soil test based NPK T_1 treatment 96.8, 6.9 and 85.2 respectively (Table 3). T_3 treatment is on par with T_4. The zinc deficiency in plants will leads to reduce plant growth and intensify in plant susceptibility to abiotic stress and pathogenic attack (Dubey *et al*., 2020) [1]. Zinc solubilizing microbes' application is an alternative source to supply Zn. Several Zn solubilizing microbes' strains are used in the production of organic agricultural inputs. These microbes include Pseudomonas spp., Rhizobium spp., Bacillus aryabhattai, Thiobacillus thioxidans, and Azospirillum spp. (Ijaz *et al*., 2019) [4]. The Bacillus spp. AZ6, as a Zn solubilizing biofertilizer on maize, was denoted by Hussain *et al*., 2020 [3] to have a positive effect on total maize biological production and improve plant physiological parameters, chlorophyll content of leaf by 90%, and yield when compared to control (without biofertilizer application) plots.

Impact of different forms of Zn application on grain and straw yield (kg ha^{-1})

Soil test based NPK+ 2.5 kg Zinc lysinate (T_3) treatment having significantly increases grain yield (5157 kg ha^{-1}) and Straw yield (7660 kg ha^{-1}) compare to the control treatment
(Table 4). The percentage increase in grain and straw yield over Soil test based NPK only (T_1) is 23% and 29.9% respectively. T_4 treatment is on par with T_3. This study explores the possible effects of Zn-solubilizing microbes to enhance micronutrient content in rice, aiming to address these deficiencies of micronutrients. The same findings were obtained by Singh *et al*., 2024 [12] that microbial consortia, particularly Consortium1, can effectively replace traditional zinc fertilizers, enhancing sustainable agriculture by promoting plant growth and yield. These results are consistent with recent studies on the role of plant growth-promoting rhizobacteria (PGPR) in improving nutrient uptake and crop performance.

Impact of different forms of Zn application on DTPA available Zn (ppm)

Soil test based NPK+ 2.5 kg Zinc lysinate (T_3) treatment having significantly increases soil available zinc at Active tillering stage (0.48 ppm), Panicle initiation stage (0.44 ppm) and post-harvest stage (0.40 ppm) compare to the Soil test based NPK only (T_1) treatment (Table 5). T_4 treatment is on par with T_3.

Impact of different forms of Zn application on grain and straw zinc uptake (g ha^{-1})

Soil test based NPK+ 2.5 kg Zinc lysinate (T_3) treatment having significantly increases the grain zinc uptake (52.5 g) and straw zinc uptake (69.4 g) over the Soil test based NPK only (T_1) treatment (Table 6). T_3 treatment is on par with T_4. The same treatment shows that increased Zn uptake in grain was 52.5 g ha^{-1} and in straw was 69.4 g ha^{-1}. The increased available Zn in the soil might be bacterial inoculants as various organic acids producing bacteria aids in reducing the rhizospheric soil pH (Ramesh *et al*., 2014; Krthika and Baachandar, 2016 and Shakeel *et al*., 2015) [10, 6, 13]. The availability of zinc directly correlated to zinc uptake in grain and straw which is possible by the effect of ZSB. The micronutrients availability increased by application ZSB. Microorganisms such as *Bacillus* and *Pseudomonas* were producing organic acids that finally resulted in the decline of soil pH, and ensure the Zn availability to plants (Saravanan *et al*. 2004) [11]. The effects of these microbial treatments on soil health and exploring their potential in other crop systems (Nabi, 2023) [8]

Table 1: Chemical properties of initial soil sample

Soil analysis	
pH	8.70
EC (dS m^{-1})	2.5
Organic C (g kg^{-1})	2.58
Nitrogen (kg ha^{-1})	112
Phosphorus	12
Potassium	145
Iron (ppm)	1.35
Zinc (ppm)	0.25
CEC (C mol (p^+) kg^{-1})	12.6
Exchangeable Ca (C mol (p^+) kg^{-1})	5.0
Exchangeable Mg (C mol (p^+) kg^{-1})	4.1
Exchangeable Na (C mol (p^+) kg^{-1})	2.0
Exchangeable K (C mol (p^+) kg^{-1})	1.5
Exchangeable Sodium Percentage	15.8

Table 2: Chemical properties of initial water sample

Irrigation Water analysis	
pH	7.9
EC (dS m^{-1})	1.20
Carbonate (meq. L^{-1})	1.1
Bicarbonate (meq. L^{-1})	3.9
Sodium (meq. l^{-1})	1.1
Calcium (meq. l^{-1})	2.6
Magnesium (meq. l^{-1})	1.1
RSC (meq. l^{-1})	1.6
SAR	1.19

Table 3: Impact on plant height and yield attributing characters

No.	Treatments	Plant height (cm)	No. of Productive tillers	No. of filled grains per panicle
T_1	Soil test based NPK	96.2	6.9	85.2
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	109.4	10.9	97.4
T_3	Soil test based NPK+ 2.5 kg Zinc lysinate	123.9	12.8	113.9
T_4	Soil test based NPK + FYM enriched Zinc sulphate at 37.5 kg ha^{-1} (1:10 ratio)	116.9	10.4	107.0
T_5	Soil test based NPK+ 18.75 kg Zinc sulphate + 500 ml of ZSB ha^{-1}	104.1	9.30	96.2
T_6	Soil test based NPK+ 1.25 kg Zinc lysinate + 500 ml ZSB ha^{-1}	107.7	10.0	89.8
T_7	Soil test based NPK+ FYM enriched Zinc sulphate at 18.75 kg ha^{-1} + 500 ml ZSB ha^{-1}	113.2	11.7	100.4
	SE(d)	2.9	0.29	2.6
	C.D	5.7	0.56	5.2

Table 4: Impact of ZSB on grain and straw yield

No.	Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	Soil test based NPK	4210	5896
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	4729	6562
T_3	Soil test based NPK+ 2.5 kg Zinc lysinate	5157	7660
T_4	Soil test based NPK + FYM enriched Zinc sulphate at 37.5 kg ha^{-1} (1:10 ratio)	5074	7520
T_5	Soil test based NPK+ 18.75 kg Zinc sulphate + 500 ml of ZSB ha^{-1}	4527	6855
T_6	Soil test based NPK+ 1.25 kg Zinc lysinate + 500 ml ZSB ha^{-1}	4586	7017
T_7	Soil test based NPK+ FYM enriched Zinc sulphate at 18.75 kg ha^{-1} + 500 ml ZSB ha^{-1}	4803	7359
	SE(d)	124	184
	C.D	248	367

Table 5: Impact of ZSB on DTPA available Zn (ppm)

No.	Treatments	Active Tillering stage	Panicle Initiation stage	Post Harvesting stage
T_1	Soil test based NPK	0.21	0.19	0.15
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	0.32	0.29	0.19
T_3	Soil test based NPK+ 2.5 kg Zinc lysinate	0.48	0.44	0.4
T_4	Soil test based NPK + FYM enriched Zinc sulphate at 37.5 kg ha^{-1} (1:10 ratio)	0.45	0.4	0.37
T_5	Soil test based NPK+ 18.75 kg Zinc sulphate + 500 ml of ZSB ha^{-1}	0.37	0.32	0.28
T_6	Soil test based NPK+ 1.25 kg Zinc lysinate + 500 ml ZSB ha^{-1}	0.34	0.28	0.24
T_7	Soil test based NPK+ FYM enriched Zinc sulphate at 18.75 kg ha^{-1} + 500 ml ZSB ha^{-1}	0.43	0.38	0.35

Table 6: Impact of ZSB on Zn uptake (g ha^{-1})

No.	Treatments	Grain	Straw
T_1	Soil test based NPK	41.9	50.3
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	48.3	61.7
T_3	Soil test based NPK+ 2.5 kg Zinc lysinate	52.5	69.4
T_4	Soil test based NPK + FYM enriched Zinc sulphate at 37.5 kg ha^{-1} (1:10 ratio)	50.3	65.3
T_5	Soil test based NPK+ 18.75 kg Zinc sulphate + 500 ml of ZSB ha^{-1}	43.0	51.5
T_6	Soil test based NPK+ 1.25 kg Zinc lysinate + 500 ml ZSB ha^{-1}	47.2	55.6
T_7	Soil test based NPK+ FYM enriched Zinc sulphate at 18.75 kg ha^{-1} + 500 ml ZSB ha^{-1}	49.9	62.6
	C.D	0.29	0.43
	SE(d)	0.14	0.20

Table 7: Impact of ZSB on GR, NR and BCR

No.	Treatments	GR	NR	BCR
T_1	Soil test based NPK	67360	40493	2.51
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	75664	47895	2.72
T_3	Soil test based NPK+ 2.5 kg Zinc lysinate	81184	53488	2.93
T_4	Soil test based NPK + FYM enriched Zinc sulphate at 37.5 kg ha^{-1} (1:10 ratio)	82512	54118	2.91
T_5	Soil test based NPK+ 18.75 kg Zinc sulphate + 500 ml of ZSB ha^{-1}	72432	45583	2.70
T_6	Soil test based NPK+ 1.25 kg Zinc lysinate + 500 ml ZSB ha^{-1}	73376	45609	2.64
T_7	Soil test based NPK+ FYM enriched Zinc sulphate at 18.75 kg ha^{-1} + 500 ml ZSB ha^{-1}	76848	49143	2.77

Conclusion

Application of Soil test based NPK+ 2.5 kg Zinc lysinate having significantly increases the plant growth parameters, yield attributing characters, grain and straw yield of rice compare to Soil test based NPK only (T_1) treatment. T_3 treatment is on par with T_4. The GR, NR and BCR was significantly high in the treatment receiving Soil test based NPK application + 2.5 kg Zinc lysinate ha^{-1}. T_3 treatment is on par with T_4. Application of zinc solubilizing bacteria in sodic soil increase the availability of zinc as well as uptake of zinc positively in sodic soil. The outcomes of the study advocate the use of zinc solubilizing bacterial strains in the form of biofertilizers to intensify the uptake of zinc and available zinc both in edible parts of plants and in the soil, respectively. This technology has suitable alternative practice for improving higher yield and socio-economic status of the farmers in sodic soil. The farmers were willing to take up the seed treatment, soil application of biofertilizer.

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