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S Krishnakumar
Assistant Professor, Krishi Vigyan Kendra, Agricultural College and Research Institute, Madurai, Tamil Nadu, India

J Selvi
Assistant Professor, Krishi Vigyan Kendra, Agricultural College and Research Institute, Madurai, Tamil Nadu, India

M Jegadeesan
Assistant Professor, Krishi Vigyan Kendra, Agricultural College and Research Institute, Madurai, Tamil Nadu, India

P Arul Arasu
Assistant Professor, Krishi Vigyan Kendra, Agricultural College and Research Institute, Madurai, Tamil Nadu, India

E Subramanian
Programme Coordinator, Krishi Vigyan Kendra, Agricultural College and Research Institute, Madurai, Tamil Nadu, India

Corresponding Author:
S Krishnakumar
Assistant Professor, Krishi Vigyan Kendra, Agricultural College and Research Institute, Madurai, Tamil Nadu, India

Evaluation of zinc solubilizing bacteria for enhancing zinc nutrition in rice under alkaline conditions of Madurai Dt.

S Krishnakumar, J Selvi, M Jegadeesan, P Arul Arasu and E Subramanian

Abstract
Phospate ion readily reacts with calcium and magnesium during alakaline pH, to form less soluble compounds. This will leads to less nutrient availability and poor yield. When the pH increases, the availability of the micronutrients *viz*., manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B) be likely to decrease. The above said reasons; field experiment was conducted at Varichur village, Madurai East Block during 2022-23. The treatments *viz*., Soil test based NPK nutrient application, Enriched farmyard manure, Enriched Cow dung manure with and without Zinc solubilizing bacteria was imposed and positive results were obtained. Application of soil test based NPK + FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) + soil application of ZSB 500 ml having significantly increases plant height (124.2 cm), Number of productive tillers (12.7) and number of filled grains panicle (114.2) compare to the control treatment 88.4, 4.9 and 60.6 respectively and also significantly increases grain yield (5463 kg ha^{-1}) and Straw yield (7659 kg ha^{-1}) compare to the control treatment. The percent increase in grain and straw yield over control is 56.2% and 56.9% respectively. The increased thousand grain weight was noticed in T_8 treatment over control treatment (25.20 g). Application of zinc solubilizing bacteria in alkaline soil increase the availability of zinc as well as uptake of zinc positively in alkaline soil.

Keywords: Rice, zinc solubilizing bacteria, zinc availability, zn uptake, yield and economics

Introduction
Rice is a most important crop grown in Madurai district as it is under Periyar Vaigai command area. There are nearly 500 ha of area in alkaline soils in Madurai District. Continuous usage of drainage water as irrigation leads to the soil alkalinity. In alkali pH, the moicronutrients availability is very less and uptake by the plant also less. There were a number of helpful soil micro organisms that can help plants to absorb soil mineral nutrients. Their effectiveness can be improved with human intercession by selecting important efficient microorganisms, multiplying them and adding them through soil application. 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) [1, 2]. Organic amendments like bio-fertilizer and rotten straw are more effective than inorganic amendments (e.g., gypsum Shaaban *et al*., 2013) [3] for altering soil nutrient and physiochemical properties, changing the soil microbial communities and increasing crop yields (Tejada, *et al*., 2006) [4] and (Celestina *et al*., 2019) [5]. Biofertilizers are organic amendments (Mahdi, 2010) [6], (Pindi and Satyanarayana, 2012) [7] and (Borkar, 2015) [8] this can widely used in problem soils (Abd-Alla *et al*., 2014) [9] to increase soil fertility and thereby increase productivity (Singh, 2019) [10].

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 ZnSO4 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. The ZSB with zinc phosphate will also improve the availability of P and K contents of soil. The yield increase (15-20%) along with Zn content in paddy grains (25-30 mg/kg). The objectives of the studies were to assess the zinc dynamics in alkaline soil, to know the Zinc solubilizing bacteria on the plant development and yield and economics of rice in alkaline soil.

Materials and Methods

The field trial was carriedout at Varichur village, Madurai East Block, during 2022-23. The paddy variety TRY 4 (Salinity/alkalinity tolerant variety) was taken for the experiment. The treatments *viz.*, T_1: Absolute control, T_2: Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}, T_3: Soil test based NPK+ 5 kg Zinc EDTA ha^{-1}, T_4: FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio), T_5: Cow dung enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio), T_6: T_2 + Soil application of ZSB (500 ml), T_7: T_3 + Soil application ZSB (500 ml), T_8: T_4 + Soil application ZSB (500 ml), T_9: T_5 + Soil application ZSB (500 ml). Randomized Block Design (RBD) was the experimental design. Totally nine treatments were taken and three replications was done. The chemical properties of the soil and water is given in the table 1 & 2.

Table 1: Chemical properties of initial soil sample

Soil analysis	
pH	8.40
EC (dS m^{-1})	2.2
Organic C (g kg^{-1})	2.58
N (kg ha^{-1})	102
P (kg ha^{-1})	11
K (kg ha^{-1})	135
Iron (ppm)	1.30
Zinc (ppm)	0.20
CEC (C mol (p^{+}) kg^{-1})	14.5
Exchangeable Ca (C mol (p^{+}) kg^{-1})	6.0
Exchangeable Mg (C mol (p^{+}) kg^{-1})	4.8
Exchangeable Na (C mol (p^{+}) kg^{-1})	2.0
Exchangeable K (C mol (p^{+}) kg^{-1})	1.5
Exchangeable Sodium Percentage	13.8

Table 2: Chemical properties of initial water sample

Irrigation Water analysis	
pH	8.00
EC (dS m^{-1})	1.10
CO_3 (meq. L^{-1})	1.0
HCO_3 (meq. L^{-1})	4.0
Na (meq. l^{-1})	1.0
Ca (meq. l^{-1})	2.5
Mg (meq. l^{-1})	1.0
RSC (meq. l^{-1})	1.5
SAR	1.14

Results and Discussion

Growth and Yield attributes

Zinc is an crucial micronutrient for effective plant growth. The zinc deficiency in plants will leads to reduction in leaf size and chlorosis, amplify in plant susceptibility to heat, light stress, and pathogenic attack (Dubey *et al.*, 2020) [11]. The Zn fertilizers has been suggested to solve this problem (Rajput *et al.*, 2020) [12]. Zinc solubilizing Microorganisms application is an alternative to Zn supply is gaining traction. Several strains of Zn solubilizing microorganisms are used in the production of biofertilizers. These include Pseudomonas spp., Rhizobium spp., Bacillus aryabhattai, Thiobacillus thioxidans, and Azospirillum spp. (Ijaz *et al.*, 2019) [13]. The Bacillus spp. AZ6, as a Zn solubilizing biofertilizer on maize, was given by Hussain *et al.*, 2020 [14] to have a positive impact on total maize biological production and improve plant physiology, chlorophyll content by 90%, and yield when compared to uninoculated plants. FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) with soil application of ZSB 500 ml having significantly increases plant height (124.2 cm), Number of productive tillers (12.7) and number of filled grains panicle (114.2) compare to the control treatment 88.4, 4.9 and 60.6 respectively (Table 3).

Table 3: Impact on plant height and yield attributing characters

No.	Treatments Details	Plant height (cm)	No. of Productive tillers	No. of filled grains per panicle
T_1	Absolute control	88.4	4.9	60.6
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	98.7	9.0	81.7
T_3	Soil test based NPK+ 5 kg Zinc EDTA ha^{-1}	96.7	9.1	85.7
T_4	FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio)	108.0	9.9	90.0
T_5	Cow dung enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio)	104.3	9.2	96.4
T_6	T_2 + Soil application of ZSB (500 ml)	109.3	10.8	97.3
T_7	T_3 + Soil application ZSB (500 ml)	117.6	10.4	107.6
T_8	T_4 + Soil application ZSB (500 ml)	124.2	12.7	114.2
T_9	T_5 + Soil application ZSB (500 ml)	113.9	11.7	101.0
	C.D	0.34	0.07	0.5
	SE(d)	0.16	0.03	0.2

Grain and straw yield

Application of FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) with soil application of ZSB 500 ml having significantly increases grain yield (5463 kg ha^{-1}) and Straw yield (7659 kg ha^{-1}) compare to the control treatment. The percentage increase in grain and straw yield over control is 56.2% and 56.9% respectively. The increased thousand grain weight was noticed in T_8 treatment over control treatment (25.20 g).

Zinc availability and uptake

Application of soil test based NPK application, FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) with soil application of ZSB 500 ml having increases soil available zinc at Active tillering stage (0.47 ppm), Panicle initiation stage (0.43 ppm) and post harvest stage (0.39 ppm) compare to the control treatment. The percent increase at active tillering stage over control is 55%. The same treatment increases the grain zinc uptake (52.5 g) and straw zinc uptake (69.4 g) over the control treatment.

Economic analysis

The cost benefit ratio was significantly higher (2.57) in the treatment receiving soil test based NPK application, FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) with soil application of ZSB 500 ml than the absolute control (1.70).

Overall zinc solubilizing bacteria having high impact on economic benefits for the farmers (Table 4).

Table 4: Impact on economic benefits

No.	Treatments	GR	NR	BCR
T_1	Absolute control	59800	24600	1.70
T_2	Soil test based NPK+ 37.5 kg Zinc sulphate ha^{-1}	82840	45228	2.20
T_3	Soil test based NPK+ 5 kg Zinc EDTA ha^{-1}	84180	46859	2.26
T_4	FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio)	97920	55388	2.30
T_5	Cow dung enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio)	95080	58091	2.57
T_6	T_2 + Soil application of ZSB (500 ml)	104580	61879	2.45
T_7	T_3 + Soil application ZSB (500 ml)	106540	63265	2.46
T_8	T_4 + Soil application ZSB (500 ml)	109260	66811	2.57
T_9	T_5 + Soil application ZSB (500 ml)	107420	63976	2.47

Conclusion

Soil test based NPK fertilizers, FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) with soil application of ZSB 500 ml having significantly increases the plant development parameters, yield quality characters of rice. Moreover same treatment appreciably increases the zinc availability in soil as well as grain and straw zinc uptake over control treatment. The GR, NR and BCR was significantly high in the treatment receiving soil test based NPK fertilizers, FYM enriched Zinc sulphate 37.5 kg ha^{-1} (1:10 ratio) with soil application of ZSB 500 ml. Application of zinc solubilizing bacteria in alkaline soil increase the availability of zinc as well as uptake of zinc positively in alkaline soil.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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