ROLE OF ZINC AND SILICA SOLUBILIZING BACTERIA AND THEIR CONSORTIA ON NUTRIENT STATUS OF SOIL AND PLANT IN DIRECT SOWN PADDY UNDER FIELD CONDITIONS

ABSTRACT

Effect of zinc and silica solubilizing bacteria and their consortia on paddy was studied under field conditions at Agricultural Research Station, Janagamaheswarapuram, ANGRAU. Thirteen treatments were assessed for availability of nutrients *viz*., Nitrogen, Phosphorus, Potassium, Zinc and Silica in soil and concentration of Nitrogen, Phosphorus and Potassium in plant at 45, 90 and 120 days after sowing (DAS). Significantly highest nitrogen (198.9, 262.3 and 240.2 kg ha^{-1}), available phosphorus (36.7, 64.7 and 40.6 kg ha^{-1}), potassium (221.4, 349.6 and 263.5 kg ha^{-1}), zinc (0.86, 1.14 and 0.98 ppm) and silica (66.8, 98.9 and 84.8 ppm) were recorded in T_{13} (RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3) at 45, 90 and 120DAS. In plant, nitrogen (0.89, 1.10 and 0.98 %), phosphorus (0.46, 0.67 and 0.58 %) and potassium (1.87, 2.29 and 1.98 %) were significantly highest in T13. There was increase in available nutrient content up to 90 DAS which then decreased at 120DAS. It is inferred that consortia of two zinc solubilizing and two silica solubilizing microorganisms (T_{13}) is useful for increased availability of Nitrogen, Phosphorus, Potassium, Zinc and Silica in soil and increased uptake of NPK by rice plant.

KEYWORDS: Paddy, zinc solubilizing bacteria, silica solubilizing bacteria, Zinc and silica bacterial consortia, nutrients.

INTRODUCTION

India is one of the leading producers of rice crop. Rice is the basic food crop and being a tropical plant, it flourishes comfortably in a hot and humid climate. Rice is mainly grown in rain-fed areas that receive heavy annual rainfall. That is why it is fundamentally a *kharif* crop in India. Plants need several macro and micro nutrients for their growth and development. Nitrogen, phosphorus and potassium, or NPK, are the primary nutrients in commercial fertilizers. Each of these fundamental nutrients plays a key role in plant nutrition. Nitrogen is considered to be the most important nutrient, and plants absorb more nitrogen than any other element. Nitrogen is essential to in making sure plants are healthy as they develop and nutritious to eat after they're harvested. Phosphorus, is linked to a plant's ability to use and store energy, including the process of photosynthesis. It's also needed to help plants grow and develop normally. Potassium is the third key nutrient of commercial fertilizers. It helps strengthen plants' abilities to resist disease and plays an important role in increasing crop yields and overall quality. In rice zinc (Zn) is one of the most important micronutrients necessary for the normal healthy growth and reproduction of plants. Silica is useful for proper cuticle development and grain formation in rice [14]. Zinc Solubilizing Bacteria (ZnSB) and Silica Solubilizing Bacteria (SiSB) and their consortia improved the bioavailable fraction of

N, P, K, Zn and Si to host plant for enlightening the crop growth, yield and quality [19]. It will directly effect on the crop nutrient content and yield parameters. Inoculation of rice with silica solubilizing bacteria enhanced available silica in soil and silica content in plant and improved rice yield. Dissolution of silicate results in rendering phosphorus available for plant absorption as silica competes with phosphorus fixation sites; silica acts like auxiliary for phosphorus in plants [15]. Hence, an experiment was conducted to study the availability of nutrients in soil and uptake by rice plants by inoculating selected zinc and silica solubilizing isolates and their combinations under pot culture and field conditions.

MATERIALS AND METHODS

Estimation of nutrient (N, P, K, Zn and Si) content in soil samples

Paddy variety, MTU-7029 (Swarna) was sown in pots by adopting 20cm X 10 cm spacing at ARS, Jangamaheswarapuramon 8-09-2019. Thirteen treatments, replicated thrice, were imposed incompletely randomized design as detailed below.

Treatment details:

T_1: RDF (Control)
T_2: RDF + $ZnSO_4$
T_3: RDF + Calcium silicate
T_4: RDF + $ZnSO_4$ + Calcium silicate
T_5: RDF + ZnKJJ-4
T_6: RDF + ZnPGG-1
T_7: RDF + SiKPP-1
T_8: RDF + SiPYY-3
T_9: RDF + ZnKJJ-4 &ZnPGG-1
T_{10}: RDF + SiKPP-1 &SiPYY-3
T_{11}: RDF + ZnKJJ-4+ SiKPP-1
T_{12}: RDF + ZnPGG-1+ SiPYY-3
T_{13}: RDF + ZnKJJ-4 &ZnPGG-1 + SiKPP-1 &SiPYY-3
Where,
RDF = Recommended dose of fertilizer
ZnKJJ-4, ZnPGG-1, SiKPP-1 and SiPYY-3: Efficient zinc and silica solubilizing isolates.

Soil sample collection and processing

Soil samples collected at 45, 90 and 120 DAS, from all the 13 treatments were dried under shade, gently ground with wooden hammer, sieved through 2 mm sieve and stored in labelled new polythene lined cloth bags for analysis. Processed soil samples were used for analysing various physical, physico-chemical and available nutrients and for assessing the biological properties *viz.*, microbial population in undisturbed soil samples by adopting standard procedures.

Available nutrients (nitrogen, phosphorus, potassium, zinc and silica) in soil

Nitrogen was estimated by alkaline permanganate method as outlined by [17] and expressed in kg ha^{-1}**.** Available phosphorus content of soil was determined by Olsen's method as described by [11] and phosphorus in the extract was determined using spectrophotometer at 680 nm wavelength. It was expressed in kg ha^{-1}. Available potassium in the soil was determined by ELICO flame photometer after extracting the soil with neutral normal ammonium acetate as described by [6]. It was expressed in kg ha^{-1}. The available zinc in the digested soil samples was determined by atomic absorption spectrophotometer after making proper standards as described by [7]. It was expressed in ppm. The available silicain the soil samples was determined by 0.5M acetic acid extractant method after making proper standards as described by [16]. It was expressed in ppm.

Estimation of nutrient (N, P, K, Zn and Si) content in plant samples Collection, preparation and analysis of plant samples

The plant samples were collected at 45 DAS, 90 DAS and 120 DAS, washed thoroughly with distilled water and dried under shade. Then, they were dried in hot air oven at 65°C till a constant weight was obtained. Dried plant samples were ground in a wooden pestle and mortar and stored in polythene bags for further chemical analysis. N, P, K, Zn and Si contents were estimated by following standard methods.

Digestion of plant sample

Powdered whole plant samples were separately treated with concentrated HNO_3 overnight for pre digestion. Then, the pre-digested samples were treated with diacid mixture [HNO_3:$HClO_4$ (9:4 ratio)] and digested on sand bath at low temperature till colourless white precipitate was obtained. The residue was dissolved in 6N HCl, filtered, made to known volume by using 6N HCl. This was used for further nutrient analysis. The following analyses were carried out from the diacid digested samples of whole plant.

Nitrogen concentration

Nitrogen concentration in plant samples were estimated by Kelplus method [12] after digesting the organic matter by H_2SO_4 and H_2O_2.

The nitrogen content in plant sample is calculated as follows:

Weight of sample = 0.1g

Normality of H_2SO_4 = 0.02

Titration value (TV) = Sample titration value – Blank titration value

$$\%\text{ N in plant sample} = \frac{\text{T.Vx } 0.00028 \text{ x } 100}{0.1} = 0.28\text{xT.V}$$

Concentration of macronutrients was expressed as % and micro nutrients in ppm

Phosphorus concentration

The phosphorus content in the digested plant samples was determined by Vanadomolybdo-phosphoric acid yellow colour method using spectrophotometer at 470 nm wave length [18].

Calculation:

$$\%\text{ P in plant sample} = \text{sample conc. in ppm} \times \frac{\text{Final volume (50 ml)} \times 100 \times 100}{\text{Wt of sample (1g)} \times \text{aliquot (5ml)} \times 10^6}$$

Potassium concentration

The plant samples for K estimation were digested by diacid through wet digestion. The samples are then read in flame photometer using filter for K [6].

Calculation:

$$\%\text{ K in plant sample} = \text{R} \times \frac{100 \times 100}{\text{Wt. of sample (1g)} \times 10^6}$$

$= R \times 0.01$

Where R = concentration of K in ppm obtained from standard curve

RESULTS AND DISCUSSION

Influence of zinc and silica solubilizing bacterial isolates and their consortia on available nutrients in the soil

Available nitrogen in soil

Available nitrogen content was 142.03 kg ha^{-1} (Table 1) in the initial soil sample. At 45 DAS all the treatments showed increased available nitrogen content compared to initial stage. Highest available nitrogen was recorded in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (198.9 kg ha^{-1}) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 196.7 kg ha^{-1}, which were on par. Available nitrogen content further increased with highest recorded in T_{13} (262.7 kg ha^{-1}) at 90DAS, followed by T_{12} (258.7 kg ha^{-1}) and both were on par. At 120 DAS available nitrogen content decreased to 240.2 kg ha^{-1} in T_{13} followed by T_{12} (238.5 kg ha^{-1}) and T_{11} (237.2 kg ha^{-1}) and were superior to other treatments, (Table 2 & Fig 1).

Similar findings were obtained by [2] where biofertilizers and the recommended dose of fertilizers expanded the soil available nitrogen (63 %). The most effective treatment was ZSB + PSB + KRB + RDF [20] reported increased available nitrogen with the applied fertilizers and biofertilizers.

Available phosphorus in soil

Phosphorus helps a plant convert other nutrients into usable building blocks to grow. Available phosphorus content was initially 26.28 kg ha^{-1} (Table 1). At 45 DAS all the treatments exhibited increased available content of phosphorus than initial. The highest phosphorus availability was registered in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (36.7 kg ha^{-1}) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 35.4 kg ha^{-1} and were on par. At 90 DAS also increased available phosphorus was observed in T_{13} (64.7 kg ha^{-1}), on par with T_{11} (RDF + ZnKJJ-4 + SiKPP-1) *i.e.*, 62.4 kg ha^{-1} and T_{12} (RDF + ZnPGG-1 + SiPYY-3) (59.6 kg ha^{-1}). At 120 DAS available phosphorus content decreased to 40.6 kg ha^{-1} in T_{13} and found superior to T_{12} (38.5 kg ha^{-1}) (Table 2 & Fig 2). An increasing trend until 90 DAS followed by decreasing trend by 120 DAS though more than 45 DAS was observed in general for all the available major nutrients.

Present results indicates that available phosphorus content increased slightly and depleted gradually in all the treatments with insufficient dose of phosphatic fertilizers. Inoculated zinc and silica microbial consortium stimulated root length development under reduced phosphorus supply with stabilized ammonium by 52 %. This was accompanied by the increased auxin production capacity of rhizosphere bacteria [4].

Available potassium in soil

Potassium has significant role in the regulation of water in plants (osmoregulation). Potassium influences both uptake of water through plant roots and its loss through the stomata. Available potassium content was 202.14 kg ha^{-1} (Table 1) in the initial soil sample. At 45 DAS all the treatments showed increased potassium compared to initial stage. The highest available potassium was recorded in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (221.4 kg ha^{-1}) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 220.9 kg ha^{-1} and T_{11} (220.6 kg ha^{-1}) and were on par. At 90 DAS, all the treatments showed increased potassium availability than 45 DAS; significantly highest available potassium was recorded in

T_{13} (349.6 kg ha^{-1}). At 120 DAS amount of available potassium decreased to 263.5 kg ha^{-1} in T_{13} but significantly higher than other treatments (Table 2 & Fig 3).

Similar observations was made by earlier works of [13] reported increased chlorophyll content by inoculated bacteria, soluble and rock potassium. Many microorganisms like zinc and silica solubilizers in the soil, apart from zinc and silica, they can solubilize ‘unavailable’ forms of K bearing minerals, such as micas, illite and orthoclases by excreting organic acids which either directly dissolve rock K or chelate silicon ions to bring the K into solution [3].

Available zinc in soil

Available zinc content was 0.48 ppm (Table 1) in the initial soil sample. At 45 DAS all the treatments showed increased available zinc content compared to initial. Highest available zinc was recorded in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (0.86 ppm), followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 0.83 ppm. Available zinc content further increased in all the treatments at 90DAS. Higher available zinc content was recorded in T_{13} (1.14 ppm) at 90 DAS. At 120 DAS available zinc content was decreased among the treatments over 90 DAS and significantly highest zinc availability was recorded in T_{13} (0.98 ppm), followed by T_{12} (0.96 ppm) (Table 3 & Fig 4).

The above results were in agreement with [9] where growth and yield parameters of paddy showed a significant increase in the treatment that received combination of MZSB 6, MZSB 8 and 75% recommended dose of fertilizer (RDF) as compared to control and other treatments.

Available silica in soil

Available silica content was 46.0 ppm (Table 1) in the initial soil sample. At 45 DAS all the treatments showed increased available silica content compared to initial stage. Highest available silica was recorded in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (66.8 ppm) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) and T_{11} (RDF + ZnKJJ-4 + SiKPP-1) *i.e.,* 65.9 and 65.7 ppm and found on par. All the treatments at 90 DAS showed increased available silica content than initial and 45 DAS, T_{13} recorded highest (98.90 ppm), followed by T_{12} and T_{11} (97.7 and 97.3 ppm) and were on par. At 120 DAS available silica content decreased among the treatments over 90 DAS and significantly highest silica availability was recorded in T_{13} (84.8 ppm), T_{12} and T_{11} recorded 82.6 and 82.4 ppm, respectively (Table 3 & Fig 5).

Available silica was observed highest in T_{13}. Similar results were observed with [5] where application of silica solubilizing bacteria increased availability of silica in soil by 12.45 - 60.15 % more over the control. It might be due to the silica solubilizing microorganisms present in the soil influenced the available silica content in soil by additional application externally.

Influence of zinc and silica solubilizing bacterial isolates and their consortia on nutrient concentration in plants

Percent nitrogen in plant

Percent nitrogen in plant was influenced by the zinc and silica solubilizing bacterial isolates and their consortia by easy availability of the nutrients. Percent N significantly differed among the treatments. Highest nitrogen concentration of 0.87 %, 1.10 % and 0.98 % was recorded inT_{13} (RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3) followed by T_{12} (0.87 %, 1.08% and 0.95%) at 45, 90 and 120DAS, respectively, and 0.95% in T11 at 120DAS, which were on par. Control recorded the least nitrogen of 0.81 % (Table 4 & Fig 6).

Growth enhancement of inoculated plants could be due to the higher N accumulation by bacterial N_2 fixation and better root growth, which might have promoted the greater uptake of water and nutrients. Similar results were found by [8] where addition of SSB-enriched biofertilizer to clay substrate significantly increased the content of total nitrogen, phosphorus and potassium in the leaves of *Brassica juncea*. They concluded that SSB-enriched biofertilizer improved the photosynthetic function of *B. juncea.*

Percent phosphorus in plant

Zinc and silica solubilizing bacterial isolates have the ability to solubilize P to some extent, these microorganisms help for the growth and development of the crop and also elevated crop tolerance under water deficit condition. At 45 DAS significant concentration of plant phosphorus was found in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 &SiPYY-3 (0.46 %), followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 0.44 %. At 90 DAS significantly higher plant phosphorus concentration was recorded in T_{13} (0.67 %). At 120 DAS highest phosphorus concentration was obtained in T_{13} (0.58 %), followed by T_{12} (0.56 %) and T_{11} (0.55 %) and statistically they were on par (Table 4 & Fig 7).

Phosphorus (%) was highest in T_{13} treatment at all the intervals studied. Similar findings were observed by [1] where zinc solubilizing bacterial isolates *i.e., Pseudomonas striata* along with *Pseudomonas florescence* strains showed phosphate solubilizing ability apart from zinc, resulted in significant increase in percent of phosphorus in plant compared to individual inoculations in paddy.

Percent potassium in plant

Osmoregulation is maintained by the potassium concentration in the plant. More the concentration of potassium, higher the osmoregulation, and helps the plant during transpiration. At 45 DAS and 90 DAS higher plant potassium concentration was obtained in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (1.87 % and 2.29 %), followed by T_{12}: RDF + ZnPGG-1 + SiPYY-3 (1.85 % and 2.28 %), respectively. At 120 DAS significant maximum potassium concentration was recorded in T_{13} (1.98 %), followed by T_{10} (RDF + SiKPP-1 & SiPYY-3) and T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 1.96 % (Table 4 & Fig 8).

Present results revealed that a higher value of potassium concentration was noticed in treatments those received potassium along with N or P or combinations at all the growth stages. The concentration of potassium decreased slowly from 90 to 120 DAS. Besides silicon, silicate minerals contain potassium, calcium, magnesium, iron and zinc and therefore inoculation of Silica solubilizing bacteria (SiSB) to soil benefit the crop by releasing several of these nutrients [10]. By the action of SSB potassium availability was more in soil that showed direct impact on the percent potassium in the plant.

Conclusion

Nitrogen, phosphorus and potassium were essential for crop growth and development in paddy. Apart from that, zinc and silica nutrients were also very useful for the grain quality and quantity. Zinc and silica solubilizing bacteria and their consortia showed significant effect on available nitrogen, phosphorus, potassium, zinc and silica in soil as well as nitrogen, phosphorus and potassium concentration in plant compared to individual zinc and silica solubilizing microorganisms. Hence it is concluded that Zinc and silica solubilizing bacteria and their consortia effectively enhance the availability of nutrients in the paddy crop under field conditions.

Table 1. Initial Physico-chemical and microbiological properties of experimental field soil

Soil property	**Field**
Available N (kg ha^{-1})	142.03
Available P (kg ha^{-1})	26.28
Available K (kg ha^{-1})	202.14
Available Zn (ppm)	0.48
Available Si (ppm)	46.0

Table 2. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available major nutrients N, P and K (kg ha^{-1}) in soil of direct sown paddy under field conditions

Treatments	**Available nitrogen (kg ha^{-1})**			**Available phosphorus (kg ha^{-1})**			**Available potassium (kg ha^{-1})**		
	45 DAS	**90 DAS**	**120 DAS**	**45 DAS**	**90 DAS**	**120 DAS**	**45 DAS**	**90 DAS**	**120 DAS**
T_1	179.1	218.1	208.2	26.9	48.8	28.7	212.4	330.1	251.4
T_2	181.4	224.9	212.6	28.4	50.1	30.2	213.6	331.8	252.9
T_3	180.7	220.5	210.8	30.5	51.0	31.4	213.4	332.2	253.3
T_4	184.1	230.3	218.6	29.5	52.1	30.6	215.4	333.4	254.2
T_5	182.8	228.5	214.4	30.6	54.0	31.5	215.7	333.5	254.5
T_6	186.6	232.2	221.1	28.8	52.4	30.7	215.8	333.7	255.5
T_7	190.2	248.5	233.2	30.9	56.6	31.8	216.6	334.6	256.1
T_8	190.8	247.1	230.2	31.7	58.5	32.7	217.4	335.7	256.7
T_9	191.5	248.3	232.4	31.0	55.7	32.2	218.1	336.2	257.1
T_{10}	192.3	250.5	235.6	32.9	58.5	35.3	218.8	338.6	258.4
T_{11}	194.2	254.8	237.2	33.3	62.4	36.4	220.6	340.8	260.0
T_{12}	196.7	258.7	238.5	35.4	59.6	38.5	220.9	341.4	261.8
T_{13}	198.9	262.3	240.2	36.7	64.7	40.6	221.4	349.6	263.5
SE(m)	2.32	2.50	2.14	1.23	2.04	2.02	1.15	2.12	1.01
CD (*p*=0.05)	6.97	7.35	6.43	3.70	6.12	6.06	3.44	6.37	3.04
CV	3.14	1.80	2.43	4.14	6.34	5.23	3.48	4.13	2.15

T_1: RDF (Control), **T_2**: RDF + $ZnSO_4$, **T_3**: RDF + Calcium silicate, **T_4**: RDF + $ZnSO_4$ + Calcium silicate, **T_5**: RDF + ZnKJJ-4, **T_6:** RDF + ZnPGG-1, **T_7**: RDF + SiKPP-1, **T_8**: RDF + SiPYY-3, **T_9**: RDF + ZnKJJ-4 & ZnPGG-1, **T_{10}**: RDF + SiKPP-1 & SiPYY-3, **T_{11}**: RDF + ZnKJJ-4 + SiKPP-1, **T_{12}**: RDF + ZnPGG-1 + SiPYY-3, **T_{13}**: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3

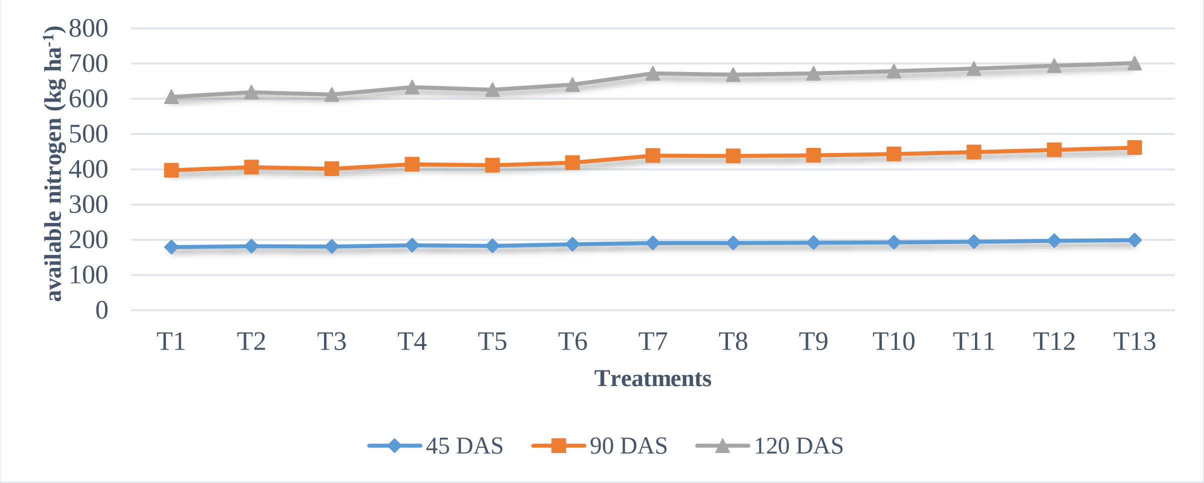

Figure 1. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available nitrogen (kg ha^{-1}) in soil under field conditions

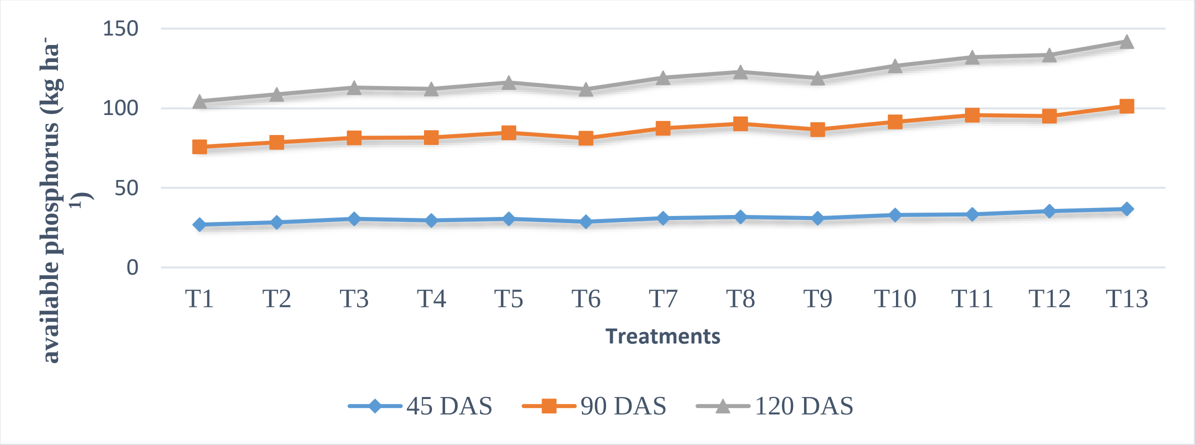

Figure 2. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available phosphorus (kg ha^{-1}) in soil under field conditions

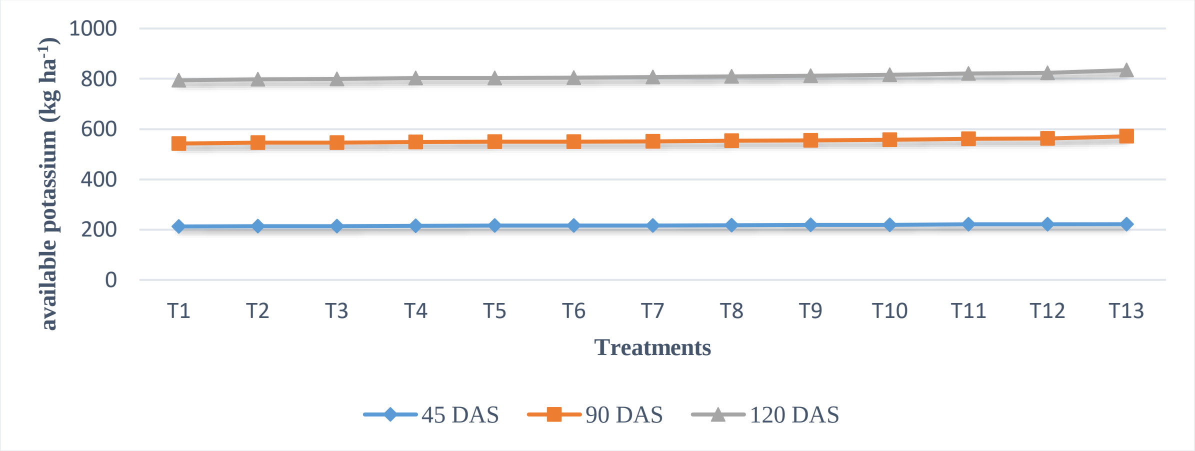

Figure 3. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available potassium (kg ha^{-1}) in soil under field conditions

Table 3. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available micro nutrients Zn and Si (ppm) in soil of direct sown paddy under field conditions

Treatments	**Available Zinc (ppm)**			**Available Silica (ppm)**		
	45 DAS	**90 DAS**	**120 DAS**	**45 DAS**	**90 DAS**	**120 DAS**
T_1	0.60	0.91	0.69	57.2	90.1	72.1
T_2	0.61	0.94	0.74	58.4	91.2	74.2
T_3	0.69	0.98	0.79	59.6	92.2	75.2
T_4	0.68	0.97	0.76	60.8	93.3	76.4
T_5	0.67	0.96	0.78	62.2	94.5	78.3
T_6	0.69	0.99	0.79	60.4	93.1	77.2
T_7	0.74	1.02	0.81	62.3	94.7	79.7
T_8	0.76	1.05	0.84	63.4	95.2	80.4
T_9	0.77	1.08	0.86	63.7	95.6	80.6
T_{10}	0.78	1.09	0.88	64.6	96.4	81.2
T_{11}	0.81	1.10	0.93	65.7	97.3	82.4
T_{12}	0.83	1.11	0.96	65.9	97.7	82.6
T_{13}	0.86	1.14	0.98	66.8	98.9	84.8
SE(m)	0.004	0.009	0.006	0.628	0.426	0.541
CD(*p*=0.05)	0.013	0.027	0.017	1.844	1.278	1.623
CV	1.428	1.668	1.354	1.744	1.365	1.416

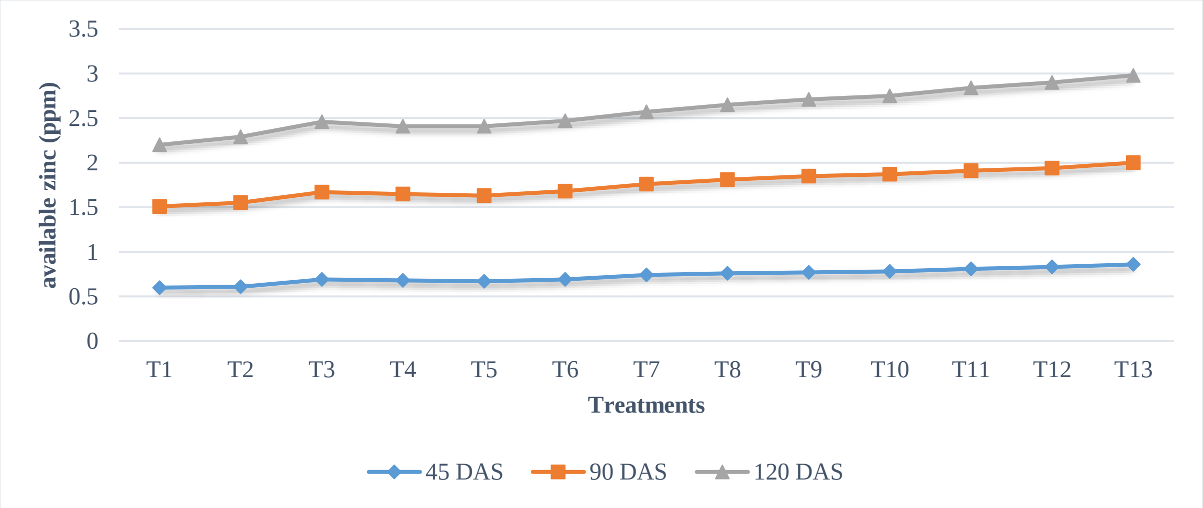

Figure 4. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available zinc (ppm) in soil under field conditions

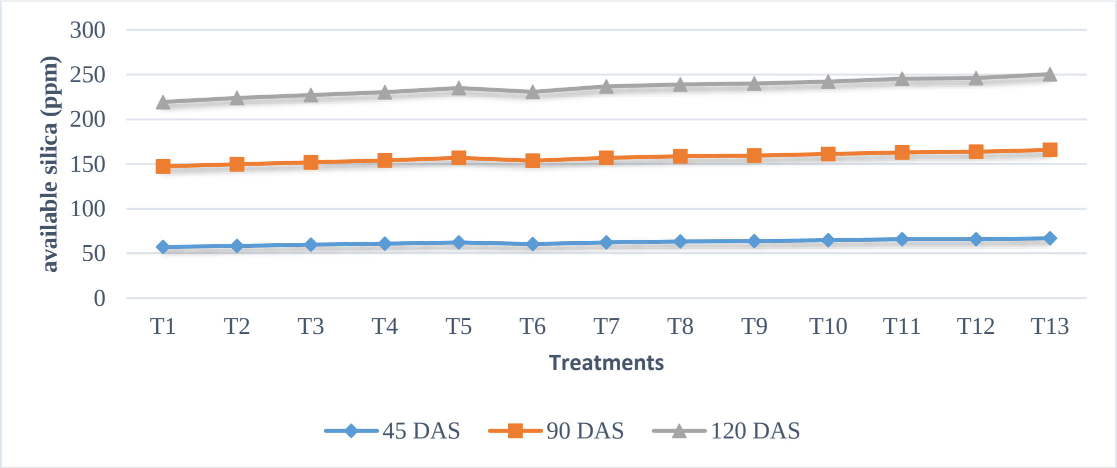

Figure 5. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available silica (ppm) in soil under field conditions

Table 4. Influence of zinc and silica solubilizing bacterial isolates and their consortia on N, P and K concentration (%) in plant of direct sown paddy under field conditions

Treatments	**Nitrogen (%)**			**Phosphorus (%)**			**Potassium (%)**		
	45 DAS	**90 DAS**	**120 DAS**	**45 DAS**	**90 DAS**	**120 DAS**	**45 DAS**	**90 DAS**	**120 DAS**
T_1	0.70	0.93	0.81	0.32	0.53	0.38	1.71	2.10	1.84
T_2	0.71	0.95	0.83	0.35	0.54	0.41	1.73	2.14	1.86
T_3	0.73	0.97	0.84	0.36	0.55	0.44	1.74	2.16	1.85
T_4	0.76	0.98	0.86	0.37	0.56	0.46	1.76	2.17	1.88
T_5	0.77	0.99	0.87	0.38	0.57	0.45	1.78	2.19	1.89
T_6	0.81	1.02	0.93	0.37	0.58	0.47	1.80	2.20	1.90
T_7	0.82	1.03	0.92	0.38	0.60	0.51	1.82	2.23	1.93
T_8	0.83	1.05	0.90	0.40	0.61	0.52	1.81	2.22	1.92
T_9	0.85	1.06	0.93	0.41	0.62	0.54	1.83	2.24	1.94
T_{10}	0.86	1.07	0.94	0.42	0.62	0.53	1.85	2.26	1.96
T_{11}	0.85	1.06	0.95	0.43	0.63	0.55	1.84	2.25	1.95
T_{12}	0.87	1.08	0.96	0.44	0.64	0.56	1.85	2.28	1.96
T_{13}	0.89	1.10	0.98	0.46	0.67	0.58	1.87	2.29	1.98
SE(m)	0.005	0.006	0.007	0.002	0.004	0.006	0.015	0.006	0.008
CD(*p*=0.05)	0.016	0.019	0.022	0.062	0.013	0.019	0.046	0.018	0.017
CV	1.146	2.182	1.465	1.852	2.179	1.284	2.554	1.246	1.465

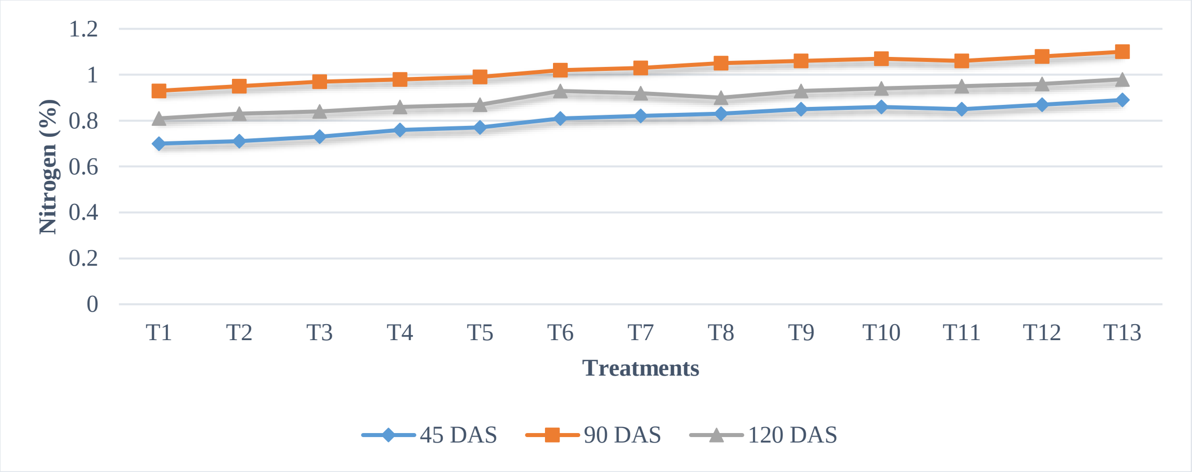

Figure 6. Influence of zinc and silica solubilizing bacterial isolates and their consortia on nitrogen concentration (%) in plant under field conditions

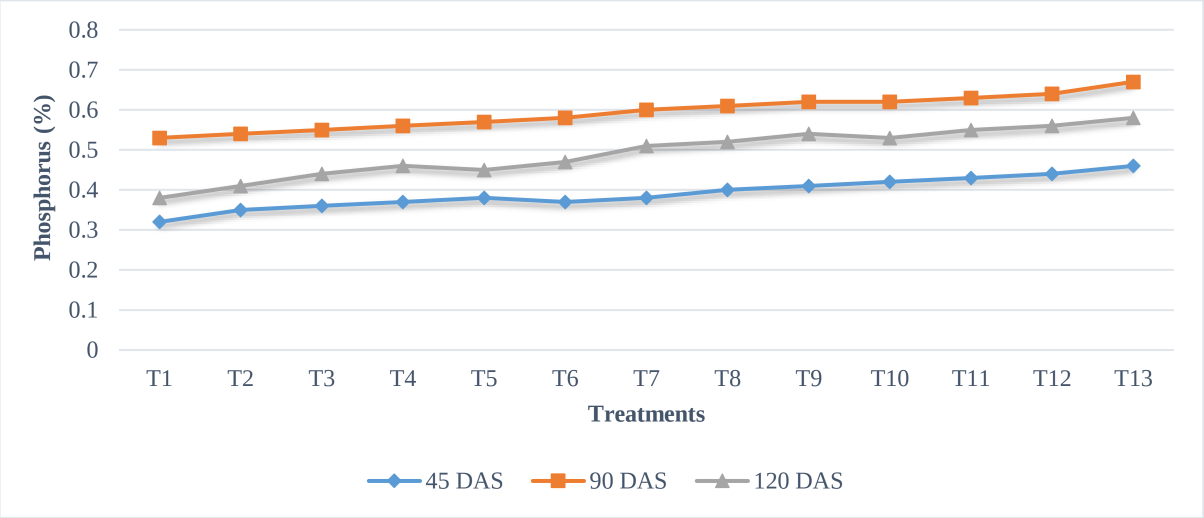

Figure 7. Influence of zinc and silica solubilizing bacterial isolates and their consortia on phosphorus concentration (%) in plant under field conditions

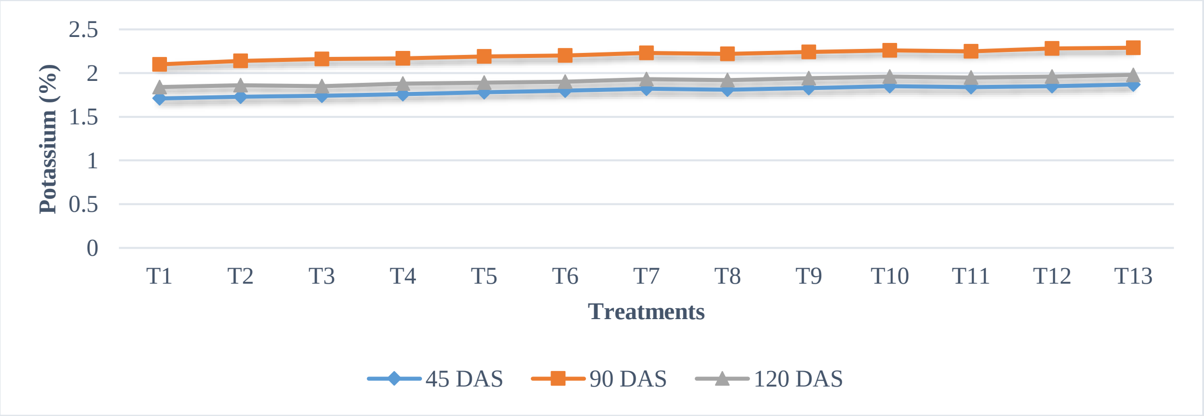

Figure 8. Influence of zinc and silica solubilizing bacterial isolates and their consortia on potassium concentration (%) in plant under field conditions

References :

1. Alagawadi AR and Gaur AC. Inoculation of zinc solubilizing pseudomonas bacterial isolates their effect on yield of paddy. *Tropical Agriculture*: 2012; 5:16-18.
2. Anusha A, Kadali SK, Udayasaukar A and Thakurs KD. Influence of biofertilizers on uptake of NPK in soils and eggplant. *International Journal of Analytical Microbiology and Applied Sciences*. 2017; 6 (12): 1259-1263.
3. Bennett PC, Choi WJ and Rogers JR. Microbial destruction of feldspars. *Mineralogical Magazine*. 1998; 8 (62A): 149-150.
4. Bradacova K, Kandeler E, Berger N, Ludewig U and Neumann G. Microbial consortia inoculants stimulate early growth of maize depending on nitrogen and phosphorus supply. *Plant, Soil and Environment*. 2020. 66 (3): 105-112.
5. Chandrakala C, Voleti SR and Bandeppa S. Silicate solubilization and plant growth promoting potential of *Rhizobium sp.* Isolated from Rice Rhizosphere. *Silicon.* 2019; 11, 2895-2906.
6. Jackson ML. *Soil Chemical Analysis*. Prentice- Hall of India private limited. New Delhi.1973.
7. Lindsay WL and Norvell WA. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of American Journal.* 1978; 41:421-428.
8. Maleva WM, Hussein MM, Mehanna HM and El-Moneim DA. Bacteria polysaccharides elicit resistance of wheat against some biotic and abiotic stress. *International Journal of Pharmaceutical Sciences Review and Research*. 2017; 29 (2): 50: 292-298.
9. Manasa S, Mahadevaswamy G, Yadav R, Nagaraj MN and Gundappagol RC. *In vivo* efficacy of zinc solubilizing bacteria on available zinc content, growth and yield attributes of paddy (*Oryza sativa* L*). Journal of Agriculture and Ecology Research International.* 2019; 1-9.
10. Muralikannan N. Biodissolution of silicate, phosphate and potassium by silicate solubilizing bacteria in rice ecosystem. M. Sc (Ag) thesis submitted to Tamil Nadu Agricultural University. Coimbatore. 1996; pp: 125.
11. Olsen SR, Code CL, Watanable FS and Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Development Agency, Washington DC, Circular Number.* 1954; 939. 1-19.
12. Piper CS. Soil and Plant Analysis. Hons publishers, Bombay. 1966.
13. Prajapati MC and Modi HA. Isolation of two potassium solubilizing fungi from ceramic industry soils. *Life Sciences Leaflets.* 2012. 5: 71-75.
14. Rodriguiz H, Gonzalez T, Goire I and Bashan Y. Gluconic acid production and phosphate solubilization by the plant growth promoting bacterium *Azospirillum*sp. *Nature.* 2004; 91: 552-555.
15. Sang MK, Muhammad W, Raheem S, Young HY and Sajjad A. Isolation and characterization of a novel silicate-solubilizing bacterial strain *Burkholderiaeburnea* CS4-2 that promotes growth of japonica rice (*Oryzasativa* L. cv. Dongjin). *Soil Science and Plant Nutrition.* 2017; 63(3). 233-241.

16. Snyder GH.Development of a silicon soil test for Histol-grown rice. Belle Grade EREC Research report EV-1991-2, University of Florida, Belle grade, FL. 1991.
17. Subbiah BV and Asija CL. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. 1956; 25: 259-260.
18. Tandon HLS. Analysis of plant material for macro and micronutrients. In method of analysis of soils, plant, water and fertilizer. 1993. pp. 49-82.
19. Thompson JP. Correction of dual phosphorous and zinc deficiencies of linseed with cultivars of vesicular-arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry*. 1996; 28: 941-951.
20. Yuvaraj K. Effect of biofertilizers and inorganic fertilizers on soil health, growth and yield of Rice (*Oryzasativa* L.) crop. M. Sc. (Agri.) Thesis, Punjab Agricultural University, Ludhiana, India. 2016.