EFFECT OF ZINC AND SILICA SOLUBILIZING MICROORGANISMS AND THEIR CONSORTIA ON NUTRIENT STATUS IN SOIL AND PLANT ON PADDY

Abstract

Effect of zinc and silica solubilizing bacteria and their consortia on paddy was studied under pot culture conditions at Agricultural Research Station, Janagamaheswarapuram, under Acharya NG Ranga Agricultural University, Lam, Guntur, India. 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 (189.3, 249.4 and 239.7 kg ha^{-1}), available phosphorus (34.6, 61.8 and 38.5 kg ha^{-1}),potassium (214.2, 347.9 and232.1 kg ha^{-1}), zinc (0.78, 0.99 and 0.86 ppm) and silica (60.1, 90.8 and 78.4 ppm) were recorded in T_{13} (RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3) at 45, 90 and 120DAS. In plant, nitrogen (0.79, 0.99 and 0.89 %), phosphorus (0.37, 0.58 and 0.49 %) and potassium (1.78, 2.18 and 1.89 %) were significantly highest in T_{13}. There was increase in available nutrient content upto 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.

Key words: Paddy,Zinc solubilizing bacteria, Silica solubilizing bacteria, Zinc and silica bacterial consortia and nutrients.

Introduction

Plants need several macro and micro nutrients for their growth and development. Nitrogen is ubiquitous in the environment. It is important plant nutrient and forms mobile compounds in soil. Phosphorus helps a plant convert other nutrients into usable building blocks for growing. Potassium plays a crucial role in the regulation of water in plants (osmoregulation). Both uptake of water through plant roots and its loss through the stomata are affected by potassium. 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 (Rodriguiz *et al.,* 2004).Importance of Zinc

Solubilizing Bacteria (ZnSB) and Silica Solubilizing Bacteria (SiSB) and their consortia improvedthe bioavailable fraction of N, P, K, Zn and Si to host plant for enlightening the crop growth, yield and quality (Thompson, 1996). 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 (Sang *et al.*, 2017).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 combinationsunder pot culture and field conditions.

Materials and methods

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

Treatments:

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

Paddy variety, MTU-7029 (Swarna) was sown in pots by adopting 20 cm X 10 cm spacing at ARS, Jangamaheswarapuram under Acharya NG Ranga Agricultural University, Lam, Guntur, India. Thirteen treatments, replicated thrice, were imposed incompletely randomized designas detailed below:

Soil sample collection and processing

Soil samples collected from all the 39 potsat45, 90 and 120 DASwere dried under shade, gently ground with wooden hammer, sieved through 2 mm sieve and stored in labelled new polythene lined cloth bags. 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.

Estimation of available nitrogen in soil sample

The alkaline potassium permanganate method of Subbiah and Asija (1956) was followed for the estimation of available N content in soil. Twenty grams of soil was taken in 800 ml dry Kjeldahl flask and 20 ml of distilled water was added. Then 100 ml,each of 0.32% $KMnO_4$and 2.5% NaOH solutions were added. The froth formation during boiling was prevented by adding liquid paraffin (1ml) and bumping by adding a few glass beads. Contents were distilled in Kjeldahl assembly at a steady rate and liberated ammonia was collected in a conical flask (250ml)containing 20 ml of boric acid solution (with mixed indicator). The pink colour of the boric acid solution turns to green with the absorption of ammonia. 150 ml distillate collected in about 30 minutes was titrated with 0.02 N H_2SO_4 till the original shade (pinkish) was obtained. Blank titration was performed without soil and expressed in kg ha^{-1}.

$$\text{Available N (kg ha}^{-1}\text{)} = \frac{(A-B)\times(\text{N of acid})\times 0.014\times 100}{\text{weight of the soil}}$$

Where,

A (ml) = volume of standard acid required for soil

B (ml) = volume of standard acid required for blank

N = Normality of sulphuric acid.

Estimation of available phosphorus in soil sample

Available P in soil was determined by Olsen's method (Olsen *et al.,* 1954).Two and half g air dried soil was placed into a 250 ml conical flask and added a pinch ofDarco charcoal and 50 ml of Sodium bicarbonate extractant (0.5 M) was added. Then the contents were shaken for 30 minutes and filtered through Whatman No 1 filter paper, 5 ml of clear and colourless filtrate was transferred into a 25 ml volumetric flask, 2-3 drops of p-nitrophenol was added, it turns to yellow colour. Then the filtrate was titrated with 5N H_2SO_4 drop by drop till yellow colour disappears, to this 5 ml of Olsen's extract solution was added then diluted up to 20 ml with distilled water. Then 4 ml of ascorbic acid was added and volume was made up to 25 ml and shaken well. After 5 minutes and the intensity of the blue colour developed was measured using 660 nm, blank was run without soil, and standard curve of P was plotted. Available P was expressed in kg ha^{-1}.

Calculation:

$$\text{Available Phosphorus} = R \times \frac{\text{Total volume of the extract}}{\text{weight of the soil taken}} \times \frac{25}{\text{volume of aliquot}} \times 2.24 \times 2.29$$

Available Phosphorus (kg ha^{-1}) = R×513

Where R = ppm of P in the aliquot

Estimation of available potassium in soil sample

Available potassium content in soil was extracted by using 1N neutral normal ammonium acetate as described by Jackson (1973).The concentration of potassium in the extractant was determined by flame photometer and expressed in kg ha^{-1}.

Calculation:

$$\text{Available Potassium (kg ha}^{-1}) = R \times \frac{\text{Total volume of the extract}}{\text{weight of the soil taken}} \times 2.24 \times 1.2$$

Where R = ppm of K in the extract

Estimation of available zinc in soil sample

Estimation of available zinc based on the principle of Diethylene Triamine Penta Acetic acid (DTPA), a chelating agent, combined with free metal cations in soil solution to form ring like soluble complexes or chelates and separate them from soil which are then estimated by Atomic Absorption Spectrophotometer. Standard Solution for Zn 1000 ppm, (commercial) was used. As per the standard procedure *i.e.*, 10 g soil sample was taken into 10 ml conical flask, added 20 ml DTPA extractant solution DTPA extracting solution (pH7.3 ±0.5)and shaken for 2 hours and then filtered,later placed in the AAS, calibrated by standard solution of different concentration and reading of the unknown solution was recorded (Lindsay and Novell 1978).

Where,

Reading of unknown solution = X

Dilution factor = 2

Concentration in soil = X × 2 ppm

Estimation of available silica in soil sample

Estimation of available silica based on method of 0.5M Acetic Acid Extraction for Silicon (Snyder, 1991).Air-dried sieved (< 2 mm) soil (10 cm^3) was scooped out into a 75 ml plastic extraction bottle. 25 ml of the 0.5 M acetic acid extracting solution was added to each bottle with automatic dispenser and left overnight (approximately 20 hours). The mixture was shaken on reciprocating shaker (120 OPM) for 50 minutes, filtered and extract was collected into plastic containers. Using working standards (0.0,5.0, 10.0 and 20.0 ppm Si) Si in the soil extracts was measured by spectrophotometer. Si in the soil was calculated:

Si (ppm) in soil = Si in soil extract (ppm) × 2.5.

Estimation of nutrient (N, P and K) contentin plant samples

Collection, preparation and analysis of plant samples

The plant samples were collected at 45 DAS, 90 DASand 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.

Estimation of nitrogen concentration in plant sample

Nitrogen concentration in plant samples were estimated by Kelplusmethod (Piper, 1966) after digesting the organic matter by H_2SO_4 and H_2O_2.

Calculation:

The nitrogen contentin 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

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

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

Estimation of phosphorus concentration in plant sample

The phosphorus content in the digested plant samples was determined by Vanadomolybdo-phosphoric acid yellow colour method using spectrophotometer at 470 nm wavelength (Tandon, 1993).

Calculation:

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

Estimation of potassium concentration in plant sample

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(Jackson, 1973).

Calculation:

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

$$= R \times 0.01$$

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 138.42 kg ha^{-1}(Table. 1) in the initial soil sample. All the treatments showed increased available nitrogen content at 45-120 DAS. Highest available nitrogen was recorded in T$_{13}$: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (189.3 kg ha^{-1}) followed by T$_{12}$ (188.2 kg ha^{-1}), T$_{11}$ (187.3 kg ha^{-1}) and T$_{10}$ (186.3 kg ha^{-1}) at 45

DAS.Significantly highest available nitrogen content at 90 DAS was recorded in T_{13} (249.4 kg ha^{-1}) than in T_{12} (244.6 kg ha^{-1}). At 120 DAS available nitrogen content was decreased with 239.7 kg ha^{-1}nitrogen availability in T_{13}, followed by T_{12} (235.6 kg ha^{-1}) (Table 2& Fig 1).The above results were accordance with Padmaja*et al.,* (2019) who evaluated silica solubilizing bacteria along with vermicompost and farm yard manure and recorded the highest available nitrogen 299.54 kg ha^{-1} in crop over the control and individual inoculants. Similar findings were reported earlier by Molla*et al.* (1984) and Gupta *et al.* (1994).

Available phosphorus in soil

Available phosphorus content was initially 23.62 kg ha^{-1}(Table 1). All the treatments exhibited increased available content of phosphorus at 45-120 DAS. The highest phosphorus availability was attained in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (34.6 kg ha^{-1}), significantly superior to T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 32.3 kg ha^{-1}. At 90 DAS increased available phosphorus was registered in T_{13} (61.8 kg ha^{-1}), significantly superior to T_{11} (RDF + ZnKJJ-4 + SiKPP-1) *i.e.,* 59.5 kg ha^{-1}. At 120 DAS available phosphorus content decreased in T_{13} to 38.5 kg ha^{-1} superior to T_{12} (36.4 kg ha^{-1})(Table 2&Fig 2). These results indicated the superiority of $T_{13}$for available phosphorus in soil.Kannaiyan*et al.* (2004) studied solubilization of silicate and concurrent release of phosphorous and potassium inrice ecosystem and reported that bacteria are plentiful in soiland few of them have the capacity to solubilize silicate minerals,silica. Phosphorous was released concurrently and enhanced grain yield.Sundara*et al.* (2002) found that application of PSB, *Bacillus megatherium* var. *phosphaticum,* increased the PSB population in the rhizosphere and hence increment in P availability in the soil.

Available potassium in soil

Available potassium content was 198.25 kg ha^{-1}(Table 1) in the initial soil sample. At 45 to 120 DAS all the treatments showed increased potassium compared to initial. At 45 DAS the highest available potassium was recorded in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (214.2 kg ha^{-1}) significantly superior to T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 211.8 kg ha^{-1}. Similarly highest available potassium was recorded in T_{13} (347.9 kg ha^{-1}) at 90 DAS significantly superior to T_{12} (343.5 kg ha^{-1}). At 120 DAS available potassium decreased to 232.1 kg ha^{-1} in T_{13}, followed by T_{12} (230.4 kg ha^{-1})(Table 2 & Fig 3).Thus T_{13} was statistically superior to all the other treatments with respect to available potassium in the soil.

In the present study available potassium was influenced by the treatments at the beginning of the experiment. Silica solubilizing bacteria like*Bacillus mucilaginosus*promoted the growth of eggplant through increasing the availability of potassium and uptake. *B.mucilaginosus* was also found to increase the availability of potassium in the soil, uptake of potassium in roots and the growth of cucumber and pepper (Han *et al.*, 2006).

Available zinc in soil

Available zinc content was 0.42 ppm(Table 1) in the initial soil sample. At 45 to 120 DAS all the treatments showed increased available zinc content compared to initial value. Highest available zinc was recorded in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (0.78 ppm), superior to T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 0.74 ppm at 45 DAS. At 90 DAS highest available nitrogen content was recorded in T_{13} (0.99 ppm), followed by T_{12} (0.97 ppm) and T_{11} (0.94 ppm). At 120 DAS available zinc content decreased in all the treatments with 0.86 ppm in T_{13} followed by T_{12} (0.82 ppm) and T_{11} (0.80 ppm) and were statistically on par (Table 3 & Fig 4).The above results are in accordance with Dinesh *et al.* (2018) who reported that treatment with 75% Zn + ZnSB2 (12.69 ± 2.96 mg kg^{-1}) resulted in the highest available zinc in soil in paddy over the control.

Available silica in soil

Available silica content was 44.0 ppm (Table 1) in the initial soil sample. At 45 to 120 DAS all the treatments showed increased available silica content compared to initial. Highest available silica was recorded in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (60.1 ppm), followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) and T_{11} (RDF + ZnKJJ-4 + SiKPP-1) *i.e.*, 59.4 and 59.3 ppm and were statistically on par at 45 DAS. Available silica content was highest in T_{13} (90.80 ppm), followed by T_{12} (89.6 ppm) and superior to T_{11}(89.2 ppm). At 120 DAS available silica content decreased to 78.4 ppm in T_{13}, followed by T_{12} and T_{11} (77.6 and 77.1 ppm) and were statistically on par(Table3& Fig 5).Available silica was observed highest in the T_{13} treatment. It might be due to silica solubilizing potentiality of the isolates used in the T_{13} that had directly impact on the available silica in soil. Similar results were found by Mongia*et al.* (2003)who observed the 114 ppmavailable silica content in soil treated with silica solubilizing bacteria + calcium silicate in paddy crop.

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

Percent nitrogen in plant

At 45 DAS significantly highest nitrogen concentration was obtained in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (0.79%), followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 0.78% while least was observed in T_1 (control) *i.e.,* 0.61%. At 90 DAS maximum plant nitrogen concentration was obtained in T_{13} (0.99%), followed by T_{12} (0.97%) whereas the lowest was recorded in T_1 *i.e.,* 0.82 %. From 90 DAS to 120 DAS there was decrease in the concentration of nitrogen in plant. At 120 DAS significantly highest nitrogen concentration was recorded in T_{13} (0.89%), followed by T_{12} (0.87%) and lowermost was observed in T_1 *i.e.,* 0.72% (Table 4& Fig 6).PGPR (*Bacillus sphaericus* UPMB10 and *Azospirillum* Sp7) inoculation, increased (28-40 %) the N concentration in roots and leaves, which consequently resulted in greater rise of N as evidenced by more (129-176 %) total dry matter production. This increase in N concentration consequently increased N accumulation which certainly promoted nitrogen fixation by the PGPR (Baset*et al*., 2010).

Percent phosphorus in plant

Phosphate solubilizing microorganisms could increase growth and concentration leading to elevated crop tolerance under water deficit stress. At 45 DAS significant concentration of plant phosphorus was found in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (0.37 %) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.,* 0.36 %. At 90 DAS significantly highest plant phosphorus concentration was recorded in T_{13} (0.58 %), whereas T_{12} showed 0.55 %. At 120 DAS highest phosphorus concentration was obtained in T_{13} (0.49 %), followed by T_{12} (0.47 %), and T_{11} (0.46 %) and were statistically on par (Table 4 & Fig 7).There are several microorganisms, which can also solubilize the cheaper sources of phosphorus, such as rock phosphate. Bacteria like *Pseudomonas* and *Bacillus* are widely used in the organic production system and also important phosphate solubilizing microorganisms, resulting in improved growth and yield of crops (Dobereiner, 1997).

Percent potassium in plant

Better concentration of potassium might have maintained the turgor of cells and stomatal conductance by osmoregulation.At 45 DAS significant plant potassium concentration was obtained in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (1.78 %), followed by T_{12}: RDF + ZnPGG-1 + SiPYY-3 (1.76 %). At 90 DAS highest plant potassium concentration was obtained in T_{13} (2.18 %), followed by T_{12} (2.17 %), T_{11} (2.16 %),

T_{10} (2.14 %)and T_9 (2.12 %). At 120 DAS significantly higher potassium concentration was recorded in T_{13} (1.89 %), followed by T_{10} (RDF + SSB 1 & 2) and T_{12} (RDF + ZSB 2 + SSB 2) *i.e.*, 1.87 %(Table 4 & Fig 8).

The solubilized silicon interacts with other nutrients, particularly, potassium. Si in solution increase potassium availability to plants by reversing its fixation as Si competes for potassium fixation sites in the soil thus application of silicates released more of potassium in soil system (Chinnasami and Chandrasekaran, 1978).The PGPRs, *Pseudomonaskoreensis* and *Bacilluscoagulans*likely improve the uptake of potassium in plant. Potassium will help the plant in different abiotic and biotic adverse environment (Baig*et al.*, 2014).

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.

Table 1. Initial Physico-chemical and microbiological properties of soil used in pot culture experiment.

Soil property	**Pot**
Available N (kg ha^{-1})	138.42
Available P (kg ha^{-1})	23.26
Available K (kg ha^{-1})	198.25
Available Zn (ppm)	0.42
Available Si (ppm)	44.0

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 in pot culture experiment

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	174.0	190.2	189.2	24.8	44.9	26.6	202.1	333.4	220.3
T_2	176.7	200.6	199.4	26.3	47.2	28.1	204.2	334.1	222.2
T_3	175.2	195.8	191.6	28.4	49.2	29.2	206.8	337.9	224.8
T_4	177.1	218.4	2004	27.5	48.4	28.5	206.4	337.4	224.2
T_5	178.2	225.4	209.6	28.3	50.0	29.4	207.4	338.1	225.2
T_6	177.8	222.1	207.2	26.7	48.5	28.6	207.6	338.4	225.6
T_7	179.0	228.6	218.1	28.8	52.7	29.7	208.1	338.9	226.4
T_8	183.2	232.2	221.8	29.6	54.6	30.6	208.3	339.3	226.8
T_9	183.5	233.2	227.3	28.9	51.8	30.1	209.7	340.7	228.1
T_{10}	186.3	233.4	227.2	30.8	56.6	33.2	210.0	341.6	228.3
T_{11}	187.3	238.9	228.1	31.2	59.5	34.3	210.2	342.9	229.6
T_{12}	188.2	244.6	235.6	32.3	58.7	36.4	211.8	343.5	230.4
T_{13}	189.3	249.4	239.7	34.6	61.8	38.5	214.2	347.9	232.1
SE(m)	2.298	2.481	2.138	1.214	2.039	2.041	1.156	2.131	1.026
CD(P=0.05)	6.894	7.443	6.414	3.642	6.117	6.123	3.468	6.393	3.078
CV	3.264	2.914	2.358	4.624	3.264	4.521	2.236	3.851	2.265

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

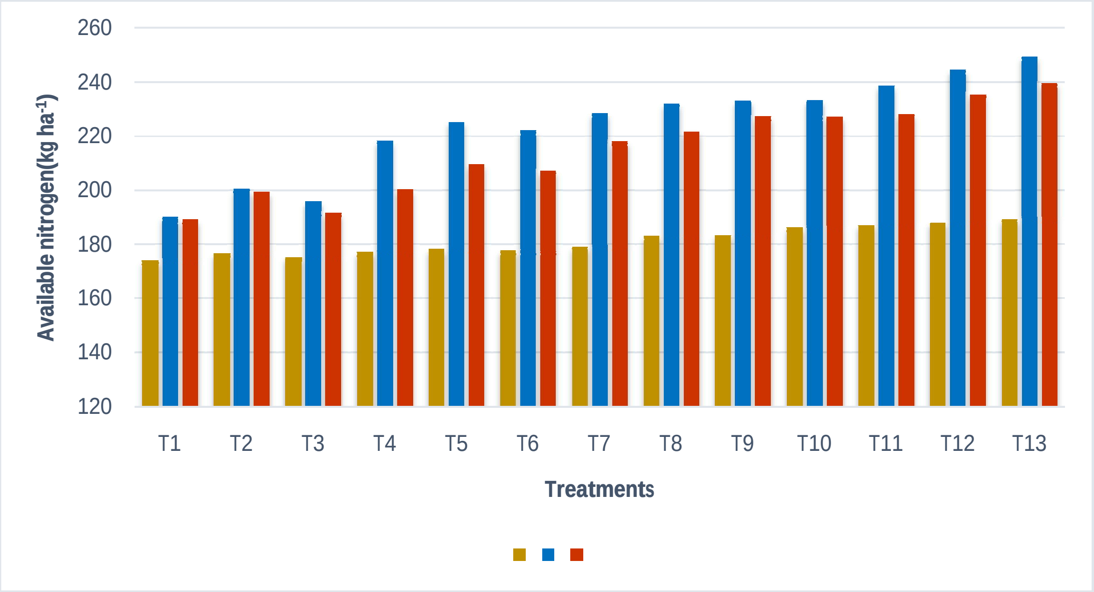

Figure 1. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available nitrogen (kg ha^{-1}) of soil in pot culture experiment

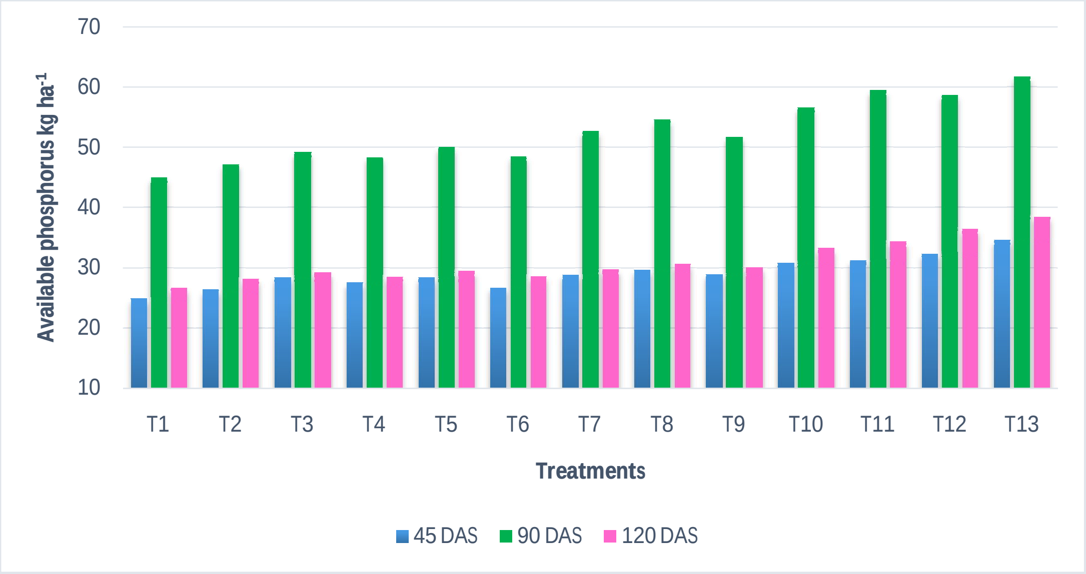

Figure 2. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available phosphorus (kg ha^{-1})of soil in pot culture experiment

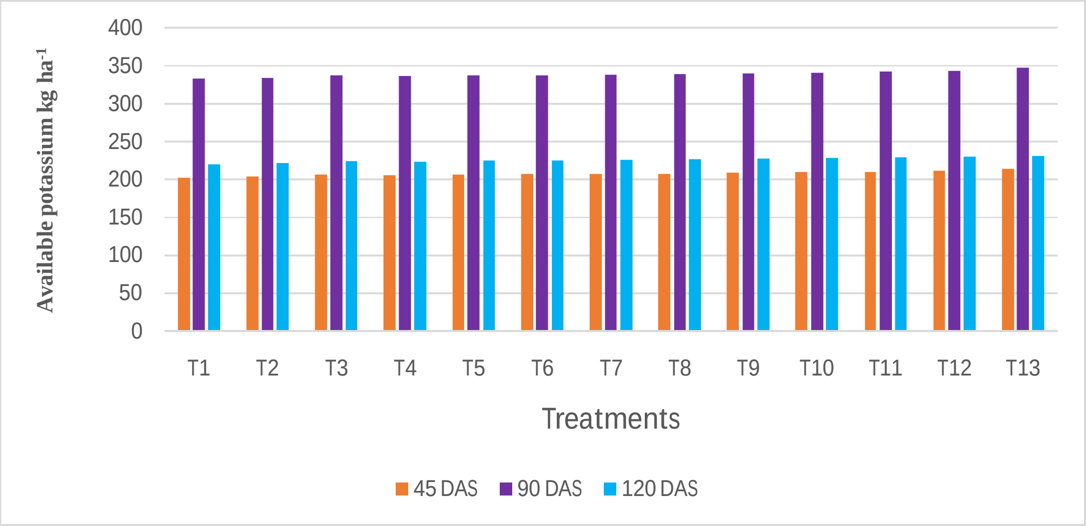

Figure 3. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available potassium (kg ha^{-1}) of soil in pot culture experiment

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 in pot culture experiment

Treatments	**Available Zinc (ppm)**			**Available Silica (ppm)**		
	45 DAS	**90 DAS**	**120 DAS**	**45 DAS**	**90 DAS**	**120 DAS**
T_1	0.52	0.70	0.62	51.4	80.8	69.3
T_2	0.54	0.72	0.64	52.3	82.6	70.9
T_3	0.59	0.78	0.68	53.1	83.1	71.8
T_4	0.58	0.76	0.66	54.2	84.2	72.7
T_5	0.57	0.74	0.66	55.2	85.6	73.6
T_6	0.59	0.79	0.68	54.7	84.8	72.4
T_7	0.61	0.82	0.71	56.1	86.2	74.1
T_8	0.65	0.83	0.74	57.3	87.4	75.6
T_9	0.66	0.86	0.76	57.8	87.6	75.7
T_{10}	0.67	0.87	0.78	58.4	88.8	76.4
T_{11}	0.72	0.94	0.80	59.3	89.2	77.1
T_{12}	0.74	0.97	0.82	59.4	89.6	77.6
T_{13}	0.78	0.99	0.86	60.1	90.8	78.4
SE(m)	0.006	0.008	0.007	0.541	0.443	0.624
CD(P=0.05)	0.018	0.024	0.021	1.623	1.329	1.872
CV	1.512	1.546	1.186	1.524	1.465	1.564

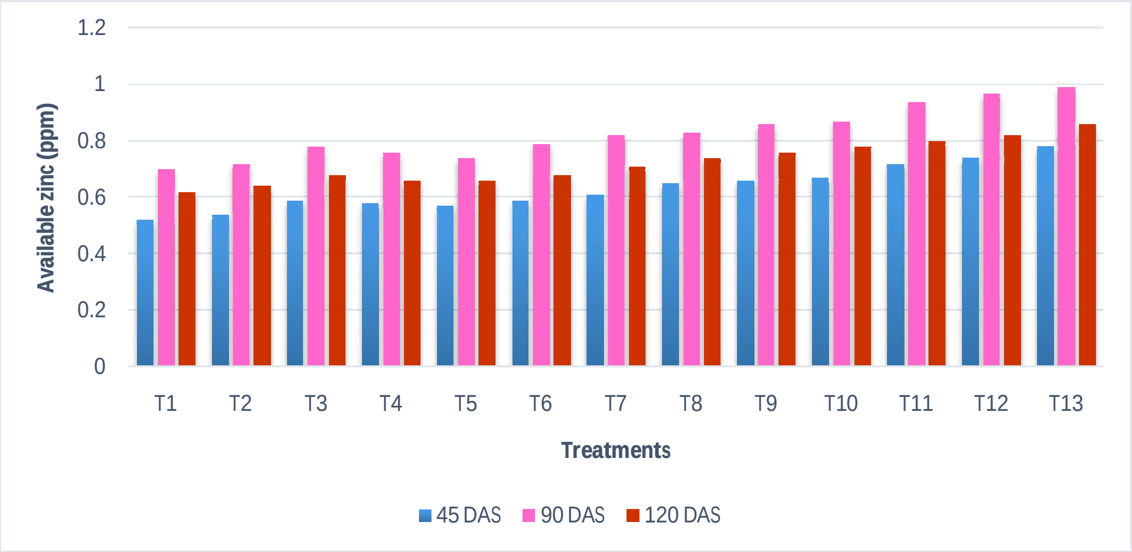

Figure 4. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available zinc (ppm) of soil in pot culture experiment

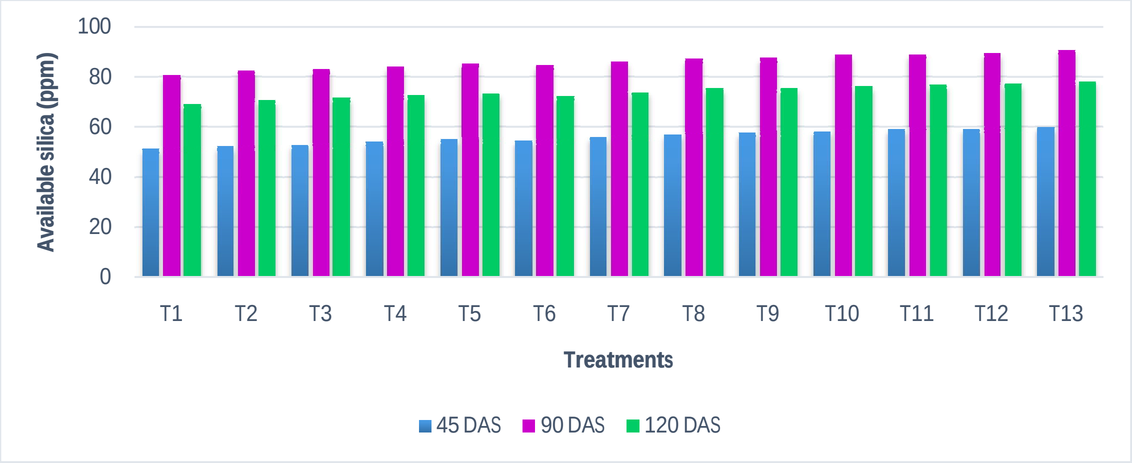

Figure 5. Influence of zinc and silica solubilizing bacterial isolates and their consortia on available silica (ppm) of soil in pot culture experiment

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 in pot culture experiment

Treatments	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS
T_1	0.61	0.82	0.72	0.21	0.44	0.30	1.62	2.02	1.73
T_2	0.63	0.84	0.74	0.26	0.45	0.32	1.64	2.03	1.75
T_3	0.64	0.86	0.75	0.27	0.46	0.35	1.65	2.04	1.76
T_4	0.67	0.88	0.78	0.28	0.47	0.37	1.67	2.07	1.78
T_5	0.66	0.89	0.76	0.29	0.48	0.36	1.69	2.06	1.80
T_6	0.72	0.90	0.84	0.28	0.49	0.38	1.70	2.08	1.81
T_7	0.73	0.92	0.83	0.29	0.50	0.42	1.73	2.10	1.84
T_8	0.74	0.94	0.81	0.30	0.52	0.43	1.72	2.09	1.83
T_9	0.76	0.93	0.84	0.32	0.53	0.45	1.74	2.12	1.85
T_{10}	0.77	0.95	0.85	0.33	0.53	0.44	1.76	2.14	1.87
T_{11}	0.76	0.96	0.86	0.34	0.54	0.46	1.75	2.16	1.86
T_{12}	0.78	0.97	0.87	0.36	0.55	0.47	1.76	2.17	1.87
T_{13}	0.79	0.99	0.89	0.37	0.58	0.49	1.78	2.18	1.89
SE(m)	0.006	0.005	0.008	0.004	0.005	0.006	0.007	0.004	0.005
CD(P=0.05)	0.018	0.015	0.024	0.012	0.015	0.018	0.021	0.013	0.015
CV	1.624	2.764	1.344	1.346	1.146	1.462	2.125	1.542	1.346

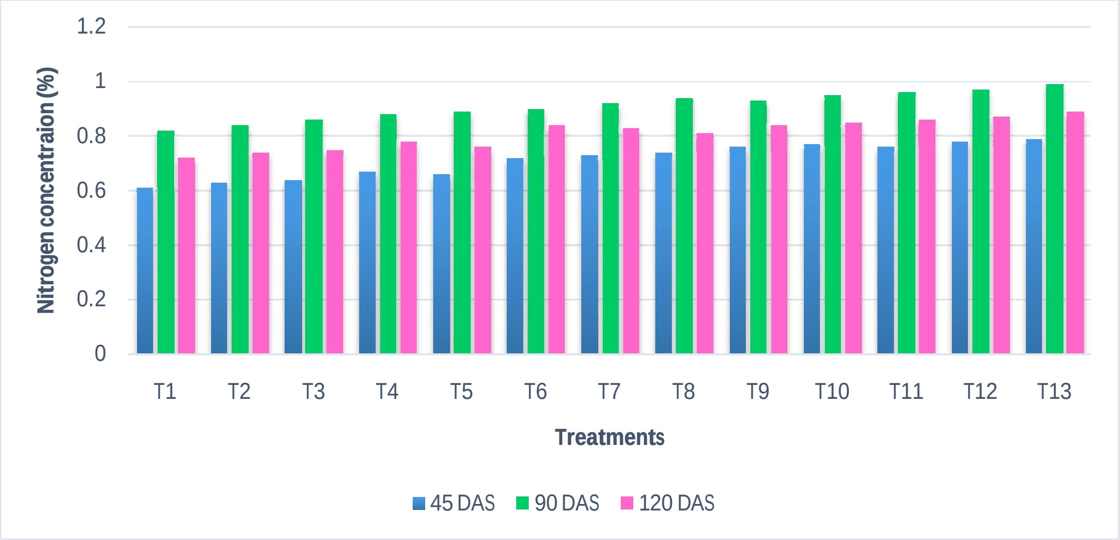

Figure 6. Influence of zinc and silica solubilizing bacterial isolates and their consortia on nitrogen concentration (%) of plant in pot culture experiment

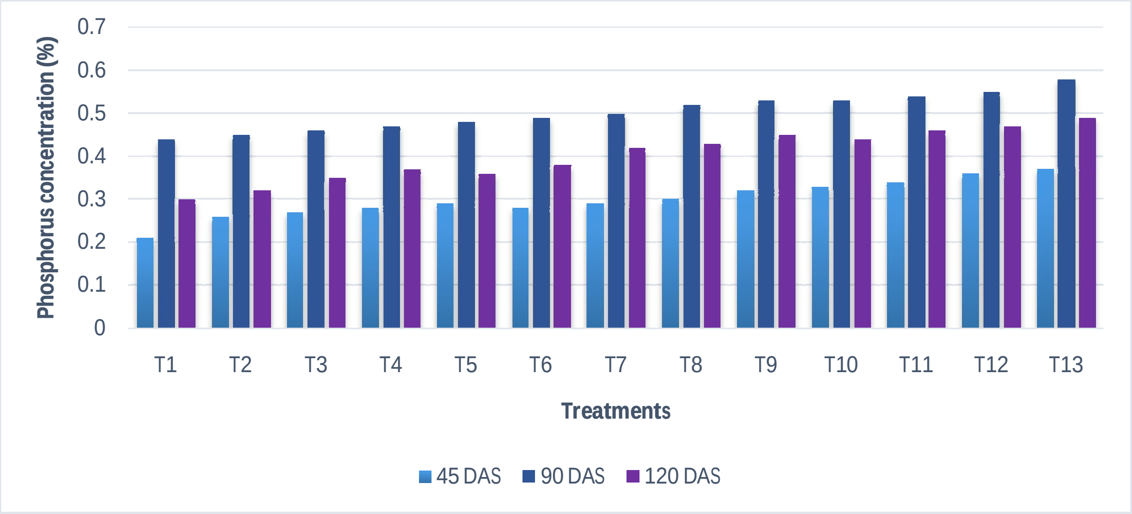

Figure 7. Influence of zinc and silica solubilizing bacterial isolates and their consortia on phosphorus concentration (%) of plant in pot culture experiment

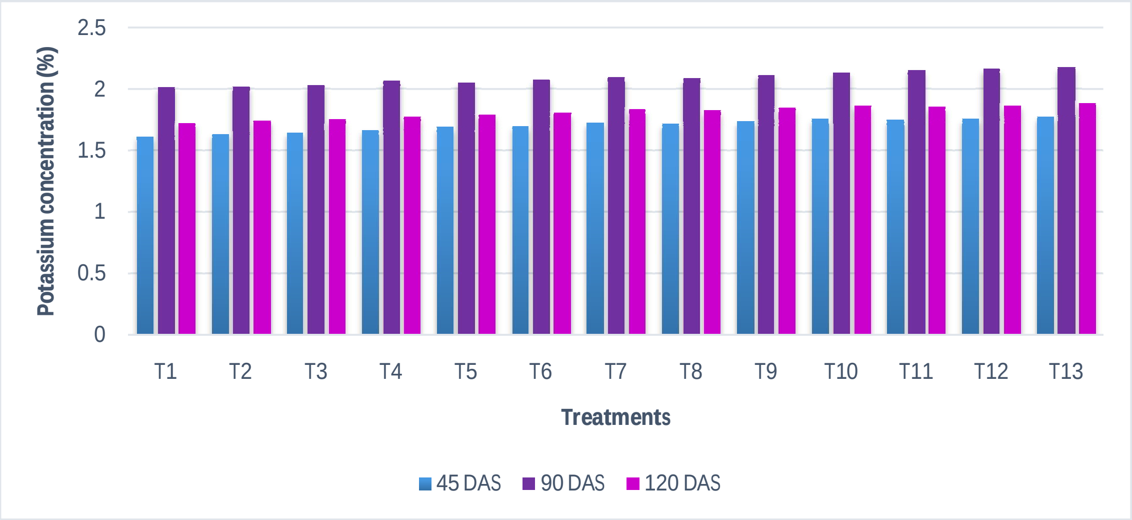

Figure 8. Influence of zinc and silica solubilizing bacterial isolates and their consortia on potassium concentration (%) of plant in pot culture experiment

References :

1. Baig, K.S., Arshad, M., Khalid, A., Hussain, S., Abbas, M.N and Imran, M. 2014. Improving growth and yield of maize through bioinoculants carrying auxin production and phosphate solubilizing activity. *Soil and Environment*. 33 (2): 159-168.
2. Baset, M., Shamsuddin, Z.H., Wahab, Z and Marziah, M. 2010. Effect of plant growth promoting rhizobacterial (PGPR) inoculation on growth and nitrogen incorporation of tissue-cultured 'musa' plantlets under nitrogen-free hydroponics condition. *Australian Journal of Crop Science*. 4 (2): 85-92.
3. Chinnasami, K.N and Chandrasekaran, S. 1978. Silica status in certain soils of Tamil Nadu. *Madras Agricultural Journal.* 65:743- 746.
4. Dinesh, R., Srinivasan, V., Hamza, S., Sarathambal, C., Gowda,S.A., Ganeshamurthy, A.N., Gupta, S.B., Nair, V.A., Subila, K.P.,Lijina, A and Divya, V.C. 2018. Isolation and characterization of potentialZn solubilizing bacteria from soil and its effects on soil Zn releaserates, soil available Zn and plant Zn content, *Geoderma*. 321. 173-186.
5. Dobereiner, J. 1997. Biological nitrogen fixation in the tropics: social and economic contributions. *Soil Biology and Biochemistry*. 29: 771-774.
6. Gupta, B.D., Macrae, E.A and Ferguson, I.B. 1994. Estimation of hydrogen peroxide in plant extracts using titanium (IV). *Analytical Biochemistry*. 139: 487-492.
7. Han, H.S., Supanjani and Lee, K.D. 2006. Effect of co-inoculation with phosphate and potassium solubilizing bacteria on mineral uptake and growth of pepper and cucumber. *Plant, Soil and Environment*. 52 (3): 130-136.
8. Jackson, M. L. 1973. *Soil Chemical Analysis.* Prentice- Hall of India private limited. New Delhi.
9. Kannaiyan, S., Kumar, K and Govindrajan, K. 2004. Solubilization of silicate and concurrent release of phosphorous and potassium in rice ecosystem. *Biofertilizer Technology*. 372-378.
10. Lindsay, W.L and Norvell, W.A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of American Journal.* 41:421-428.
11. Molla, M.A.Z., Chowdhury, A.A., Islam, A and Hoque, S. 1984. Microbial mineralization of organic phosphate in soil. *Plant and Soil.*78(3):393-399.
12. Mongia, C., Rashmi, S.N., Sharmila, V., Surekha, R., Tejaswini, R and Suresh, C.K. 2003. Growth response of *Amaranthusgangeticus*to*Azotobacterchroococcum* isolated from different agroclimatic zones of Karnataka. *Journal of Phytology*. 3(7): 29-34.
13. Olsen, S.R., Code, C.L., Watanable, F.S and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Development Agency, Washington DC, Circular Number* 939. 1-19.
14. Padmaja, H. K., Rohini, T., Ilorkar, V.M and Priya, C.A. 2019. Effect of silicon solubilizing bacteria on availability of nutrients with different sources of organic residues under *Pongamiapinnata* (Karanj). *International Journal of Chemical Studies*. 7(3): 1065-1068.
15. Piper, C.S. 1966. Soil and Plant Analysis. Hons publishers, Bombay.

16. Rodriguiz, H., Gonzalez, T., Goire, I and Bashan, Y. 2004. Gluconic acid production and phosphate solubilization by the plant growth promoting bacterium *Azospirillum*spp.*Nature*. 91: 552-555.
17. Snyder, G. H.1991. Development of a silicon soil test for Histol-grown rice. Belle Grade EREC Research report EV-1991-2, University of Florida, Belle grade, FL.
18. Subbiah, B.V and Asija, C.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. 25: 259-260.
19. Sundara, B., Natarajan, V and Hari, K. 2002. Influence of phosphorus solubilizing bacteria on the change in soil available phosphorus and sugarcane and sugar yields. *Field Crops Research*. 77(1): 43-49.
20. Tandon, H.L.S. 1993. Analysis of plant material for macro and micronutrients. In method of analysis of soils, plant, water and fertilizer. pp. 49-82.
21. Thompson, J. P. 1996. Correction of dual phosphorous and zinc deficiencies of linseed with cultivars of vesicular-arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry*. 28: 941-951.