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Impact of Zinc and Silica Solubilizing Bacterial Consortia on Soil Physicochemical Properties, Microbial Population, Chlorophyll Content and Dry Matter Production of Paddy

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Influence of zinc and silica solubilizing bacterial consortia on direct sown paddy was investigated at Agricultural Research Station (ARS), Jangamaheswarapuram, ANGRAU, Guntur, Andhra Pradesh during late *Kharif* and late *Rabi* seasons, 2019. Parameters including pH, EC, organic carbon, bacterial, fungal, actinomycetes population, zinc and silica solubilizing bacterial population, chlorophyll 'a', chlorophyll 'b', total chlorophyll content and dry matter production at different crop growth stages *i.e.*, 45, 90 and 120 days after sowing (DAS) were estimated under field conditions with three replications and 13 treatments. Highest pH (8.2) and highest organic carbon content (0.46) were recorded in T_{13} {RDF + Zinc isolate from Kurnool Dist., Jupadu Bunglow village soil sample-4 (ZnKJJ-4) & (Zinc isolate from Prakasham Dist., Giddaluru village soil sample–1(ZnPGG-1) + Silica isolate from Kurnool Dist., Pamulapadu village soil sample–1 (SiKPP-1) & Silica isolate from Prakasham Dist., Yerragondapalem village soil sample–3 (SiPYY-3)} at 45 DAS and 120 DAS, respectively. At 90 DAS, the highest soluble salt content EC (0.46 dS m^{-1}) was observed inT_{13} compared to other treatments. The highest total bacterial, fungal, actinomycetes population (9.96, 5.48 and 6.89 Log CFU g^{-1} of soil); total zinc solubilizing bacteria (ZnSB) and silica solubilizing bacteria (SiSB) population (6.98 and 6.94 Log CFU g^{-1} of soil) and highest chlorophyll 'a', chlorophyll 'b' and total chlorophyll content in leaves (1.26, 0.78 and 2.04, respectively) were observed in T_{13} at 90 DAS as against other treatments and control. The highest total dry matter production was observed in T_{13} (13936 kg ha^{-1}) at 120 DAS. In conclusion, zinc and silica solubilizing bacteria and their consortia influenced the soil pH, EC, organic carbon, bacterial, fungal, actinomycetes population, zinc, silica solubilizing microbial population, chlorophyll 'a', chlorophyll 'b', total chlorophyll content and dry matter production at different crop growth stages in comparison to the individual microorganisms, thus having direct effect on the crop growth and yield.

(***Key words:*** *Chlorophyll content, Dry matter production, Microbial consortia, Soil properties, Zinc and silica solubilizing microorganisms*)

Rice (*Oryza sativa* L.) is one of the major crops in India with an export value of 115.86 billion rupees in 2011 and reached to 721.16 billion rupees in 2022 (Das and Singh, 2014). Nutrients are necessary for any plant growth and development and applied through inorganic or organic forms. Zinc (Zn) has its own importance for healthy growth and reproduction of plants, animals and humans and when the supply of plant-available zinc is scarce, crop yields are reduced and the quality of crop products is frequently impaired. In recent years importance of zinc solubilizing bacteria (ZSB) has enhanced and these probable candidates for improving bioavailable fraction of Zn to host plant for enhancing the crop growth, yield and quality without affecting the environment are being adopted in the agriculture. Alternatively, several microorganisms, especially those associated with roots, have the ability to rise plant growth and productivity (Maheshwari and Shimizu, 2011) by enhancing the supply of mineral nutrients of low mobility in the soil like P, Zn and Cu (Sang *et al.*, 2017). Apart from zinc, silica is also very essential micronutrient for paddy. Si is accumulated in the form of silica gel and is deposited in epidermal cells, sclerenchyma, vascular bundles and inflorescence brackets in cereals (Jackson, 1973). Silicate solubilizing bacteria (SSB) can play an effective role in soil by solubilizing insoluble forms

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of silicates. In addition, some SSB can also solubilize potassium and phosphates, thus increase soil fertility and enhance plant defence mechanisms (FAO, 2019; Vinod Babu *et al.*, 2024). Hence, the present field experiment was conducted to assess the impact of zinc and silica solubilizing bacterial consortia on soil physico chemical, biological properties, chlorophyll content and dry matter production of paddy.

MATERIALS AND METHODS

Paddy variety, MTU-7029 (Swarna) was sown in black soil by adopting 20 cm × 10 cm spacing at ARS, Jangamaheswarapuram during late *Kharif* and late *Rabi* seasons of 2019. Recommended agronomic practices including weed management, fertilizer management and plant protection were adopted. The fertilizers were applied as per the treatment combinations. An entire uniform dose of 23 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} was applied as basal at the time of sowing through urea, single super phosphate and muriate of potash, respectively to all the plots. Thirteen treatments, each replicated thrice, were imposed incompletely randomized design *viz.*, T_1: RDF (Control); T_2: RDF + $ZnSO_4$ @ 25 kg ha^{-1}; T_3: RDF + Calcium silicate @ 120-200 kg ha^{-1}, T_4: RDF + $ZnSO_4$@ 25 kg ha^{-1}+ Calcium silicate @ 120-200 kg ha^{-1}; T_5: RDF + ZnKJJ-4 (Zinc isolate from Kurnool Dist., Jupadu Bunglow village soil sample-4); T_6: RDF + ZnPGG-1(Zinc isolate from Prakasham Dist., Giddaluru village soil sample-1); T_7: RDF + SiKPP-1(Silica isolate from Kurnool Dist., Pamulapadu village and Mandal soil sample-1); T_8: RDF + SiPYY-3 (Silica isolate from Prakasham Dist., Yerragondapalem village soil sample-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 and 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.

Lignite for zinc solubilizing bacterial isolates and charcoal powder for silica solubilizing bacterial isolates were used as carrier material. Sterilized carrier material at pH 7.0 was mixed with broth cultures aseptically and incubated for 24 hours. For treatments with combination of bacteria, inoculum was adjusted to the required concentration of each @ 108-109 $CFUml^{-1}$ by verifying the cell viability and then they were mixed in the ratio of 1:1 (w/w) before sowing.

Soil analysis

Physical and chemical properties of soil samples were analysed by adopting standard procedures at Department of Agricultural Microbiology, Advanced Post Graduate Centre and Department of Soil Science and Agricultural Chemistry, Regional Agricultural Research Station, ANGRAU, Lam, Guntur. Soil pH was determined in 1:2.5 soil water suspensions using a combined glass electrode (Peera *et al.*, 2016). The soluble salt content of soil samples was determined in 1:2.5 soil water extract with the help of systronic digital electrical conductivity meter (Peera *et al.*, 2016) and was expressed in dS m^{-1}.

Soil organic carbon (OC) was estimated following Walkley and Black methods described by (Vijaypriya and Muthukkaarupan, 2010). Organic carbon was rated as Wp to 0.5% as low; 0.5 to 0.75% OC as medium; more than 0.75% OC as high.

Total population count of ZnSB and SiSB

The soil samples were collected randomly from each plot and total population count of ZnSB and SiSB were recorded by serial dilution and spread plate method at different crop growth stages by using specific solubilisation media under in *vitro* condition. The cfu count was recorded at 10^4 dilutions.

For isolating the Zinc Solubilizing Bacteria (ZSB) 1g of paddy rhizosphere samples was suspended in 9.0 ml of sterile distilled water in test tubes. From the first dilution 1 ml was transferred to test tube containing 9 ml of sterile distilled water to get 10^{-2} dilution. The same method was followed for preparing up to 10^{-6} dilution. The tris-mineral salts medium composed of dextrose - 10.0 g, $(NH_4)_2$ SO_4 - 1.0 g, KCl - 0.2 g, K_2HPO_4 - 0.1 g, $MgSO_4$ - 0.2 g was prepared in distilled water (1000 ml and pH was adjusted 7.0). The source of insoluble zinc compounds such as ZnO, $ZnCO_3$ and $Zn_3(PO_4)_2$ was supplemented at 1% concentration and agar was added into the medium individually and autoclaved at 121°C for 30 min. The agar medium was poured in sterile Petri plates under aseptic conditions. After

solidification of media in Petri plates 0.1ml of sample from 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5},10^{-6} and 10^{-7} dilutions from paddy rhizosphere soil samples were transferred by sterile pipettes and spread on to respective Petri plates. The inoculated plates were incubated at 27 to 30°C for 48 h (Peera *et al.*, 2016).

Silica solubilizing bacteria (SiSB) were isolated using modified Bunt and Rovira medium containing (gL^{-1}) 10 g peptone, 20 g glucose, 0.1 g magnesium chloride, 0.01 g ferric chloride, 1 g yeast extract, 0.5 g ammonium sulphate, 0.4 g disodium hydrogen phosphate and 20 g agar. Insoluble magnesium trisilicate (0.25%) was also added to the medium along with 250 ml soil extract and the pH was adjusted to 7.0 before sterilization. Filter sterilized cycloheximide (50 mgL^{-1}) was added to prevent fungal contamination in Petri plates. Ten fold dilution series of the sieved rhizosphere soil was prepared and an aliquot of 0.1 ml from 10^{-4} dilution was plated on to Bunt and Rovira medium. After incubating the plates for 72 h in the dark at 28-30°C, the plates were observed for the appearance of clearing zone around bacterial colonies which is indicative of silica solubilization. The bacterial colony with maximum solubilization zone was selected for further experimentation (Bunt and Rovira, 1955).

Chlorophyll content of paddy leaves

Chlorophyll content was estimated by soaking 0.1 g of fresh leaf sample in 10 ml of Dimethyl sulfoxide (DMSO) and incubated for 24 hours in the dark. Then light absorbance values were recorded at 645 nm and 663 nm using UV 2450 visible spectrophotometer. The chlorophyll content was calculated by using the formula given by (Arnon, 1949).

$$\text{Chlorophyll a (mg g}^{-1}\text{ fr.wt)} = 12.7(D\,663) - 2.69(D\,645) \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll b (mg g}^{-1}\text{ fr.wt)} = 22.9(D\,645) - 4.68(D\,663) \times \frac{V}{1000 \times W}$$

$$\text{Total Chlorophyll (mg g}^{-1}\text{ fr.wt)} = 20.2(D\,645) + 8.02(D\,663) \times \frac{V}{1000 \times W}$$

where V = Volume made up

W = Weight of leaf sample

Dry matter production

At different intervals *i.e.*, 45 DAS, 90 DAS and 120 DAS three hills from each plot inoculated with different treatments were pulled out along with roots and then washed with distilled water to remove the adhered soil from the roots. The plants were dried under shade and subsequently in a hot air oven at 60°C to a constant weight and expressed dry matter as g pot^{-1} and in field kg ha^{-1}.

RESULTS AND DISCUSSION

Influence of zinc and silica solubilizing bacterial consortia

Soil pH

At 45 DAS all the treatments showed increased pH compared to initial value *i.e.*, 7.6. Increased pH was observed in T_{13} and T_{11} (7.8 and 7.7), same pH in T_{12} (7.6) and <7.6 pH was in other treatments at 90 DAS compared to initial value (Table 1). At 120 DAS observed pH in T_{13} (8.0), T_{11} (7.8) and T_{12} (7.7) was higher, equal pH was observed in T_{10} (7.6), T_9 (7.6), T_7 (7.6) T_5 (7.6) and lower pH was observed in T_8, T_4, T_3 (7.5), T_6, T_2 and T_1 (7.4) as compared to initial. These results were accordance to Patel *et al.* (2014) and Lin *et al.* (2006) where they indicated that microbes lower the soil pH by releasing organic acids.

Electrical conductivity

Electrical conductivity (EC) of soil is a measure of the amount of salts in soil. Initial electrical conductivity was 0.32 dS m^{-1}. At 45 DAS, EC in all the treatments increased and highest EC was noticed in T_3: RDF + calcium silicate (0.58 dS m^{-1}), followed by T_2 (0.55 dS m^{-1}) whereas lowest was in T_{10} (0.35 dS m^{-1}) and T_1 (control) recorded 0.51 dS m^{-1} (Table 1). At 90 DAS highest EC was recorded in T_3 (0.64 dS m^{-1}) followed by T_2 (RDF + $ZnSO_4$) *i.e.*, 0.59 dS m^{-1} and the lowest EC was in T_{10} (0.41 dS m^{-1}). At 120 DAS highest EC was recorded in T_3 (0.50 dS m^{-1}) followed by T_2 (0.47 dS m^{-1}) and the lowest in T_{10} (0.33 dS m^{-1}) (Table 1). In the present study

Table 1. *Influence of zinc and silica solubilizing bacterial isolates and their consortia on soil physico-chemical properties of direct sown paddy rhizosphere under field conditions*

Treatments	Soil pH			EC (dS m^{-1})			OC (%)		
	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS
T_1	7.7	7.2	7.4	0.51	0.56	0.44	0.37	0.38	0.39
T_2	7.8	7.3	7.4	0.55	0.59	0.47	0.37	0.38	0.39
T_3	7.7	7.4	7.5	0.58	0.64	0.50	0.38	0.39	0.40
T_4	7.8	7.4	7.5	0.49	0.51	0.40	0.39	0.40	0.41
T_5	7.7	7.5	7.6	0.47	0.52	0.39	0.37	0.38	0.39
T_6	7.8	7.3	7.4	0.50	0.55	0.43	0.39	0.40	0.41
T_7	7.7	7.5	7.6	0.43	0.48	0.40	0.38	0.39	0.40
T_8	7.8	7.4	7.5	0.43	0.49	0.39	0.38	0.39	0.40
T_9	7.7	7.2	7.6	0.45	0.50	0.41	0.39	0.40	0.41
T_{10}	7.8	7.4	7.6	0.35	0.41	0.33	0.38	0.39	0.40
T_{11}	7.9	7.7	7.8	0.38	0.43	0.34	0.38	0.39	0.40
T_{12}	7.8	7.6	7.7	0.39	0.45	0.38	0.39	0.40	0.43
T_{13}	8.2	7.8	8.0	0.40	0.46	0.37	0.40	0.42	0.44
SE (m)	0.017	0.035	0.019	0.005	0.006	0.004	0.008	0.004	0.006
CD (p=0.05)	0.032	0.106	0.046	0.016	0.018	0.011	NS	0.013	NS
CV	0.384	0.834	0.395	1.278	1.341	1.812	1.450	1.646	1.376

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

variation in EC between the treatments at different intervals of crop growth was significant. The results stand in accordance with Mathivanan *et al.* (2017) who reported biofertilizers application increased the soil EC from 0.40 to 0.99 in PGPR treatment. This might be due to increased solubility of many nutrients.

Organic carbon

Organic carbon is a strong determinant of soil fertility through soil structure and chemical properties. Initial organic carbon was recorded as 0.36%. At 45 DAS, increased organic carbon content was observed in all treatments and significantly highest was recorded in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (0.39 %) followed by T_{12}, RDF + ZnPGG-1 + SiPYY-3 (0.38 %) (Table 1). At 90 and 120 DAS, highest organic carbon content was registered in T_{13} (0.42 and 0.44%, respectively) (Table 1). The applied microbial consortia might have produced a variety of growth promoting substances including IAA and gibberellins, which stimulate the production of root exudates shown to transfer nearly 5-21 % of all photosynthetically fixed carbon to the rhizosphere, resulting in a substantial increase of soil organic carbon level (Walker *et al.*, 2003).

Bacterial population in rhizosphere soil

Initially bacterial population was 8.44 Log CFU g^{-1} soil. The population of bacteria increased at 45 DAS and the highest population of bacteria was recorded in T_{13} (RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3) *i.e.*, 8.72 Log CFU g^{-1} soil), which was statistically on par with T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, (8.71 Log CFU g^{-1} soil) and T_{11} (8.70 Log CFU g^{-1} soil). Bacterial population showed increasing trend at 90 DAS, the highest population was found in T_{13} (9.96 Log CFU g^{-1} soil), followed by T_{12} (9.94 Log CFU

Table 2. *Influence of zinc and silica solubilizing microbial isolates and their consortia on rhizosphere microflora of direct sown paddy under field conditions*

Treatments	Bacteria (Log CFU g^{-1} soil)			Fungi (Log CFU g^{-1} soil)			Actinomycetes (Log CFU g^{-1} soil)		
	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS
T_1	8.51	9.76	7.63	4.37	5.13	4.14	5.78	6.59	5.13
T_2	8.52	9.77	7.67	4.46	5.22	4.23	5.92	6.62	5.24
T_3	8.61	9.79	7.69	4.43	5.20	4.19	6.04	6.75	5.41
T_4	8.60	9.78	7.68	4.49	5.24	4.28	5.99	6.64	5.29
T_5	8.56	9.81	7.70	4.52	5.29	4.29	6.15	6.76	5.54
T_6	8.61	9.83	7.71	4.55	5.24	4.36	6.16	6.78	5.60
T_7	8.62	9.86	7.72	4.58	5.33	4.40	6.18	6.80	5.66
T_8	8.64	9.87	7.73	4.60	5.37	4.39	6.33	6.86	5.69
T_9	8.65	9.89	7.74	4.63	5.40	4.44	6.32	6.84	5.68
T_{10}	8.67	9.90	7.75	4.62	5.38	4.44	6.38	6.85	5.73
T_{11}	8.70	9.92	7.79	4.64	5.42	4.45	6.44	6.87	5.75
T_{12}	8.71	9.94	7.80	4.66	5.43	4.47	6.45	6.88	5.77
T_{13}	8.72	9.96	7.82	4.68	5.48	4.51	6.49	6.89	5.82
SE(m)	0.005	0.006	0.004	0.001	0.006	0.007	0.005	0.008	0.002
CD(p=0.05)	0.014	0.019	0.012	0.033	0.018	0.022	0.016	0.024	0.061
CV(%)	1.15	1.23	1.19	2.32	1.25	2.28	1.17	1.3	1.43

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

g^{-1} soil) and T_{11} (9.92 Log CFU g^{-1} soil). The bacterial population decreased at 120 DAS to 7.82 Log CFU g^{-1} soil in T_{13}, followed by T_{12} (7.80 Log CFU g^{-1} soil) and T_{11} (7.79 Log CFU g^{-1} soil) (Table 2). The bacterial population was significantly reduced at 120 DAS due to reduction in available nutrients as crop matured and there was not much root exudates from plants as compared to flowering stage. The results showed that soil microbial (bacterial) biomass is highly correlated with soil organic matter content, availability of root exudates and nutrients in soil. Pankhurst *et al.* (1995) also reported increased rhizosphere bacterial population at flowering stage.

Fungal population in rhizosphere soil

The total fungal population was 4.24 Log CFU g^{-1} in the initial soil. Fungal population increased at 45 DAS and reached the highest in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (4.68 Log CFU g^{-1} soil) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 4.66 Log CFU g^{-1} soil which were on par. Fungal population further increased and at 90 DAS population attained the highest in T_{13} (5.48 Log CFU g^{-1} soil) followed by T_{12} (5.43 Log CFU g^{-1} soil) and T_{11} (5.42 Log CFU g^{-1} soil). Fungal population decreased to 4.51 Log CFU g^{-1} soil in T_{13} followed by T_{12} (4.47 Log CFU g^{-1} soil) and T_{11} (4.45 Log CFU g^{-1} soil) at 120 DAS (Table 2). It was observed that fungal population significantly decreased at 120 DAS as compared to other time intervals. The lower fungal biomass is due to the insufficient availability of nutrients at the time of harvest stage of paddy crop. The results showed that soil fungal population is highly correlated with soil organic matters, more availability of root exudates and higher dose of N

fertilizers applications (Yevdokimov *et al.*, 2008).

Actinomycetes population in rhizosphere soil

The total actinomycetes population was 5.44 Log CFU g^{-1} in the initial soil. Actinomycetes population increased at 45 DAS compared to initial and the highest population of actinomycetes were observed in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (6.49 Log CFU g^{-1} soil), followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 6.45 Log CFU g^{-1} soil and T_{11} (6.44 Log CFU g^{-1} soil). Actinomycetes population further increased in T_{13} to 6.89 Log CFU g^{-1} soil followed by T_{12} (6.88 Log CFU g^{-1} soil), T_{11}, T_{10}, T_9 and T_8 (6.87, 6.85, 6.84 and 6.86 Log CFU g^{-1} soil). Actinomycetes population drastically decreased to 5.82 Log CFU g^{-1} soil in T_{13} at 120 DAS and was statistically superior to T_{12} (5.77 Log CFU g^{-1} soil) (Table 2). The actinomycetes population was significantly less at initial stage and 45 DAS compared to maturity stage (90 DAS) of crop. During this stage high nutrient availability and major root exudates might enhance the growth of the microbes (Zhong *et al.*, 2010).

Zinc solubilizing bacterial (ZnSB) population in rhizosphere soil

ZnSB population was 3.78 Log CFU g^{-1} in the initial soil. ZnSB population increased at 45 DAS compared to initial stage. Significantly highest ZnSB population was obtained in T_{13}: RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3 (5.99 Log CFU g^{-1} soil) followed by with T_{12} (RDF + ZnPGG-1 + SiPYY-3 *i.e.*, 5.72 Log CFU g^{-1} soil. The ZnSB population further increased in T_{13} to 6.98 Log CFU g^{-1} soil at 90 DAS followed by T_9 (4.84 Log CFU g^{-1} soil). At 120 DAS, ZnSB population drastically decreased in T_{13} to 4.92 Log CFU g^{-1} soil followed by T_9 (4.89 Log CFU g^{-1} soil) (Table 3). In the present study, application of ZnSB individual isolates along with their consortia had significantly increased the population

Table 3. *Influence of zinc and silica solubilizing bacterial consortia on population of zinc and silica solubilizing bacteria (Log CFU g^{-1} soil) on direct sown paddy under field conditions*

Treatments	ZnSB (Log CFU g^{-1} soil)			SiSB (Log CFU g^{-1} soil)		
	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS
T_1	5.12	6.16	4.14	5.20	6.24	4.24
T_2	5.18	6.20	4.19	5.26	6.30	4.28
T_3	5.20	6.18	4.22	5.29	6.32	4.34
T_4	5.24	6.28	4.26	5.38	6.40	4.36
T_5	5.64	6.62	4.63	5.48	6.50	4.48
T_6	5.62	6.60	4.61	5.46	6.48	4.46
T_7	5.34	6.32	4.28	5.52	6.54	4.56
T_8	5.31	6.28	4.30	5.54	6.56	4.58
T_9	5.76	6.84	4.89	5.34	6.36	4.32
T_{10}	5.36	6.34	4.36	5.84	6.82	4.79
T_{11}	5.66	6.67	4.62	5.62	6.64	4.72
T_{12}	5.72	6.64	4.74	5.63	6.68	4.84
T_{13}	5.99	6.98	4.92	5.99	6.94	4.88
SE(m)	0.008	0.005	0.006	0.004	0.009	0.002
CD(p=0.05)	0.025	0.014	0.019	0.013	0.026	0.064
CV (%)	1.28	2.16	1.25	1.20	2.32	1.50

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

of ZnSB as compared to uninoculated controls at 90 DAS rather than other intervals. Similar findings were reported by Othman *et al.* (2017) who observed that combined inoculation of two zinc solubilizing bacterial isolates *Acinetobacter* sp. (TM56), *Serratia* sp. (TM9) showed higher population count *i.e.*, 5.91 Log CFU g^{-1} soil than individual organism at different intervals of paddy crop.

Silica solubilizing bacterial (SiSB) population in rhizosphere soil

SiSB population was 3.46 Log CFU g^{-1} in the initial soil. SiSB population increased at 45 DAS and reached significantly highest) 5.99 Log CFU g^{-1} soil) in T_{13}, RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 &SiPYY- 3 followed by T_{10} (5.84 Log CFU g^{-1} soil), T_{12} (RDF + ZnPGG-1 + SiPYY-3) and T_{11} (RDF + ZnKJJ-4 + SiKPP-1) with 5.63 and 5.62 Log CFU g^{-1} soil, respectively, but both were statistically on par. The SiSB population further increased at 90 DAS, with the highest in T_{13} (6.98 Log CFU g^{-1} soil) followed by T_{10} (6.82 Log CFU g^{-1} soil). At 120 DAS SiSB population significantly decreased of 4.88 Log CFU g^{-1} soil in T_{13} followed by T_{12} (4.84 Log CFU g^{-1} soil) (Table 3). Results revealed that the population of SiSB increased in the treatments of SiSB individual isolates along with their consortia compared to uninoculated controls at 90 DAS than at other intervals. Hafeez and Hassan (2011) also observed silica solubilizing bacterial population of 5.26 Log CFU g^{-1} soil at vegetative stage and decreased population at harvesting stage of paddy crop. It may be due to the non-availability of the root exudates sufficiently for the silica solubilizing microbial population.

Chlorophyll content in leaves

Zinc and silica solubilizing bacteria along with recommended dose of fertilizer had a significant effect on the chlorophyll content at 45, 90 and 120 DAS

Table 4. *Influence of zinc and silica solubilizing bacterial consortia on chlorophyll content (mg g^{-1}) of direct sown paddy rhizosphere under field conditions*

Treatments	Chlorophyll 'a'			Chlorophyll 'b'			Total chlorophyll content		
	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS
T_1	0.14	0.78	0.72	0.12	0.31	0.28	0.26	1.09	1.00
T_2	0.17	0.82	0.74	0.15	0.33	0.30	0.32	1.15	1.04
T_3	0.18	0.84	0.76	0.18	0.35	0.31	0.36	1.19	1.07
T_4	0.22	0.98	0.81	0.19	0.38	0.32	0.41	1.36	1.13
T_5	0.18	0.80	0.71	0.20	0.50	0.41	0.38	1.30	1.12
T_6	0.26	0.92	0.82	0.21	0.53	0.45	0.47	1.45	1.27
T_7	0.39	1.16	1.04	0.26	0.39	0.31	0.65	1.55	1.35
T_8	0.32	1.18	1.06	0.52	0.45	0.36	0.84	1.63	1.42
T_9	0.61	1.21	1.14	0.32	0.55	0.42	0.93	1.79	1.56
T_{10}	0.54	1.22	1.11	0.39	0.56	0.43	0.93	1.78	1.54
T_{11}	0.77	1.23	1.12	0.61	0.68	0.59	1.38	1.91	1.71
T_{12}	0.68	1.24	1.15	0.60	0.64	0.54	1.28	1.88	1.69
T_{13}	0.98	1.26	1.20	0.82	0.78	0.70	1.80	2.04	1.90
SE(m)	0.002	0.005	0.004	0.006	0.007	0.004	0.006	0.002	0.008
CD(p=0.05)	0.061	0.016	0.014	0.020	0.022	0.012	0.018	0.067	0.025
CV (%)	2.52	3.15	1.34	4.26	2.15	1.03	3.54	2.65	1.48

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

under field conditions. Chlorophyll content of leaves is an indirect indicator on plant health and reflects plants photosynthetic capacity and overall vitality. The data on total chlorophyll content indicated significant differences among all the treatments (Table 4). Maximum chlorophyll content was recorded at 90 DAS and declined towards harvest.

At 45 DAS, T_{13} (RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3) had significantly highest chlorophyll content "a" (0.98 mg g^{-1} tissue) followed by T_{11} (RDF + ZnKJJ-4 + SiKPP-1) with 0.77 mg g^{-1} tissue and the lowest chlorophyll content "a" value in T_1 (Control) (0.14 mg g^{-1} tissue). At 90 DAS, T_{13} had the highest chlorophyll content "a" (1.26 mg g^{-1} tissue) followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 1.24 mg g^{-1} tissue and both were on par. T_1 reported the least chlorophyll content "a" 0.78 mg g^{-1} tissue. At 120 DAS, T_{13} recorded chlorophyll content "a" (1.20 mg g^{-1} tissue), significantly superior to T_{12} (1.15 mg g^{-1} tissue) and T_9 (1.14 mg g^{-1} tissue). The lowest chlorophyll content "a" (0.72 mg g^{-1} tissue) was obtained in T_1.

At 45 DAS, T_{13} had significantly highest chlorophyll content "b" (0.82 mg g^{-1} tissue) followed by T_{11} (0.61 mg g^{-1} tissue) and T_{12} (0.60 mg g^{-1} tissue). The lowest chlorophyll content "b" in T_1 was 0.12 mg g^{-1} tissue. At 90 DAS, T_{13} had significantly highest chlorophyll content "b" (0.78 mg g^{-1} tissue) followed by T_{11} *i.e.,* 0.68 mg g^{-1} tissue and T_{12} (0.64 mg g^{-1} tissue). T_1 reported the least chlorophyll content "b" 0.31 mg g^{-1} tissue. At 120 DAS, T_{13} recorded significantly highest chlorophyll content "b" (0.70 mg g^{-1} tissue), followed by T_{11} (0.59 mg g^{-1} tissue). The lowest chlorophyll content "b" (0.28 mg g^{-1} tissue) was obtained in T_1.

In case of total chlorophyll content at 45 DAS, T_{13} had significantly highest total chlorophyll content (1.80 mg g^{-1} tissue) followed by T_{11} (1.38 mg g^{-1} tissue). The lowest total chlorophyll content was observed in T_1 was 0.26 mg g^{-1} tissue. At 90 DAS, T_{13} had highest total

Table 5. *Influence of zinc and silica solubilizing bacterial consortia on drymatter accumulation (kg ha^{-1}) at different growth stages of direct sown paddy under field condition*

Treatments	45 DAS	90 DAS	120 DAS
T_1	357	1003	9647
T_2	377	1137	9828
T_3	381	1243	9882
T_4	382	1311	10027
T_5	386	1426	11488
T_6	390	1551	11399
T_7	393	1907	12105
T_8	415	2030	12366
T_9	421	2090	12439
T_{10}	426	2249	12666
T_{11}	433	2294	13373
T_{12}	439	2450	13556
T_{13}	449	2547	13936
SE (m)	6.104	17.115	9.696
CD (p=0.05)	17.922	50.254	28.469
CV (%)	2.62	1.62	3.14

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

chlorophyll content (2.04 mg g^{-1} tissue) followed by T_{11} (1.91 mg g^{-1} tissue), T_{10}, T_9 and T_8 were on par. T_1 reported the least total chlorophyll of 1.09 mg g^{-1} tissue. At 120 DAS, T_{13} recorded the highest total chlorophyll content (1.90 mg g^{-1} tissue), followed by T_{11} (1.71 mg g^{-1} tissue) and T_{12} (1.69 mg g^{-1} tissue) which were on par. The lowest total chlorophyll content (1.00 mg g^{-1} tissue) was obtained in T_1. The chlorophyll content increased from 45 to 90 DAS due to the photosynthetic activity and the availability of nutrients during the vegetative stage of the crop. Chlorophyll content reduced towards 120 DAS because of diversion of nutrients to economic parts of the plant (Mathivanan *et al.*, 2017) reported mixtures of microbial consortium essentially expanded photosynthetic activity (chlorophyll a and b and carotenoid) and protein content.

Dry matter production

The chlorophyll content directly shows the impact on the dry matter production in plants. Zinc and silica solubilizing bacteria influence the dry matter production in the crop due to easy availability of the nutrients to plants. Significant differences were observed among all the treatments. At 45 DAS, T_{13} (RDF + ZnKJJ-4 & ZnPGG-1 + SiKPP-1 & SiPYY-3) had significantly highest dry matter production (449 kg ha^{-1}), followed by T_{12} (RDF + ZnPGG-1 + SiPYY-3) *i.e.*, 439 kg ha^{-1} (Table 5). T_1 (Control) recorded the least dry matter production (357 kg ha^{-1}) content. From 45 to 90 DAS dry matter production was enormously increased. At 90 DAS, T_{13} had significantly highest dry matter production (2547 kg ha^{-1}) followed by T_{12} (2450 kg ha^{-1}). The lowest dry matter production of 1003 kg ha^{-1} was observed in T_1 (Control). At 120 DAS, T_{13} (13936 kg ha^{-1}) recorded the highest dry matter production followed by T_{12} (13556 kg ha^{-1}). The least dry matter production (9647 kg ha^{-1}) was obtained in T_1. The above findings agree with Peera *et al.* (2016) where combined application of 25 t ha^{-1} fly ash with silica solubilizing bacteria + farm yard manure recorded the highest dry matter production (3291 kg ha^{-1}) when compared to treatments of SSB, FYM imposed individually in paddy. Aarekar (2013) reported similar results on plant height, total number of productive tillers per pot and dry matter per hill of paddy due to silicon application through different sources (Silica solubilizing bacteria, rice husk ash, bagasse ash, fly ash and calcium silicate) in a pot culture experiment.

CONCLUSION

In conclusion, zinc and silica solubilizing bacterial consortia significantly influenced the soil pH, EC, organic carbon, bacterial, fungal, actinomycetes population, zinc, silica solubilizing microbial population, chlorophyll 'a', chlorophyll 'b', total chlorophyll content and dry matter production at different crop growth stages as compared to the individual microorganisms under field conditions. Thus, exogenous application of bacterial consortia can be exploited to increase zinc and silica solubilizing bacterial population, chlorophyll content and dry matter production in direct sown paddy.

CONFLICTS OF INTEREST

The authors have declared that no competing interest exists.

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