Research Article

The Role of Cyanobacteria in Availability of Major Plant Nutrients and Soil Organic Matter to Rice Crop under Saline Soil Condition

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Abstract | A pot experiment in pots was conducted with the aim to assess the role of different strains of cyanobacteria in improvement of some major plant nutrients and soil organic matter content (SOM) under saline soil and yield of rice crop at National Agricultural Research Center (NARC) Islamabad during summer 2016. Pots were induced with salinity of 7.0 dS m^{-1} and arranged in Completely Randomized Design (CRD) with three replications. Six treatments consisted of a control (no strains) and 5 different strains of cyanobacteria i.e Oscillatory-MMF-1 (*Oscillatoria princeps*), Leptolyngbaya-MMF-2 (*Lyngbya mucicola*), Leptolyngbaya- MMF-3 (*Lyngbya Phormidium*), Gloeobacter-MMF-4 (*Gloeocapsa*) and Microcoleus-MMF-5 (*Cryophilus*) were applied randomly to flooded rice in pots. Rice seedlings were transplanted to each pot on July 18, 2016. The data were recorded on agronomic parameters of rice crop, plant tissue and post-harvest soil analysis. But in this paper, data on availability of major plant nutrients, soil organic matter and plant dry weight are presented. The data revealed that cyanobacteria strains had significantly ($p \leq 0.05$) increased the availability of major plant nutrients and SOM under the saline soil conditions. Among the strains, Gloeobacter MMF-4 significantly increased the soil organic matter (SOM), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and plant dry weight. Results showed that soil organic matter content improved from 1 to 5.2 g kg^{-1}, NO_3-N from 1.96 to 3.53 mg kg^{-1}, P from 1.87 to 2.79 mg kg^{-1} and K from 273 to 296 mg kg^{-1} in treatment where MMF-4 Gloeobacter strain was applied. It was concluded that all cyanobacteria strains increased the soil fertility status in the saline soils but Gloeobacter-MMF-4 (*Gloeocapsa)* strain was most efficient as compared to other strains.

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Introduction

There are various types of constrains to crop production in the field of agriculture in the world, particularly in Pakistan. One of them is salt affected soils. The increase of salt concentration in the soils usually causes both sodicity and salinity and pose a main threat to various crops cultivation in arid and semi-arid regions of the Pakistan (Ashraf and Khan, 1994). In these regions precipitation is not sufficient to percolate salts and sodium ions out of the root zone. These salts are greatly responsible for declining the cultivated land worldwide. Globally, irrigated land covers about 310 million hectares (m ha), an estimated 20% of it is salt affected (62 m ha) (Qadir et al., 2014). In Pakistan, total geographical area is 79.6 m ha, out of which only 25 % (19.82 m ha) is under cultivation. The whole country has more than 6.30 m ha salt affected land (Alam et al., 2000). Also, salinity is a major constrain in both irrigated and un-irrigated agriculture (Mujeeb and Diaz, 2002). In arid and semi-arid regions, fertilization and use of brackish water for irrigation purposes build up root zone salinity (Villa et al., 2003). Osmotic stress, specific ion toxicity and disturbance of nutrients are the dangerous effects of salinity on plants (Qayyum et al., 2007).

The application of N, P and K and other essential nutrients from various sources to saline soil can reduce the stress of salts and increase salt tolerance of various crops. Imbalance nutrition due to impaired uptake and transport of essential plant nutrients under saline condition is well documented in crops leading to diminished plant growth and production (Shahzad et al., 2012; Qu et al., 2012). Crop growth is severely affected by N-deficiency under salinity (Shahzad et al., 2012)

Different types of micro-organisms are used for increasing crop production, number of plants, improvement and availability of essential plant nutrients and microbial activity under saline soils. In microbes, cyanobacteria can easily survive in saline conditions and high pH (Verma and Abrol, 1980). Cyanobacteria may increase the soil fertility by different methods like secretion of harmons, acids, enzymes which when added to a soil, dissolve the fixed and unavailable nutrients. It also controls the nutrient loss through run-off, de-nitrification and leaching. Potassium is first accumulated by cyanobacteria from the saline medium by K^+ up taking system (Reed and Stewart, 1985). The native cyanobacteria of soil, over a period of time improve the soil physical and chemical properties (Kaushik and Subhashini, 1985). Cyanobacteria significantly solubilize and make available the soil phosphorus and sulfur (Hashem, 2001). Cyanobacteria secrete different type of chemicals which can make available the soil plant nutrients like P, K and S in saline ecosystem (Singh, 1961). The cyanobacteria also help in decreasing soil pH (Elayarajan, 2002; Prabu and Udayasoorian, 2007), electrical conductivity (Prabu and Udayasoorian, 2007) and improve the soil aggregation i.e soil structure (Rogers and Burns, 1994; Rai et al., 2006).

Due to the above mentioned facts present experiment was designed to assess the role of cyanobacteria on some major plant nutrients availability and resultant improvement in soil organic matter under saline soil conditions.

Materials and Methods

An experiment in pots was carried out with the aim to assess the role of different strains of cyanobacteria in improvement of major plant nutrients, soil organic matter content and rice production under saline soil condition at the National Agricultural Research Center (NARC) Islamabad during summer 2016. The experimental pots were arranged in completely randomized design (CRD) with three replications. Each pot was induced with salinity of 7.0 dS m^{-1}. Five different locally identified strains of cyanobacteria i.e Oscillatory-MMF-1 (*Oscillatoria princeps)*, Leptolyngbaya-MMF-2 (*Lyngbya mucicola)*, Leptolyngbaya- MMF-3 (*Lyngbya Phormidium)*, Gloeobacter-MMF-4 (*Gloeocapsa)* and Microcoleus-MMF-5 (*Cryophilus)* were collected from the Laboratory of Microbiology and Genetics, University of Punjab, Lahore and further multiplied for mass production in the Laboratory of Soil Biology and Biochemistry, National Agricultural Research Center, Islamabad. These five strains of cyanobacteria and a control (no strains) (a total of 6 treatments) were used to treat the pots with 7.0 dS m^{-1} induced saline soil.

Solution method was used for the application of cyanobacteria. In this method, the required amount of cyanobacteria was dissolved in one-liter water and applied to particular pot. Recommended rate (20 kg ha^{-1}) of cyanobacteria of each strain was applied (Roger, 1991). No organic and chemical fertilizers were applied. Five seedlings of rice (Kainat, smooth cv.) crop from the nursery were transplanted to each pot on 18th August 2016 for their growth and development. The rice in all pots was flooded from transplanting to harvesting. All the cultural practices were applied during the growth period in green house and temperature ranged from 30-38 °C. Rice crop growth was maintained for about 3 months and harvested on October 30, 2016 and data on different rice parameter were collected.

The pre-sowing composite soil and post-harvest soil samples were obtained for analysis of various physicochemical properties of soil according to the standard methods/procedures in the laboratory of Soil Biology and Biochemistry, National Agriculture Research Center, Islamabad. Soil NO_3-N, P and K were determined using ammonium bicarbonate-diethylene triamine pentaacetic acid extractable (AB-DTPA ext.) solution by the method of Soltanpour and Schwab (1977) and soil Ca++ and Mg++ by Atomic Absorption using the procedure of Richards (1954). Soil organic matter was determined by the method of Nelson and Sommer (1996).

Characterization of the pre-sowing soil

The analysis of pre-sowing soil sample was done before starting of the experiment, to determine the physiochemical properties of soil i.e. electrical conductivity, pH (McLean, 1982), organic matter, calcium, magnesium, texture, nitrogen, phosphorus and potassium (Ryan et al., 2013). The soil texture of the experimental soil was silt loam in nature, alkaline in reaction and having less organic matter content (Table 1).

Table 1: *Physio-chemical properties of soil.*

Soil property	Value
Particle size distribution %	
Clay	7.0
Silt	68.40
Sand	24.60
Textural class	Silt loam
Chemical properties	
pH	8.3
EC (dS m^{-1})	7.0
AB-DTPA Ext. Cations (mg kg^{-1})	
Na+	2552
Ca^{2+}	870
Mg^{2+}	285
AB-DTPA Ext. Nutrients (mg kg^{-1})	
NO_3-N	1.96
P	1.87
K	273

Statistical analysis

The collected data were statistically analyzed by ANOVA method of Completely Randomized Design procedure using Statistix 8.1 Package. The probability level for LSD test i.e 5 % level of significance was used to distinguish between the means (Steel and Torrie, 1980).

Results and Discussion

AB-DTPA extractable soil nitrate-nitrogen (NO_3-N)

Statistical analysis of the data on soil NO_3-N showed that differences between the mean values were significant ($p \le 0.05$) (Table 2). The highest amount of soil NO_3-N (3.53 mg kg^{-1}) was recorded in MMF-4 Gloeobacter strain followed by MMF-1 Oscillatoria (3.27 mg kg^{-1}) which is statistically at par with each other. In control the lowest amount of NO_3-N (162 mg kg^{-1}) was observed as compared to other treatments (Table 2). Among the strains, the low content of nitrate-N (2.83 mg kg^{-1}) was noted in MMF-3 Leptolyngbaya. The data of MMF-2 and MMF-5 are statistically similar. These results are supported by previous findings of Roger and Kulasooriya (1980), Metting (1990), Apte (1992); (1993), Lange et al. (1994), Aziz and Hashem (2003) and Wafaa et al. (2013). The researchers reported that cyanobacteria have ability to accumulate soil NO_3^-, NH_4^+ and P from other source and further release these ions in soil.

AB-DTPA extractable soil P

Statistical analysis of the data on soil P (Table 2) showed that the treatments means were significantly different ($p < 0.05$). The maximum amount of P (2.79 mg kg^{-1}) was recorded in MMF-4 treatment followed by MMF-1 treatment (2.67 mg kg^{-1}). MMF-2 treatment was (2.64 mg kg^{-1}). The lowest value of P (1.59 mg kg^{-1}) was measured in control. These findings are in accordance with Roychoudhury et al. (1985), Roychoudhury and Kaushik (1989), Hashem (2001) and Wafaa et al. (2013). These scientists reported that the application of cyanobacteria increased the availability of P, S and solubilized the unavailable rock phosphate and made it available to plants.

AB-DTPA extractable soil K^+

Data on soil potassium showed that the treatments mean values of K^+ were significantly ($p < 0.05$) different from one another (Table 2). The maximum amount of potassium (296 mg kg^{-1}) was noted in MMF-4 treatment followed by MMF-5 treatment (283 mg kg^{-1}). The treatments MMF-1, MMF-2 and MMF-3 were statistically at par with one another. The lowest value of potassium (226 mg kg^{-1}) was recorded in control. These results are supported by the work of Reed and Stewart (1985), Matsuda et al. (2004) and Wafaa et al. (2013). They reported that cyanobacteria accumulate the potassium from medium by their uptake system and prepare glutamate compound thus K^+ ions concentration increase in cytoplasm and by efflux of water.

Soil organic matter content (SOM)

Data on soil organic matter (Table 2) showed that the treatments mean values were significantly ($p \leq 0.05$) different. The maximum amount of soil organic matter (5.4 g kg^{-1}) was measured in MMF-4 treatment followed by MMF-2 treatment (4.9 g kg^{-1}). The lowest amount of soil organic matter (1.4 g kg^{-1}) was recorded in control. MMF-1 treatment (3.5 g kg^{-1}) and MMF-5 treatment (3.3 g kg^{-1}) was statistically similar. This might be due to the further growth of cyanobacteria (Heterotrophic one producing biomass) in the flooded pots and also due to the secretion of exudates from cyanobacteris, roots of rice. The cyanobacteria also make the environment favorable for the root growth in saline soil by producing more biomass, due to which the organic matter was improved. These results were supported by De and Sulaiman (1950), Kannaiyan and Pandiyarajan (1992), Rogers and Burns (1994), Apte and Thomas (1997), Prabu and Udayasoorian (2007) and Wafaa et al. (2013).

Table 2: *AB-DTPA extractable NO_3^-N, P, K+ (mg kg^{-1}) and soil organic matter (g Kg^{-1}) of saline soil as influenced by application of different strains of cyanobacteria*

Treatments	NO_3-N	P_2O_5	K^+	SOM
Control	1.62 c	1.59 c	226 c	1.4 d
MMF-1 *Oscillatoria*	3.27 a	2.67 ab	275 b	3.5 c
MMF-2 *Leptolyngbaya*	3.18 ab	2.64 ab	268 b	4.9 a
MMF-3 *Leptolyngbaya*	2.83 b	2.39 b	276 b	4.3 b
MMF-4 *Gloeobacter*	3.53 a	2.79 a	296 a	5.2 a
MMF-5 *Microcoleus*	3.19 ab	2.66 ab	283 ab	3.3 c
LSD (5 %)	0.363	0.302	16.78	0.47

Means followed by different letter(s) are significantly different from one another

Soil calcium and magnesium (Ca^{+2} & Mg^{+2})

Data on Ca^{+2} & Mg^{+2} were presented in Table 3. The analysis of variance indicated that the treatments means were significant ($p \leq 0.05$). The maximum amount of Ca^{+2} (944 mg kg^{-1}) was measured in MMF-4 treatment followed by MMF-2 treatment (910 mg kg^{-1}). MMF-3 treatment (892 mg kg^{-1}) and MMF-5 treatment (829 mg kg^{-1}) were statistically different from each other. The lowest concentration of Ca^{+2} (715 mg kg^{-1}) was noted in control. The analysis of magnesium showed that highest concentration of magnesium (358 mg kg^{-1}) was recorded in MMF-4 treatment and MMF-2 treatment (341 mg kg^{-1}). The lowest amount of magnesium (277 mg kg^{-1}) was measured in control treatment. These results are similar to Shehata and Whitton (1982), Keurson et al. (1984), Singh (1985), Smith et al. (1987) and Pandey et al. (1996).

Plant dry weight (g pot^{-1})

Data on the plant dry weight (Table 3) revealed that the treatment mean values were significantly ($p < 0.05$) different from one another. The maximum dry weight (25 g pot^{-1}) was measured in MMF-4 treatment and followed by MMF-3 treatment (24 g pot^{-1}) which was statistically at par with each other. The rest of treatments were statistically similar. The minimum dry weight was recorded in control (18 g pot^{-1}). These results are in accordance with the findings of Pendleton and Warren (1995) and Aziz and Hashem (2004).

Table 3: *Calcium, magnesium (mg kg^{-1}) of saline soil and plant dry weight (g pot^{-1}) as influenced by different strains of cyanobacteria.*

Treatments	Ca^{2+}	Mg^{2+}	Plant dry Wt.
Control	716 e	277 d	18 b
MMF-1 *Oscillatoria*	770 d	290 cd	21 ab
MMF-2 *Leptolyngbaya*	910 ab	341 a	22 ab
MMF-3 *Leptolyngbaya*	892 b	332 ab	24 a
MMF-4 *Gloeobacter*	944 a	358 a	25 a
MMF-5 *Microcoleus*	829 c	314 bc	21 ab
LSD (5 %)	39.3	26.6	4.62

Means followed by different letter(s) are significantly different from one another

Conclusions

All cyanobacteria strains showed significant role on soil health and fertility improvement but Gloeobacter and Microcoleus strains of cyanobacteria surpassed the availability and solubility of soil nutrients like nitrogen, phosphorus and potassium by building the soil organic matter. Based on the results of the study, inoculation of Gloeobacter and Microcoleus cyanobacteria strains are recommended for rice crop in saline soil.

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Author's Contribution

ZJ conducted this research for his M. Sc (H) degree. SA supervised, planned this research and conceived the idea. TS provided the research facilities. Wasiullah helped in writing of manuscript and WA did proof reading and data analysis.

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