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BIORECLAMATORY STUDIES ON SALT AFFECTED SOIL BY USING CYANOBACTERIAL BIOFERTILIZERS

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ABSTRACT

In the present investigation, three strains of cyanobacteria isolated from agricultural fields near to salt mine were used as biofertilizer individually and in consortia. Farm yard manure was also used along with cyanobacterial biofertilizers to see the ameliorative effect on soil physical, chemical and biological properties. The algalization experiment was conducted in pots in the glass house of the department for 240 days. There was an improvement in carbon, nitrogen, phosphate, potassium, magnesium, calcium, zinc, iron, copper and manganese with biofertilizers treatment whereas sodium ion, EC and pH were found to be decreased. Soil microbial activities and plant growth parameters were found to be improved. Thus, the cyanobacterial species show promise in effective exploitation for phytoremediation and improved productivity of saline soils.

Keywords : Cyanobacteria, salt mine, algalization, biofertilizer, ameliorative.

INTRODUCTION

Vast area of world lies in the category of wastelands. Wastelands are degraded and unutilized lands due to different constraints. It includes areas affected by water logging, riverine lands, shifting cultivation, degraded forest land, sandy area and salt affected land. These wastelands are ecologically unstable with complete loss of topsoil and are unsuitable for cultivation due to decline in their quality and productivity. Among various causes of wastelands, salinity is a major problem and may be caused due to wrong agriculture practices, water logging and mining. Nearly 23 million hectare land is subjected to degradation due to salinity / alkalinity / acidification in our country (Kumar and Sharma, 2020).

Mining is very important next only to agriculture and also critical to the development of a nation. So far most mining activities have been unscientific with scant respect of environmental protection. Mining operations whether they are open or cave have resulted into ecological problems like soil erosion, biodiversity loss and heavy metal contamination of ground water and surface water worldwide (Kraus and Wiegand, 2006). Salt mining produces salinity and sodicity which are serious worldwide land degradation issues, and may be even increase rapidly in the future (Wong *et al*., 2009). Saline soil commonly known as 'reh' soil consist of mainly soluble salts of sodium and calcium, which are brought to the surface by capillary action and evaporation. These soils are poor in nitrogen, phosphorous and carbon. Soils affected by neutral salts of sodium (NaCl, Na_2SO_4) known as saline soils are characterized by soil electrical conductivity (EC) more than 4 dS/m. These soils lack distinguish structural profile (Rangaswamy *et al.,* 2003; Miller and Donahue, 1992). Soils affected by sodium salts known as alkali soils, have a pH exceeding 8.3.The alkali soils may or may not have structural B horizon. The soils without structural horizon always contain free-alkali carbonates, while those with structural horizon are free from carbonates (Szabolcs, 1989).

In the last few decades the use of chemical fertilizers has been increased exponentially because of their immediate effect on crop productivity. But in long run it results in degradation of soil health and causes various type of pollution such as water, air pollution. Production of chemical fertilizers is an energy intensive process and it is based on mineral reserves. Industries produce 47 million tones of nitrogen per year involving a cost of 15 billion and consuming 2 million barrels of oil every day. They are accompanied with disadvantages such as leaching, pollution of water basins, destroying microorganisms and friendly insects (El-Lithy *et al*., 2014).

Lack of adequate productive lands to fulfill the food requirements of increasing population has become a major problem for mankind. The needs of human population for food, fiber, housing and settlement, energy and water supply and also for congenial environment to survive are met by land. Therefore, proper use and management of marginal lands is necessary.

A major focus in the coming decades would be on the use of safe and environment friendly micro-organisms for sustainable crop production (Nina *et al*., 2014). The inoculation of such microbes to the soil ecosystem enhances soil physicochemical properties, microbial properties, soil health, plant growth and development and crop productivity (Sahoo *et al*., 2013). Use of cyanobacterial biofertilizers has attracted much attention being cost effective and environment friendly approach. They are primary producers and play an important role in nitrogen, carbon and oxygen cycles (De Ruyter and Fromme, 2008). Out of 180 million tones of nitrogen added on earth, 1/3 comes from industries whereas 2/3 comes from biological processes by microbial activities (Kaushik, 2014).

They play an important role in improvement of soil aggregation by secreting mucilaginous substance and improves crop yield (Roger and Burns, 1994). Though, most of the studies has been done on paddy field cyanobacteria and less information is available about saline soil cyanobacteria where paddy cannot be grown due to saline water constraint. One of the major constraint in popularizing the bio-fertilizer is lack of region specific strains. Use of native cyanobacterial strains as biofertilizer for reclamation of salt affected soil is expected to be more effective as they have inherent tolerance to salt and osmotic stress being exposed to such stress over the years (Manchanda and Kaushik, 2000). Therefore, keeping in view this objective the native cyanobacterial strains were isolated and their consortium with farm yard manure were explored for their potential role in bioreclamation of such marginal lands in terms of physical, chemical and microbial properties of soil as well as growth of wheat and maize crop.

MATERIALS AND METHODS

Soil sampling

Soil was collected in large quantity (0-15 cm depth) from salt mine site Drang, Mandi, Himachal Pradesh, India and agricultural fields around the mine. The soil was homogenized, mixed well and sieved through a 20 mm mesh screen before filling into the pots. The experiments were conducted using pot culture in glass house of the department.

Cyanobacterial species isolation and biofertilizer production

Standard culturing and purification technique (Stainer *et al*., 1971; Kaushik, 1987) were followed to isolate native strains of cyanobacteria using BG-11 as growth medium. Three strains *Cylindrospermum muscicola, Phormidium* sp. and *Fischerella ambigua* were isolated. The biofertilizers were prepared following (Nisha *et al*., 2007).

Pot culture

The pot culture experiment was conducted in two sets i.e. amended pots that received biofertilizers at the rate of 0.3 gm/pot which is equivalent to 100 kg/ha and unamended pots serving as control. The biofertilizers were applied at seedling as well as flowering stage. Each pot was filled with 3 Kg soil. The cultivars adapted to the adverse conditions of the area were selected for the present study. Screening of the most suitable cultivar of wheat and maize was done by testing the germination in triplicate. *Triticum vulgare* (VL-892) and Maize (115-08-01 Vyas) were selected for the present study. The wheat crop was grown from November to March for 120 days. After final harvesting the soil of pots was turned separately and kept for stabilization for 30 days before the cultivation of second crop from April to August for a period of 120 days.

Analytical methods

The soil samples were collected from pot culture experiments at regular intervals i.e. 60, 90, 120 days (wheat experiment) and at 160, 240 days (maize experiment) for quantitative analyses of soil physico-chemical and biological parameters in triplicates.

Saturation paste of soil was used to measure electrical conductivity (EC) and pH. Total organic carbon (TOC) was determined by Black and Walkley's rapid dichromate titration method. Phosphate was estimated by molybdenum blue complex formation method, total kjeldahl nitrogen (TKN) by Kjeldahk method. Allen *et al*. (1986) was followed to estimate exchangeable Na^+ and K^+ using flame photometer while Ca^+ and Mg^+were estimated by EDTA titration method. Zn, Cu, Fe and Mn were estimated by using atomic absorption spectrophotometer.

Phosphomonoesterase activity was measured by following (Eivazi and Tabatabi, 1977) and invertase activity (IA) following (Cole, 1977).Buoyoucous hydrometer method was used to study soil texture. Bulk density was measured by following (Phogat *et al*., 1999). Different parameters of vegetative growth, grain yield, dry weight and crude proteins (multiplication of Kjeldahl nitrogen by 6.33) in grain yield were determined.

RESULTS AND DISCUSSION

Microorganisms are very important part of soil. They play an important role in chemical transformation and nutrient cycling in soil. They help in improving soil fertility and further plant growth. The potential of these microorganisms can be assessed by using them as biofertilizers. Biofertilizers are live formulates which, when applied to seed, plant surfaces, root or soil, inhabit the rhizosphere and enhance the bioavailability of nutrients and increasing the microflora through their biological activities and thereby promoting plant's growth (Babalola, 2010; Schoebitz *et al*,. 2014). The biofertilizers are not used as a whole by the crop like chemical fertilizers but only products of biological activity are used (Renault *et al.,* 1975).

The autotrophic cyanobacteria produced biomass and thus organic matter to the soil, increasing soil organic carbon. The soil of agriculture fields of Drang area have EC (3.5 dS/m), alkaline pH (9.67) and low organic matter (TOC=9.03). It was sandy loam in texture with moderately good water holding capacity (41.6%). This soil was observed with low organic matter and medium nitrogen status, high available phosphorous and low to medium available potassium. The concentration of micronutrients (Cu, Fe, Mn and Zn) is high except Ca^+ion where concentration is moderate as compared to ideal soil conditions.

Application of biofertilizers showed a remarkable effect on physical properties of soil with wheat-maize croppingat 120 day (Table 1) and were observed to be improved as compared to control soil.The bulk density and porosity of soil was found to be better with all the treatments (cyanobacterial biofertilizers) and maximum increase was observed when cyanobacterial biofertilizer (consortia) was mixed with farm yard manure (MF+FYM) and showing 117 %, 119 % increase respectively as compared to control. Water holding capacity was also improved. Maximum increase was observed with MF and FYM treatment (124%) while minimum increase was observed with *Cylindrospermum* *muscicola*. Particle density was also increased with all biofertilizers treatment which was maximum in *F. ambigua* (135 %) while minimum in *C. muscicola*. The same trend was true for 240 day (Table 2) where an increase in all the parameters was observed. Synergistic effect of mix biofertilizer and farm yard manure treatment showed greater improvement but particle density was maximum in *F. ambigua* (128 %). It was observed that all physical properties of soil were improved with biofertilization. Time also played an important role as these properties were quite low at 120 day whereas towards the end of experiment they were remarkably improved.

The mucillagenous sheath present in cyanobacteria helps in holding soil particles together and stabilize the soil by forming aggregates. Thus improves infiltration rate, hydraulic conductivity, permeability and water holding capacity of soil (De Philippis and Vicenzini, 1998). Application of microbial biofertilizer for reclamation of marginal lands such as saline alkaline soils has been proved very useful (Hedge *et al*., 1999). Biofertilizers act as soil conditioners, improve soil fertility by adding nitrogen and carbon and also improves the soil physical properties (Malam Issa *et al*., 2001).Role of EPS in improving soil aggregation is also evidenced from the studies of (Rogers and Burns, 1994), who inoculated *Nostoc* into soils and observed improved C, N and soil aggregates. Use of cyanobacterial biofertilizers deliver genetic constituents and bioactive compounds which affect sustainable agriculture and hence improve crop production and soil health (Dilnashin *et al*., 2020).

Tables 3 and 4 depicted the effect of different biofertilizer application on the ionic composition of soil with wheat- maize cropping sequence. Soil pH was declined with application of all biofertilizers. As the initial soil was highly alkaline, addition of cyanobacterial biofertilizer results in reduction of soil pH. Maximum decline was observed in *F. ambigua* (93 %) at 120 day during wheat crop. The soil pH was further improved with time and at the end of 240 d approaches towards ideal soil condition. Mixed biofertilizer and farm yard manure together showed better improvement as compared to individual treatment. Electrical conductivity (EC) also showed a decreasing trend as observed with all the treatments. Maximum decline was observed in mix BF, MF+FYM treatment (75 %). The response to exchangeable sodium showed a decline with all the treatmentsand a good effect was observed in mix biofertilizer and farm yard manure (61.81 %) at 120 d. The decline become comparable with all treatments and *Fischerella ambigua* showed 81.17% declineat 240 day. The concentration of available potassium was also increased with time and treatments. Further, improvement was seen with all treatments at 240 day (109 % to 161 %). Calcium ion concentration in soil was decreased with treatment and time as compared to control at 120 d and the same trend was continue with time (240 d) and maximum decline was observed with mixed biofertilizer treatment (consortia) whereas minimum decline was observed in *F. ambigua*. Magnesium ion concentration was increased except *C. muscicola* where it remains same as control. Maximum increase in magnesium concentration was observed in mixed biofertilizers treatment. It was observed that pH, EC, and concentration of other ions was much affected by biofertilizer application and with time. At 120 days the effect shown was less but with time an improvement was observed.

Cyanobacterial biomass is reported to have a store of labile pools of C, N, P and mineral nutrients like Ca, Mg, Na and K (Henriksson, 1971, Mandal *et al.,* 1999) which are released into the soil due to death and rapid mineralisation (Yanni and Abd-El-Rahman, 1993).Our investigations are in compatibility with earlier studies done where cyanobacteria modulated changes and its impact on bioremediation of saline- alkaline soils of Varanasi, Uttar Pradesh has been investigated (Singh and Singh, 2015). The soil was inoculated with cyanobacteria *Nostoc calcicola* and gypsum and observed significant decrease in EC, pH and Na^+ and increase in organic carbon. Anand *et al*. (2015) studied physico-chemical characterization of Usar soil (saline-alkaline soil) and their natural reclamation by cyanobacteria and observed decrease in pH, exchangeable sodium and collective increase in nitrogen and phosphorous, organic carbon and water holding capacity of soil and improved soil fertility.

Tables 5 and 6 showed biofertilizer treatment which led to improvement in key nutrients like total kjeldahl nitrogen (TKN), total organic carbon (TOC) and available phosphorous in the saline soil. It was observed that total organic carbon (TOC) was increased with application of all the biofertilizer in soil as compared to control soil. Maximum increase was observed when amended with FYM along with algal biofertilizer. Cyanobacterial application and farm yard amendments increased TOC in the soil by 5-30% after 120 days, that is, by the end of wheat crop. Subsequently, the TOC build up in soil due to BF became gradual and stabilized when maize was grown and the treated soil showed only 0-21 % more organic carbon than control.

Algalization increased total Kjeldahl nitrogen in the soil by 6-30% and the build-up of TKN was of the same order during the wheat and maize cropping. The macronutrients such as nitrogen and available phosphate in the soil were consistently improved and maximum increase was observed in MF+FYM treatment while minimum increase was observed in *F. ambigua* and *Phormidium* sp. Available potassium was also observed to be increased and maximum increase was observed in mixed BF+FYM while minimum increase was observed in *F. ambigua* during wheat cropping. Effects of Cyanobacterial application on available phosphorus in soil in the form of soluble phosphates become prominent with time. During maize experiment available phosphate (125 %) and potassium (152 %) were increased, maximum increase in concentration was observed with mixed BF+FYM while minimum increase was observed with *F. ambigua.*

The micronutrients (Cu, Fe, Mn, Zn) were quite high in the mining soil initially. Copper concentration was declined with all the treatments except mixed biofertilizer and farm yard manure treatment during 120 d experiment of wheat crop. Subsequently copper concentration remained almost same with all treatments except *Cylindrospermum muscicola* and *Phormidium* sp. where it was declined as compared to control during maize crop at 240 d. Iron and manganese concentration was increased with all the treatments, maximum increase was observed with *C. muscicola* and *Phormidium* sp. respectively while minimum increase was observed with mixed BF+FYM. At 240 d,with time an increase of 2-8% was observed in all treatments. Manganese concentration was also increased and maximum increase was observed with *Fischerella ambigua* and mixed BF+FYM treatments while minimum increase was observed in MF+FYM and *Phormidium* sp. Zink concentration was observed to be declined with *C. muscicola* and increased with mixed biofertilizer treatment, while it was quite low in all other treatments at 120 d. Further, a decrease of 12-17% was observed at 240 d in maize experiment with maximum decrease was observed in *C. muscicola.*

Our studies are in accordance with the earlier investigations where saline soil of Satkhira, Bangladesh was inoculated with cyanobacterial strains inoculum at the rate 20 kg ha^{-1} which resulted in increase in organic matter, total N and P of the soil. This shows that cyanobacterial applications are helpful in improving the fertility of soil (Aziz and Hashem, 2003). Cyanobacterial application to salt affected soils results in increased nitrogen content (Subhashini and Kaushik, 1981). By application of native algal flora to saline sodic soil of Karnal, Haryana up to 45% of phosphorous availability was observed (Kaushik, 1983). Cyanobacterial consortia (*A. doliolum, C. sphaerica* and *Nostoc calcicola*) were used in wheat and millet crops and an improvement in nitrogen and phosphorous availability in soil was observed (Rani *et al*., 2007).

Fig. 1 and 2 has depicted the microbial activities i.e. phosphatase and invertase activity of soil at different days. The activity was species specific and increased with time period. At 60 day maximum phosphatase activity has shown by mix biofertilizer treatment (135.18 µgNP/gdm/h; 173%) as compared to control. Similarly at 120 day maximum and minimum activity has been shown by mix BF (225.17 µgNP/gdm/h; 210 %) and *F. ambigua* (107.29 µgNP/gdm/h) respectively. At 240 day maximum activity was shown by MF+FYM treatment (283.26 µgNP/gdm/h; 173 %) as compared to control.

Similarly invertase activity increased tremendously with time and treatment as all the cyanobacterial biofertilizers showed improvement as compared to control. At 60 day maximum activity was observed with MF+FYM treatment (335.45 µg/g/h; 341 % to respective control as 100). It was somewhat got stabilized during wheat cropping at 120 d and showed remarkable improvement as compared to control with all treatments and maximum activity was shown by MF+FYM treatment (794.76 µg/g/h; 659 %), at 120 day. Similarly during maize crop at 240 day, although all the treatments showed improvement in the microbial activity showing high in farm yard amended mix fertilizer (825.59 µg/g/h; 636 %) but slight decline was observed towards the end of maize experiment as shown in Fig 2.

Biomass and exopolysaccharides secretion of algae stimulate the growth of soil microorganisms and also stimulate soil enzymatic activity which helps in liberation of nutrients by plants (Caire*et al*., 2000). Algal application also improved phosphomonoesterase activity, thus facilitating conversion of unavailable organically bound phosphorus into available form. This is also shown by higher concentrations of phosphates in algalized soils. Mandal *et al.*(1999) and Acea *et al*. (2003) reported proliferation of P-solubilizing heterotrophic bacteria by algal inoculation. The indigenous cyanobacterial species show promise in effective exploitation for phytoremediation and improved productivity of saline soils under semi-arid condition and help in adding organic matter, encourage growth of other microbial communities, maintain nutrient cycles, reduce soil erosion by improving soil aggregation and structural stability, facilitates increased crops yield (wheat and pearl millet) under water scarcity (Rani *et al*., 2018).

The effect of biofertilization on the crop parameters of salt mining soil of Drang showed an improvement as compared to control (Tables 7 and 8). The leaf area, spike length, dry weight and leaf protein were maximum in MF+FYM treatment as compared to control. The synergistic effects of three cyanobacterial biofertilizer along with farm yard manure (MF+FYM and mix biofertilizer treatment) resulted in improvement of all the parameters and showed maximum effect as compared to control. A remarkable improvement in crop growth was observed at 240 day. There was (190 %) increase in leaf area with MF+FYM treatment. Similarly spike length, dry weight and leaf proteins were improved. The plant growth was comparatively low at 120 day in wheat crop but improved at 240 day in case of maize crop which was significantly observed. Change in nutrient status, physical properties and microbial activities as a result of algal biofertilizers treatment to salt mining soil improved the fertility of soil which was reflected in growth and yield of wheat and maize.

Cyanobacterial consortia (*Anabaena doliolum, Cylindrospermum sphaerica* and *Nostoc calcicola*) were used as biofertilizers to see their effect on wheat and millet crops and observed increase in grain yield and protein content of leaves. Moreover, shoot length was also increased (Rani*et al*., 2007). During the growth period they secrete extracellular substances like polysaccharides (Jha *et al*., 1987). These substances improve the fertility of soil by aggregating soil particles together.

CONCLUSION

In the present study algal species isolated from agricultural fields adjoining the Drang salt mine possess the ability and found to be effective in tolerating the stressful and harsh conditions of wasteland. The remarkable tolerance of these species make them useful for improving the soil health in terms of physico-chemical and biological properties. Further when these native species were used in consortia along with farm yard manure showed synergistic effect and proved to be very successful in bioameliorating salt affected soil. These species help in adding organic matter, maintain nutrient cycles, reduce soil erosion by improving soil aggregation and facilitates increased crops yield (wheat and maize). This technology can be further transferred to plots and microplots of such marginal lands and repeated biofertilization on long term basis may leads to help in eco-restoration of salt affected soils.

Table 1: Effect of biofertilization (BF) on some important physical properties of soil with wheat –maize (Wh-Mz) cropping sequence at 120 d

Parameters	Control	*C. muscicola* HPUSD12	*Phormidium* sp. HPUSD13	*F. ambigua* HPUSD14	Mix BF	Mix BF+ FYM
Bulk density (g/cm^3)	1.02±0.05	1.13±0.01	1.10±0.01	1.15±0.03	1.20±0.00	1.20±0.27
Porosity (%)	40.00±0.27	40.33±0.54	42.67±0.27	43.33±0.27	45.67±0.27	47.67±0.27
Water holding capacity (%)	41.60±0.27	47.00±0.27	47.55±0.54	47.60±0.27	50.10±0.00	51.67±0.27
Particle Density (g/cm^3)	2.00±0.00	2.10±0.01	2.25±0.00	2.70±0.01	2.50±0.01	2.60±0.00

Table 2: Effect of biofertilization (BF) on some important physical properties of salt mining soil with wheat –maize (Wh-Mz) cropping sequence at 240 d

Parameters	Control	*C. muscicola* HPUSD12	*Phormidium* sp. HPUSD13	*F. ambigua* HPUSD14	Mix BF	Mix BF+ FYM
Bulk density (g/cm^3)	1.05±0.00	1.17±0.01	1.12±0.00	1.18±0.01	1.22±0.01	1.25±0.00
Porosity (%)	40.01±0.01	40.36±0.01	42.70±0.01	43.38±0.00	46.00±0.01	48.00±0.01
Water holding capacity (%)	41.80±0.54	47.09±0.27	47.60±0.54	50.30±0.27	50.37±0.27	52.00±0.27
Particle Density (g/cm^3)	2.15±0.01	2.17±0.01	2.28±0.00	2.76±0.01	2.60±0.02	2.75±0.00

Table 3: Effect of biofertilization on ionic composition of soil with wheat-maize (Wh-Mz) cropping sequence at 120 days

Parameters	Control	*C. muscicola* HPUSD12	*Phormidium* sp. HPUSD13	*F. ambigua* HPUSD14	Mix BF	Mix BF+ FYM
pH	9.00±0.05	8.76±0.03	8.75±0.03	8.43±0.05	8.90±0.03	8.50±0.05
EC (dS/m)	3.30±0.00	2.90±0.00	2.90±0.00	2.85±0.00	2.50±0.39	2.50±0.00
Na^+ (mg/kg)	250.63±4.75	213.27±1.05	212.43±2.50	207.2±2.80	170.55±1.39	154.93±2.36
K^+ (mg/Kg)	104.33±0.16	119.84±0.16	149.55±0.48	142.89±16.79	119.84±0.16	246.34±0.05
Ca^+ (ppm)	489.33±1.09	327.33±43.00	417.33±1.44	251.33±0.54	243.37±0.56	256.67±0.54
Mg^+ (ppm)	77.60±0.86	77.60±0.86	242.00±1.99	136.13±4.96	785.67±1.91	134.80±0.33

Mixed Biofertilizer: *Cylindrospermum muscicola* HPUSD12, *Phormidium* sp. HPUSD13, *Fischerella ambigua* HPUSD14. FYM: Farm yard manure

Table 4: Effect of biofertilization on ionic composition of soil with wheat-maize (Wh-Mz) cropping sequence at 240 days

Parameters	Control	*C. muscicola* HPUSD12	*Phormidium* sp. HPUSD13	*F. ambigua* HPUSD14	Mix BF	Mix BF+ FYM
pH	8.23±0.03	7.40±0.05	7.53±0.03	7.67±0.07	7.27±0.03	7.27±0.03
EC (dS/m)	3.00±0.00	2.70±0.00	2.70±0.00	2.72±0.00	2.45±0.00	2.45±0.00
Na^+ (mg/kg)	225.70±1.00	185.32±1.98	186.69±2.50	183.21±0.44	185.14±4.00	185.14±4.00
K^+ (mg/Kg)	187.86±0.28	278.20±0.14	251.26±0.11	204.80±0.19	281.13±0.19	302.43±0.38
Ca^+ (ppm)	463.33±1.09	251.33±0.54	242.00±0.94	462.67±1.44	238.67±1.09	234.00±0.82
Mg^+ (ppm)	748.40±1.82	750.40±0.33	750.40±0.33	758.00±8.57	752.00±1.18	750.83±0.34

Mixed Biofertilizer: *C. muscicola* HPUSD12, *Phormidium* sp. HPUSD13, *F. ambigua* HPUSD14, FYM: Farm yard manure

Table 5: Effect of biofertilization (BF) on macro and micronutrient composition of salt mining soil with wheat –Maize (Wh-Mz) cropping sequence at120 d

Para-meters	Control	*C. muscicola* HPUSD12	*Phormidium* sp. HPUSD13	*F.ambigua* HPUSD14	Mixed BF	Mixed BF+ FYM
TOC (g/Kg)	9.05±0.0	9.75±0.30	9.23±0.03	9.30±0.08	10.85±0.00	11.83±0.00
TKN mg/Kg)	245.65±0.01	267.00±0.20	270.55±0.17	265.33±0.01	297.30±0.40	300.20±0.00
P (mg/Kg)	39.00±0.02	39.38±0.02	39.35±0.08	39.86±0.03	40.55±0.81	42.25±0.72
K (mg/Kg)	194.33±0.16	279.94±0.45	259.55±0.48	219.45±0.00	219.84±0.16	246.34±0.05
Cu (ppm)	0.86±0.00	0.74±0.01	0.64±0.01	0.66±0.00	0.75±0.00	0.88±0.00
Fe (ppm)	11.81±0.01	12.86±0.00	12.33±0.01	12.23±0.00	12.52±0.01	12.07±0.00
Mn (ppm)	0.42±0.01	0.47±0.00	0.84±0.01	0.47±0.00	0.82±0.01	0.46±0.01
Zn (ppm)	0.12±0.00	0.10±0.00	-	-	0.23±0.01	-

Mixed Biofertilizer: *Cylindrospermum muscicola* HPUSD12, *Phormidium* sp. HPUSD13, *Fischerella ambigua* HPUSD14. FYM: Farm yard manure

Table 6 : Effect of biofertilization (BF) on macro and micro-nutrient composition of salt mining area soil with wheat – maize(Wh-Mz) cropping sequence at 240 d

Para-meters	Control	*C. muscicola* HPUSD12	*Phormidium* sp. HPUSD13	*F.ambigua* HPUSD14	Mixed BF	Mixed BF+ FYM
TOC (g/Kg)	10.00±0.07	10.07±0.05	10.35±0.05	10.35±0.03	12.10±0.03	12.17±0.05
TKN mg/Kg)	267.67±0.17	299.00±0.40	297.58±0.17	298.35±0.08	318.31±0.48	360.87±0.15
P (mg/Kg)	42.44±0.00	43.68±0.02	43.62±0.01	43.60±0.00	44.04±0.00	53.27±0.15
K (mg/Kg)	197.86±0.28	278.20±0.14	251.20±0.11	204.80±0.19	281.13±0.19	302.43±0.38
Cu (ppm)	1.01±0.00	1.00±0.00	0.67±0.27	1.01±0.00	1.01±0.00	1.01±0.00
Fe (ppm)	12.61±0.00	12.92±0.00	12.63±0.01	12.70±0.00	12.77±0.01	13.63±0.00
Mn (ppm)	1.48±0.01	1.49±0.01	1.49±0.01	1.52±0.01	1.52±0.01	1.50±0.00
Zn (ppm)	0.51±0.00	0.51±0.01	0.52±0.01	0.54±0.00	0.53±0.01	0.53±0.01

Mixed Biofertilizer: *Cylindrospermum muscicola* HPUSD12, *Phormidium* sp. HPUSD13, *Fischerella ambigua* HPUSD14. FYM: Farm yard manure

Table 7: Growth performance and yield (per pot) of wheat - maize cropping sequence in response to cyanobacterial biofertilization (BF) application in salt mine area soil at 120 day

Parameters	Control	*C. muscicola*	*Phormidium* sp.	*F.ambigua*	Mix BF	Mix BF+ FYM
Leaf Area (cm^2)	13.81±0.01	55.09±0.04	26.04±0.02	27.74±0.00	30.76±0.02	63.00±0.01
Spike Length (cm)	2.66±0.02	4.83±0.34	5.00±0.47	3.81±0.09	4.27±0.50	8.33±0.17
Dry Weight (gm)	3.23±0.12	5.08±0.48	3.62±0.14	11.54±0.22	14.00±0.47	14.00±0.47
Leaf Protein (%)	1.72±0.01	2.23±0.03	2.07±0.03	2.40±0.05	2.53±0.03	4.60±0.12

Mix biofertilizer :*Cylindrospermum muscicola, Phormidium* sp., *Fischerella ambigua,* FYM : Farm yard manure

Table 8 : Growth performance and yield (per pot) of wheat - maize sequence in response to algal biofertilization (BF) application in salt mine area soil at 240 day

Parameters	Control	*C. muscicola*	*Phormidium* sp.	*F.ambigua*	Mix BF	Mix BF+ FYM
Leaf Area (cm^2)	426.62±0.01	580.69±0.01	727.48±0.01	436.33±0.01	613±0.01	812.58±0.02
Spike Length (cm)	5.30±0.29	8.65±0.38	5.82±0.13	5.37±0.07	8.33±0.17	11.84±1.15
Dry Weight (gm)	8.15±0.08	11.10±0.64	11.76±0.12	11.48±0.21	12.67±0.27	14.33±0.72
Leaf Protein (%)	5.05±0.02	6.72±0.01	6.83±0.03	5.53±0.07	8.60±0.12	11.05±0.02

Mix biofertilizer: *Cylindrospermum muscicola, Phormidium* sp., *Fischerella ambigua*. FYM: Farm yard manure.

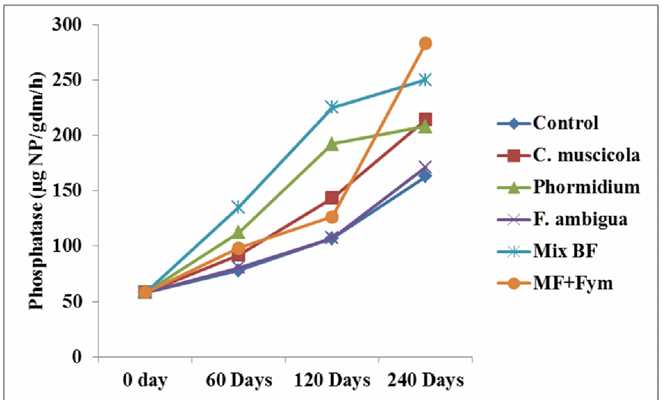

Fig. 1: Time course variations in soil microbial activity (phosphatase) due to different cyanobacterial biofertilizer (BF) in soil

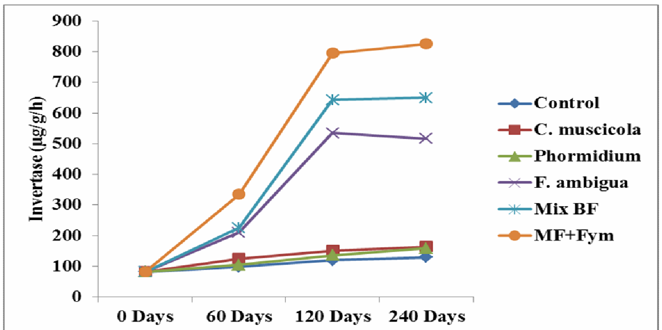

Fig. 2: Time course variations in soil microbial activity (invertase) due to different cyanobacterial biofertilizer (BF) in soil

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