Guar (*Cyamopsis tetragonoloba* L.): A Potential Candidate for the Rehabilitation of Feldspar Mine Spoil Amended with Bioinoculants

R. Junia, R.C. Kasana’, N. Jain, G.K. Aseri

**ABSTRACT**
Excessive feldspar mining is becoming an alarming issue due to the untreated mine spoil. For the success in the remediation of mine spoil, selection of plant species is an important factor. Therefore being a nitrogen fixer, legumes can be an alternative and are needed to be broadcasted for the rehabilitation of mined lands. In this context guar (*Cyamopsis tetragonoloba* L.) can be preferred which excels in enhancing soil fertility and is already in cultivation but not experimented with feldspar due to not establishing its rhizosphere fertility. In this study to enhance the fertility status and biological activities of feldspar mine spoil plantation of guar is done with the inoculation of microbes *Azotobacter Azospirillum* and *Glomus mosseae* (AMF) and organic and inorganic amendments. This attempt has successfully enhanced the rhizosphere enzymes at the rate of 10-65% maximum with AMF+ OM+ NPK50% (*T*1), nutrient uptake 10-70% maximum with *Azotobacter*+ OM+ NPK 50% (*T*2) and plant metabolites 10-51% also observed maximum with *T*3 over the uninoculated control. Guar has also shown positive response towards the applied treatment and grown well. Based on the results it can be inferred that guar can tolerate detrimental effects of feldspar mining. Hence, it is concluded that guar can be a potential crop to restore soil health of feldspar mined land for sustainable development.

**Key words:** *Azotobacter, Azospirillum, AMF, Bioinoculants, Soil Fertility, Mine spoil, Macro and micronutrients.*

**INTRODUCTION**
Feldspar is one of the most important minerals in the earth’s crust (Balic-Zunic *et al.*, 2011), comprising a complex series of aluminosilicates with varying amounts of iron, potassium, sodium, calcium and traces of barium, magnesium, phosphorus, and titanium (Sartor *et al.*, 2018). Its global production has been estimated at 25.31 million tonnes, whereas, India stands fourth with 7% reserves (Anonymous, 2015a). The industrial revolution led to a greater demand for the feldspar due to its extensive use, as a major ingredient for ceramic and glass industry (Gaied and Gallala, 2015) and India stands third as world’s leading ceramic tile producer and consumer (Anonymous, 2015b). Therefore feldspar mining is valuable for Indian economy. But feldspar mining is carried out by open cast method, which causes extensive and palpable damage to the environment (Dugaya, 2009). The problem of open cast mining is very acute in India and large areas are continually being unproductive every year (Kundu and Ghose, 2000). Simultaneously it causes detrimental effects on land ecosystem, environment and socio-economic health (Keil *et al.*, 2016).

In favour of conservation of nature and natural resources, forests and other protected lands cannot be leased out for cultivation to fetch ever growing population; therefore, we need to revive mined lands by using all available means including phytoremediation (Mukhopadhyay and Maiti, 2010). Microbes assisted phytoremediation approach has already become popular to mitigate soil fertility, which is damaged by the open cast mining (Juwarkar and Singh, 2010). Thus, plants with industrial potential and tolerance to the abiotic stress are required to address these issues for sustainable rehabilitation. In this context, guar (*Cyamopsis tetragonoloba* L.) has been used as alternate crop to establish soil fertility (Bhattacharyya, 2015) which directly support microbial consortium, thus giving a long-term solution and has wide industrial applications (Abidi *et al.*, 2015) besides drought tolerance (Kumawat and Mahla, 2015). Guar is a first choice for improving soil health, because of its ability to fix nitrogen (Brar and Singh, 2017), has short life span and less water requirement. India accounts for 80% of the total guar produced in the world and are single largest producer of guar seed, where Rajasthan has been taken as reference for all studies on guar seed, being single largest state producer (Baldodiya and Awasthi, 2018). Since, plantation alone is not enough, eco-restoration programme in any mine spoil must be...
supplemented with organic amendments for better results (Juwarkar et al., 2016), therefore microbes – assisted phytoremediation, can be planned to achieve rehabilitation of feldspar mine spoil. In this research study, *Azotobacter, Azospirillum and Glomus mosseae* (AMF) have been used in various treatments with organic and inorganic amendments to enhance soil fertility and pave the path for possibilities of guar cultivation in feldspar mine spoil.

**MATERIALS AND METHODS**

Feldspar mine at Sarana village is one of the major sites of feldspar mining, situated at Ajmer, India (25°38” and 26°58” North Latitudes and 73°54” and 75°22” East Longitudes). The experiment was conducted during summer season (May, 2017) at Greenhouse Govindgarh, Pushkar (Ajmer). Growth from guar seed was evaluated for total 16 treatments in three replication using Randomised Block Design. The treatments were: (1) mine spoil only (control); (2) mine spoil + *Azotobacter* (3) mine spoil + *Azotobacter* + organic manure (OM); (4) mine spoil + *Azotobacter* + AMF; (5) mine spoil + *Azotobacter* + NPK (50%); (6) mine spoil + *Azotobacter* + OM + NPK (50%); (7) mine spoil + *Azospirillum* (8) mine spoil + *Azospirillum* + OM; (9) mine spoil + *Azospirillum* + AMF; (10) mine spoil + *Azospirillum* + NPK (50%); (11) mine spoil + *Azospirillum* + OM + NPK (50%); (12) mine spoil + AMF; (13) mine spoil + OM + NPK (50%); (14) mine spoil + AMF + NPK (50%); (15) mine spoil + OM + NPK (50%); (16) full dose of NPK (100%). Total 48 plants and rhizosphere soil samples have been tested from zero analysis to three months.

500 kg of feldspar mine spoil from the core area of feldspar mine at Sarana village has been transported to green house and zero analysis was carried out. As per given treatments, 9 kg mine spoil was filled in earthen pots (12-15 kg capacity). *Azotobacter, Azospirillum and Glomus mosseae* (AMF) were isolated from soil samples by using Jensen Nitrogen Free media, semi solid malate media and wheat based live culture, respectively. These three cultures were mass produced on the same and inoculated as per the treatments. The pots with control (T1), of respective plants, were also inoculated with their respective microbial media after the sterilization. The full dose (100%) of NPK comprised nitrogen (urea) = 10.5 gm, super phosphate = 15.5gm, potash = 4.25gm and half dose (50 % of the same), were given on 30th day after sowing. All pots were watered up to field capacity; alternate days in first month and weekly onwards. The plant height, shoot diameter and canopy were recorded at the interval of one month. Plants were harvested after three months and their roots, shoots and leaves were oven dried and weighed for the further analysis.

The plant samples were processed in the laboratory for the estimation of chlorophyll a and chlorophyll b at 645 and 663 nm respectively (Arnon, 1949) and reducing sugar at 540 nm (Nelson, 1944). Dried powder was digested using Triacid (Nitric + Sulfuric + Perchloric acid) digestion method given by Piper (1942). Total nitrogen was determined by using Kjeldahl method (Saez-Plaza et al., 2013), phosphorus (P) determined by vanadomolybdate yellow colour method by Jackson, (1987), potassium (K), calcium (Ca), magnesium (Mg) and micronutrients (Cu, Mn, Zn and Fe) were determined through Atomic Absorption Spectroscopy (AAS) method. Rhizosphere soil was taken for the estimation of physico-chemical biological properties of soil pH, EC, available phosphorus by using method given by Olsen (1954), dehydrogenase activity was measured by using 2,3,5- triphenyltetrazolium chloride (TTC), spectro photometrically given by Tabatabai (1992), phosphatase by Tabatabai and Bremner (1969) and organic carbon (OC) method given by Walkley and Black (1934).

**Statistical Analysis**

The data was subjected to analysis of variance and mean of inoculated and control treatments were compared by the Scheffe’s test for planned comparison upto LSD (Least Significant Difference).

**RESULTS AND DISCUSSION**

**Zero Analysis**

The physical and chemical properties of the soil collected from feldspar mine showed that the soil is highly alkaline in nature and poor in major nutrients (Table 1). Feldspar mine spoil is of average 72% gravel and seasonally provide cohesive environment for water holding and microbes assisted mineral solubilization hence, the poor fertility of the feldspar mine spoil is depicted by the low concentration of major minerals (N, P, K, Ca and Mg) and micronutrients (Cu, Zn, Mn, and Fe).

According to Tripathi et al. (2012), soil clay content directly effects nutrients and nutrient transformation in the soil and is showed significant correlation with organic C, nitrogen and available phosphorous, found in coal mine spoil. Therefore, in present study the soil texture of having low clay content may be responsible for the lower

**Table 1: Characteristics of feldspar mine spoil.**

| Parameters                  | Units   | Feldspar mine spoil |
|-----------------------------|---------|---------------------|
| * pH (1:2)                  |         | 9.25                |
| **EC**                      | dS m⁻¹  | 0.279               |
| Gravel: Sand: Silt: Clay    | %       | 72.2:11.5:10.8:5.5  |
| Organic C                   | %       | 0.36                |
| Nitrogen (N)                | mg kg⁻¹ | 2.03                |
| Phosphorous (P)             | mg kg⁻¹ | 2.03                |
| Potassium (K)               | mg kg⁻¹ | 2.03                |
| Calcium (Ca)                | cmol kg⁻¹ | 3.23                |
| Magnesium (Mg)              | cmol kg⁻¹ | 3.46                |
| Copper (Cu)                 | ppm     | 0.111               |
| Zinc (Zn)                   | ppm     | 0.212               |
| Iron (Fe)                   | ppm     | 0.59                |
| Manganese (Mn)              | ppm     | 0.126               |
| Dehydrogenase               | pkat g⁻¹ | 0.175               |

* Potential of hydrogen, **Electrical conductivity.
macronutrients and OC, whereas, Yaseen et al. (2014) statistically proved the positive correlation of organic carbon with EC, available P and N. Therefore in feldspar mine spoil low EC, N and P was may be due to low organic carbon. Similarly Pasayat and Patel (2015) while assessing the iron mine spoil quality stated that, soil texture also effects other soil properties, which in turn determines microbial growth, hence low dehydrogenase activity was attributed towards the poor soil texture of feldspar mine spoil.

**Growth Parameters**

Influence of microbial inoculants, organic inorganic amendments can be clearly seen on plant growth parameters in feldspar mine spoil (Table 2). We have recorded maximum plant height (121 cm) in treatment Azotobacter + OM + NPK 50% followed by treatment AMF + OM + NPK 50% (116 cm) over the uninoculated control and other treatments. Same trend was found in shoot diameter, plant canopy and dry weight. Overall, Azotobacter has successfully influenced plant growth in comparison of Azospirillum, whereas AMF was also found to be significant at P≤0.05%. Azotobacter (Hindersah et al., 2018), Azospirillum (Widawati and Suliasih, 2019) and Mycorrhizae (Aggangan and Cortes, 2018) are known to excel in unfavourable environment and proved to establish soil fertility of groundnut (Arachis hypogaea) in mercury spoil, great millet (Sorghum bicolor) in tin spoil and Narra (Pterocarpus indicus) in copper mine spoil, respectively. As Azotobacter releases growth promoting hormones auxin, cytokinin and gibberellin (Vikhe, 2014), that stimulate cell extension and division which promote plant growth (Takatsuka and Umeda, 2014). AM fungi inoculated seedlings of Eucalyptus tereticornis showed 95% survival over the control seedlings and their growth was also significantly higher in bauxite mine spoil (Karthikeyan and Krishnakumar, 2012). Study by Gul et al. (2019), also supported our results where growth of guar responded well towards the consortium of bioinoculants and inorganic fertilizers. Hence, these bioinoculants were found to be effective in reviving the soil health and plant development and growing plants together with rhizobacteria and AMF in feldspar mine spoils stimulated the plant germination, shoot as well as root growth.

**Enzymatic Activities**

The presence of small dehydrogenase activity and 5.5% clay in feldspar mine spoil indicated the signs of possibility for the rejuvenation of mined land as clay content directly effects soil organic carbon, available P and microbial growth. Table 3 is showing the results of the improvement in rhizosphere enzymatic activity, available P and organic carbon in guar. Among the enzymatic activities, the alkaline phosphatase activity of the soil has been increased throughout the incubation period in all the treatments than uninoculated control, irrespective of feldspar concentration in the spoil. Percentage increment in AMF+ OM+ NPK 50% treatment has been recorded 46.86% which was found to be highest followed by Azospirillum+ OM+ NPK 50% with 44.4% increment. Results are in similarity with Gucwa-Przepiora et al. (2016), who recorded enhanced alkaline phosphatase activity in Plantago lanceolata by introducing AMF in Zn/Pb mine spoil.

On the other side, AMF also dominated over acid phosphatase activity which has been recorded highest in AMF+ OM+ NPK 50% treatment with 76% increment, followed by Azotobacter+ OM+ NPK 50% with 72%. This may be due to the reason given by Sinegani and Sharifi, (2007) that, phosphatase produced by plants is exclusively

### Table 2: Growth of guar as influenced by bio-inoculants in feldspar spoils.

| Treatments          | Height (cm) | Shoot diameter (inches) | Canopy (m² plant⁻¹) | Dry Wt. (gm plant⁻¹) |
|---------------------|-------------|-------------------------|----------------------|----------------------|
| T - 1: Control      | 60          | 0.091                   | 5.5                  | 22                   |
| T - 2: NPK 100%     | 80          | 0.125                   | 7.5                  | 48                   |
| T - 3: Azotobacter  | 72          | 0.098                   | 5.8                  | 34                   |
| T - 4: Azotobacter + OM | 96      | 0.101                   | 6.0                  | 53                   |
| T - 5: Azotobacter + AMF | 98  | 0.107                   | 6.3                  | 72                   |
| T - 6: Azotobacter + NPK 50% | 103 | 0.115                   | 6.6                  | 85                   |
| T - 7: Azotobacter + OM + NPK 50% | 121 | 0.132                   | 7.4                  | 119                  |
| T - 8: Azospirillum | 70          | 0.096                   | 6.0                  | 35                   |
| T - 9: Azospirillum + OM | 97      | 0.097                   | 6.2                  | 58                   |
| T - 10: Azospirillum + AMF | 99     | 0.106                   | 6.6                  | 76                   |
| T - 11: Azospirillum + NPK 50% | 101 | 0.116                   | 6.8                  | 97                   |
| T - 12: Azospirillum+ OM + NPK 50% | 104 | 0.119                   | 6.9                  | 105                  |
| T - 13: AMF         | 71          | 0.098                   | 5.9                  | 32                   |
| T - 14: AMF + OM    | 93          | 0.102                   | 6.5                  | 54                   |
| T - 15: AMF + NPK 50% | 100     | 0.111                   | 6.5                  | 81                   |
| T - 16: AMF + OM + NPK 50% | 116 | 0.129                   | 7.0                  | 109                  |
| LSD (0.05)          | 4.1         | 0.01                    | 0.21                 | 1.9                  |
acid phosphatase, in addition it may be produced by bacteria, fungi and Yeast. In present study, AMF have been found to mineralise maximum soil phosphorous in AMF + OM + NPK 50% treatment. This is similar to the findings of Kumar et al. (2011), who also observed that phosphatase activity is related to soil OM and NPK in soil. The increase in the bacterial count in Azotobacter+ OM+ NPK 50% (T10) and Azospirillum+ OM + NPK 50% (T12) was found (50 x 10^9 CFU ml^-1) and (48 x 10^9 CFU ml^-1) respectively and significant at P<0.05%, over the uninoculated control. The higher bacterial count over the control was anticipated due to the microbial stimulation with presence of plant root exudates in the rhizosphere (Rani and Juwarkar, 2012). On the same side, dehydrogenase activity in the soil followed the same trend as of microbial count. DHA activities were also found maximum with T1 (4.76 pkat g^-1) and T12 (4.69 pkat g^-1). The result is supported by Rath et al. (2010), who found that the soil enzyme activities have indicated significant positive correlation with the number of bacterial and fungal colonies in iron and chromite mine spoil in Orissa, India. Similarly Rao and Tak, (2002), while finding the effects of Glomus mosseae on the plant species grown on limestone mine spoil found that, inoculation with AM-fungus had significantly enhanced the dehydrogenase activities compared to that of the uninoculated plants.

Availability of Olsen P was found maximum with AMF in combination with OM+ NPK 50% which is higher than NPK 100% alone. Organic carbon (OC) was also increased in the reclaimed site over the control. Maximum accumulation of OC was observed in Azotobacter+ OM+ NPK 50% treatment followed by Azospirillum + OM + NPK 50% and AMF+ OM+ NPK 50%. The results are in line with the previous studies showed that, soil organic carbon of coal mine increased after inoculation with AMF (Qian et al., 2012) and organic matter (Shrestha et al., 2019). This enhancement was due to the accumulation of organic matter in the mine soil, which has accelerated organic carbon production. These findings agree with the study by Ekka and Behera (2011) and Rath et al. (2010) who found the direct relationship between amount of organic carbon and soil organic matter. Legumes are also known to increase soil organic carbon. (Rothe et al. 2002) has reported the increment in SOC by legumes. The same findings have also been observed in the present study where guar grown in feldspar mine spoil improved the SOC.

**Metabolites**

The photosynthetic pigments chlorophyll a, chlorophyll b, total chlorophyll and reducing sugar content in the leaves of guar grown on feldspar mine spoil are presented in Fig 1. Total chlorophyll content was found to be highest in treatment with Azotobacter+ OM+ NPK 50% (6.21 mg g^-1 fwt.) followed by Azospirillum+ OM+ NPK 50% (6.16 mg g^-1 fwt.) and AMF+ OM + NPK 50% (6.10 mg g^-1 fwt.). The results were found significant at P<0.05% over the uninoculated control. The increase in the chlorophyll content was may be due the nitrogen fixation by guar. This is supported by Hokiaipour and Darbandi, (2011), who found that chlorophyll content in the leaves is positively influenced by fertilizer application, especially nitrogen. Verdugo et al. (2010) observed the increased chlorophyll content after the introduction of AMF in rye grass grown in copper mine whereas, Vafadar et al. (2014), Rajashekar and Nagarajan (2005) have seen similar rise in the chlorophyll content.

### Table 3: Effect of bio-inoculants on rhizosphere enzymes, Olsen P and C availability in feldspar soil

| Treatments          | Dehydrogenase (pkat g^-1) | Acid-Phosphatase (nkat g^-1) | Alkaline-phosphatase (nkat g^-1) | Olsen P (mg g^-1) | Organic Carbon (%) |
|---------------------|---------------------------|------------------------------|----------------------------------|------------------|-------------------|
| T - 1: Control      | 2.85                      | 2.2                          | 4.9                              | 3.4              | 1.04              |
| T - 2: NPK 100%     | 3.02                      | 3.7                          | 6.0                              | 4.2              | 1.08              |
| T - 3: Azotobacter  | 2.94                      | 2.9                          | 6.1                              | 3.6              | 1.17              |
| T - 4: Azotobacter + OM | 4.12                  | 3.1                          | 6.2                              | 4.7              | 1.41              |
| T - 5: Azotobacter + AMF | 4.27                 | 3.9                          | 7.8                              | 5.8              | 1.48              |
| T - 6: Azotobacter + NPK 50% | 4.24             | 4.1                          | 7.3                              | 5.6              | 1.46              |
| T - 7: Azotobacter + OM + NPK 50% | 4.76          | 4.7                          | 7.9                              | 6.2              | 1.52              |
| T - 8: Azospirillum | 3.02                      | 2.5                          | 5.3                              | 3.6              | 1.08              |
| T - 9: Azospirillum + OM | 3.35                  | 3.6                          | 6.4                              | 4.9              | 1.16              |
| T - 10: Azospirillum + AMF | 3.59                  | 3.7                          | 6.9                              | 5.6              | 1.29              |
| T - 11: Azospirillum + NPK 50% | 3.55             | 4.3                          | 7.0                              | 5.4              | 1.27              |
| T - 12: Azospirillum + OM + NPK 50% | 4.69          | 4.5                          | 7.7                              | 6.2              | 1.36              |
| T - 13: AMF         | 3.56                      | 3.0                          | 5.1                              | 3.8              | 1.15              |
| T - 14: AMF + OM    | 3.87                      | 4.0                          | 6.6                              | 4.2              | 1.27              |
| T - 15: AMF + NPK 50% | 3.77                 | 4.1                          | 7.0                              | 4.9              | 1.37              |
| T - 16: AMF + OM + NPK 50% | 4.61          | 4.9                          | 7.9                              | 6.4              | 1.5               |
| LSD (0.05)          | 0.03                      | 0.03                         | 0.04                             | 0.02             | 0.01              |
content after the introduction of *Azotobacter chroococcum* and organic manure in mine spoil. Guar has shown increased chlorophyll content and this is directly responsible for the production of various metabolites including reducing sugar. Jin *et al.* (2015) reported that the level of sugar content increased in the leaves of maize plant with increased level of nitrogen. Similarly, in our studies the percentage of reducing sugar enhanced significantly with the increase of nitrogen, which may be due to the nitrogen fixation by the microbial inoculants and by guar itself.

**Macro & Micro nutrients**

The mineral uptake in guar upon introduction of bio inoculants in mine spoil has shown significant increase over the uninoculated control (Table 4), the percentage increase in N was found to be 7 to 29%, in P it was 11 to 86%, N 5 to 50%, in Ca to 3 to 16% and in Mg it was 16 to 71%. The present study demonstrated the highest N content in a treatment of *Azospirillum*+ OM and NPK 50%, highest P content was in AMF + OM + NPK 50% treatment and K, Ca, Mg content was highest in *Azotobacter*+ OM and NPK 50%. This result is in the line with Yang *et al.* (2016), who observed that legume- rhizobia have always provided a synergistic approach on nitrogen management and was enhanced by introducing compatible soil organisms including mycorrhizal hyphae which is known for mineral solubilisation and mobilization (Temperton *et al.*, 2007). We have observed highest N uptake with *Azospirillum* and significant intake.

![Fig 1: Influence of bio-inoculants on plant metabolites in feldspar mine spoil.](image)

**Note:** The figure describes the variations in the chlorophyll and reducing sugars accumulation in guar with different treatments at the significance level (P<0.05).

**Treatments:** T1 = control, T2 = NPK 100%, T3 = *Azotobacter*, T4 = *Azotobacter* + OM, T5 = *Azotobacter* + GM, T6 = *Azotobacter* + NPK 50%, T7 = *Azotobacter* + OM + NPK 50%, T8 = *Azospirillum*, T9 = *Azospirillum* + OM, T10 = *Azospirillum* + OM, T11 = *Azospirillum* + NPK 50%, T12 = *Azospirillum* + OM + NPK 50%, T13 = AMF, T14 = AMF + OM, T15 = AMF + NPK 50%, T16 = AMF + OM + NPK 50%.

**Table 4:** Effect of bioinoculants on nutrient influx of guar in feldspar spoil.

| Treatments               | N  | P  | K  | Ca | Mg | Fe | Cu | Mn | Zn |
|--------------------------|----|----|----|----|----|----|----|----|----|
| T - 1: Control           | 6.1| 1.7| 3.8| 27.0| 3.3| 119| 8.6| 13.0| 18.4|
| T - 2: NPK 100%          | 8.6| 2.3| 5.1| 29.6| 4.9| 137| 10.3| 14.9| 20.2|
| T - 3: *Azotobacter*     | 6.6| 1.9| 4.0| 28.0| 3.9| 132| 9.9 | 14.7| 19.4|
| T - 4: *Azotobacter* + OM| 6.9| 3.4| 4.2| 28.5| 4.6| 141| 10.4| 15.4| 20.4|
| T - 5: *Azotobacter* + AMF| 7.2| 3.6| 4.2| 29.2| 5.2| 155| 11.9| 16.3| 21.8|
| T - 6: *Azotobacter* + NPK 50%| 7.6| 3.8| 5.3| 30.8| 6.3| 187| 12.8| 17.4| 22.6|
| T - 7: *Azotobacter* + OM + NPK 50%| 8.2| 4.0| 6.4| 32.0| 7.0| 237| 13.9| 18.8| 23.3|
| T - 8: *Azospirillum*    | 6.5| 1.8| 4.1| 27.9| 3.8| 129| 9.5 | 14.5| 19.3|
| T - 9: *Azospirillum* + OM| 6.7| 3.1| 4.3| 29.3| 4.9| 163| 11.0| 15.6| 20.8|
| T - 10: *Azospirillum* + AMF| 7.3| 2.6| 4.2| 30.7| 5.6| 178| 11.7| 16.4| 21.3|
| T - 11: *Azospirillum* + NPK 50%| 7.5| 3.6| 5.2| 31.2| 6.1| 194| 12.6| 17.5| 22.7|
| T - 12: *Azospirillum* + OM + NPK 50%| 8.0| 3.9| 5.9| 31.9| 6.8| 223| 13.8| 18.7| 23.4|
| T - 13: AMF              | 6.5| 1.9| 3.9| 27.5| 4.0| 119| 9.1 | 14.6| 19.6|
| T - 14: AMF + OM         | 6.9| 3.1| 4.1| 28.8| 3.8| 164| 10.7| 16.3| 20.2|
| T - 15: AMF + NPK 50%    | 7.6| 3.4| 5.0| 29.6| 5.6| 177| 12.1| 17.4| 21.9|
| T - 16: AMF + OM + NPK 50%| 8.0| 4.3| 5.5| 31.0| 6.6| 232| 13.9| 18.8| 23.5|

**LSD (0.05)**

0.12 0.02 0.03 1.13 0.09 8.0 0.14 0.16 0.06
with AMF. Similarly, Nayak et al. (2015) indicated that organic amendments significantly enhanced the nutrient status of iron mine spoil. Nyokki and Ndakidemi (2014) reported that rhizobia inoculation of leguminous crops supplied with P fertilizer improves the uptake of N, P, K, Ca and Mg. Whereas, Haferburg and Kothe (2010) reported the use of bacteria and AMF as natural biofertilizers for the delivery of metals and nutrients to the plants in metal spoils.

Phosphorous content is low in mine spoil, but the greater P concentration in feldspar mine spoil, may be due to mobilization of P by AMF (Taratdar and Marschner, 1994). Phosphate solubilization by rhizobacterial isolates may be influenced by the production of organic acids such as formic, acetic, propionic, lactic, glycolic, fumaric and succinic acids (Yasmin et al., 2009), resulting in mineralization and mobilization of unavailable soil P, thus helping in increased uptake of P by the plants (Dotaniya et al., 2014). Feldspar has insoluble form of potassium (8-10%) and therefore, this K could be effectively utilized by native potassium solubilizing microorganisms (Kasana et al., 2017). Similarly, Ullaman et al. (1996), has seen absorption of K enhanced rapidly upon introduction of Bacillus mucilaginosus that can solubilize rock K mineral such as potash feldspar by production and excretion of organic acids. In our study, along with guar bioinoculants also have nitrogen fixing properties which have shown positive impact in the mineral solubilisation that supports the uptake of essential macro nutrients by the plant.

Cu, Mg and Zn resulted in significant increase but, Fe content (237 mg g⁻¹) was observed much higher over the control and almost three folds in case of feldspar mine spoil, since feldspar, mica and quartz are most likely responsible for the release of these metal elements (Nagaraju et al., 2013). There has been no fixed trend observed in the absorption of Cu, Zn, and Mn, these micronutrients have been found with almost similar enhancement in all the treatments.

**CONCLUSION**

Hence, successful rehabilitation must involve the development of microbially driven nutrient cycling for the long-term provision of nutrients to the plant. Besides this, the use of legume also supported the rehabilitation of the spoil due to its exclusive properties of with standing stress conditions. In this study, Azotobacter, Azospirillum and AMF played a key role in supporting guar to establish its rhizosphere fertility in feldspar mine spoil. The study clearly stated that the feldspar mine spoil showed the sign of restoration due to the gradual accumulation of OC, N and available P with the applied treatments and due to guar itself. Hence, it is concluded that guar can be a potential crop to restore soil health of feldspar mined land for sustainable development in combination with various bioinoculants.

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