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Evaluating soil quality and bioefficacy study of *Cajanus cajan* L. in coal mine-degraded land

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Abstract: Surface mining activities in past and recent times have resulted in the existence of a number of overburden dumps (mine spoils) through excavation and deposition of removed soil and rock debris. These spoils require environmental stabilization/restoration through proper revegetation. The present study was undertaken to examine the influence of various amendments to soil properties and the growth and yield of *Cajanus cajan* L. cultivation in mine-degraded soils. An experiment was conducted with nine combinations of various amendments to *C. cajan* L., a widely cultivating legume in India for its highly nutritious seeds. The physicochemical and biological properties of mine spoil before and after treatment were analyzed. Plant growth in terms of seed germination, shoot length, root length, total dry weight, number of leaves, root nodules, and yield components were measured. The experimental results revealed that combination of C_3 (mine spoil amended with biofertilizers, farmyard manure, and fly-ash) and C_8 (mine spoil amended with biofertilizers, vermicompost, and fly-ash) showed the best results to support vegetation. Percentage increases in crop growth, grain yield, and soil nutrients compared to the control were also observed. With C_3, grain yield was found to be maximum (79.66 g/pot), with an increase of 215.95%. Number of pods per plant was found to be 27.50 and 27.75 in C_3 and C_8 treatments, respectively. All the physicochemical and biological properties were enhanced significantly ($P \leq 0.05$) in all the combinations compared to the untreated control. C_8 exhibited significantly higher concentrations of nitrogen, phosphorous, and potassium of about 67.55, 5.16, and 58.33 mg kg^{-1}, proving it to be good at improving soil quality.

Key words: Bioefficacy, *Cajanus cajan*, coal mine, degraded land, soil amendments

Introduction

The mining industry uses about 0.25% of the total land as compared to other industries. As per the Vision Coal - 2025 (Ministry of Coal, 2005) document, the total land requirement for overburden and other waste dumps, mine operation, and mine infrastructure is projected to increase from an area of 1470 km^2 in 2006–2007 to 2925 km^2. An older report presented by Business Line (2000) stated that about 140,771 ha of land was covered by surface mining and in addition 57,000 ha of land was required, among which 13,000 ha was under forest cover. The overburden removal of coal in India alone increased from 500 million cubic meters (Mm^3) in 2003–2004 to 682 Mm^3 in 2009–2010 (CIL, 2011). The dumping of overburden/mine wastes/spoil materials generated from opencast coal mines is considered as a major contributor to ecological and environmental degradation (Cherfas, 1992; Chaoji, 2002; Ghose, 2004). Overburden materials are nutrient-poor, loosely adhered particles of shale, stones, boulders, cobbles, and so forth and are devoid of true soil character (Raju and Hassan, 2003; Deka Boruah, 2006; Gogoi et al., 2007).

Measures such as reclamation, restoration, and replacement are being carried out in order to prevent degradation of coal mine-degraded land. Restoration is necessary not only to control soil erosion but also to improve air quality and visual impact (landscape) apart from dump stabilization (Singh et al., 1996; Dobson et al., 1997) and removal of threats to the surrounding population (Wong, 2003). Restoration constitutes the most widely accepted and useful way to reduce erosion and protect soils against degradation during reclamation. Productivity of soil can be increased by adding various natural amendments, as these amendments stimulate the microbial activity that provides the nutrients and organic carbon to the soil (Sheoran et al., 2010). Long-term mine spoil reclamation requires the establishment of stable nutrient cycles from plant growth and microbial processes (Lone et al., 2008; Kavamura and Esposito, 2010).

A number of restoration methods, such as topsoil removal, sod cutting, and soil inversion, have been implemented to restore abiotic conditions suitable for high diversity and threatened species in seminatural calcareous grasslands (Dolman and Sutherland, 1994; Kiehl and

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Pfadenhauer, 2007; Schnoor and Olsson, 2010; Odman et al., 2011). Topsoil removal and soil disturbances may also reach deeper soil layers with a high pH and limestone content (Dolman and Sutherland, 1994; Jones et al., 2010). Successful consistent revegetation of drastically disturbed mine land throughout the United States and several other countries has been achieved by using biological tools: tree seedlings, native shrubs, and grass species (Cordell et al., 2002).

Currently revegetation of overburden dumps is done by the mine authority with the required help from the forest authority. Generally the native varieties of plant species (mostly trees and shrubs) that can grow reasonably on the dump cover material are planted and nurtured to establish the vegetative cover. This practice, while fulfilling the requirements of environmental stabilization of overburden dumps, lacks in one aspect: there is no possibility of annual harvesting of economic crops, which is very important from a socioeconomic point of view.

The aim of the present study was to evaluate the effect of different soil amendments such as chemical fertilizers, organic fertilizers, vermicompost, biofertilizers, and fly-ash in appropriate combinations to support vegetation in mine-degraded land.

2. Materials and methods

2.1. Study area

The study area was chosen at the Muraidih opencast coal mine of the Jharia coal field (JCF) area in Dhanbad, India (Figure 1). Mining is done by shovel dumper method and all the waste materials of the mine are disposed of in the form of overburden dumps. The JCF is spread over the Dhanbad and Bokaro districts of Jharkhand, considered as the coal capital of India, and is one of the most important coal fields of India containing the only remaining reserve of prime coking coal of the country.

2.2. Sample collection and analyses

Coal mine-degraded soil (mine spoil) samples were collected from ten different locations of the study area. From each location, five samples were collected by using split tube coring tools manually. The collected samples were taken to the laboratory into two parts for pot experiments and laboratory studies.

The physical properties of mine spoil and amended combinations, such as moisture content and water-holding capacity, were determined by gravimetric method. Bulk density was determined by soil core method, and porosity was calculated from the bulk density. Chemical parameters

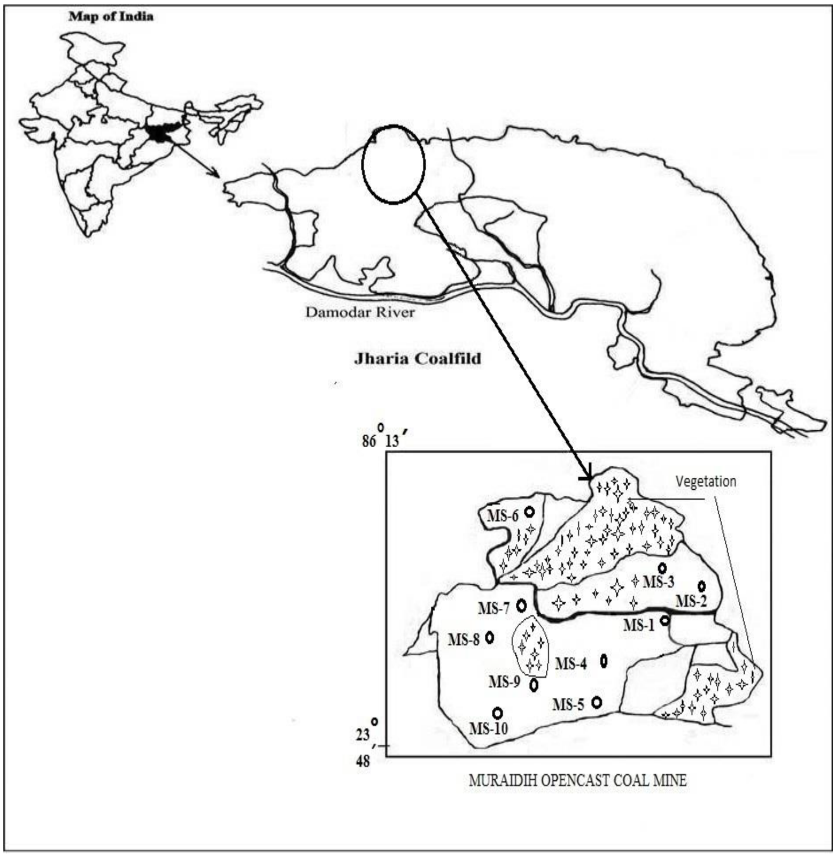

Figure 1. Location of the study sites.

such as pH and EC were determined by using a pH meter and EC meter respectively in a suspension of spoil sample in water in the ratio of spoil:water = 1:2.5. Organic carbon was determined by oxidation with potassium dichromate in an acid medium (Walkey and Black, 1934). Available N was determined by alkaline permanganate method (Subbaiah and Asija, 1996). Available P was determined by the Olsen method (Sparling et al., 1985). Available K was extracted by neutral 1(N) ammonium acetate solution (soil to extractant ratio of 1:10) and determined by flame photometer (Jackson, 1973). Available heavy metal content was determined by the DTPA (diethylene triamine penta acetic acid) extraction method, whereas total heavy metal content was analyzed using an atomic absorption spectrophotometer (GBC, Avanta, Australia). Dehydrogenase activity was assayed using 2,3,5-triphenyltetrazolium chloride as the substrate (Casida, 1977).

2.3. Experimental design

The pot experiment was carried out in greenhouse conditions with four replicates in a randomized block design with nine treatments consisting of five different amendments: chemical fertilizers (CFs; urea, diammonium phosphate (DAP), and muriate of potash), farmyard manures (FYMs), vermicompost (VC), biofertilizers (BFs; *Rhizobium*, phosphate-solubilizing bacteria, and potash-mobilizing bacteria), and fly-ash (FA) in appropriate combinations. CFs and BFs were procured from a local market, FYM and VC were prepared in-house in the departmental research field, and FA was collected from the Chandrapura thermal power plant, Jharkhand, India. Seeds were treated using BFs, whereas soil treatment was done by mixing of amendment combinations at recommended rates before sowing. The physicochemical properties of amendments (FA, VC, and FYM) were analyzed following the standard methods used in mine spoil analysis. The combinations used were as follows:

C_0 = mine spoil (100%)

C_1= mine spoil (93.5%) + FYM (2%) + BF (10 g/kg seed) + VC (2.5%) + FA (2%)

C_2 = mine spoil (93.5%) + FYM (2%) + BF (10 g/kg seed) + VC (2.5%) + FA (2%)

C_3 = mine spoil (96%) + FYM (2%) + BF (10 g/kg seed) + FA (2%)

C_4 = mine spoil (93.5%) + FYM (2%) + VC (2.5%) + FA (2%)

C_5 = mine spoil (95.5%) + FYM (2%) + BF (10 g/kg seed) + VC (2.5%)

C_6 = mine spoil (94.84%) + FYM (2%) + VC (2.5%) + CF (urea - 0.03%, DAP - 0.03%, potash - 0.06%)

C_7 = mine spoil (94.84%) + FYM (2%) + CF (urea - 0.3%, DAP - 0.3%, potash - 0.06%) + FA (2%)

C_8 = mine spoil (95.5%) + BF (10 g/kg seed) + VC (2.5%) + FA (2%)

C_9 = mine spoil (94.84%) + VC (2.5%) + CF (urea - 0.3%, DAP - 0.3%, potash - 0.06%) + FA (2%)

2.4. Plant growth experiment

Healthy seeds of *Cajanus cajan* L. were seeded into the clay pots. For inoculation, the seeds were soaked in actively growing bacterial isolates. Initially the pots were placed in the greenhouse for 7 days and later kept under direct sunlight. The positions of pots were changed every week to nullify environmental effects due to positioning. The bioefficacy study was based on seed germination, plant height (shoot and root length), dry weight, number of root nodules, and number of leaves at 30, 60, 90, and 120 days after sowing (DAS). Yield components such as number of seeds per pod, number of pods per plant, weight of 100 seeds, and grain yield per pot were estimated at the maturity of plants using standard methods at the time of harvesting (120 DAS).

2.5. Statistical analysis

The statistical analyses were conducted to determine mean, standard deviation, and correlation by using data analysis of MS Excel 2007 (Microsoft Inc.). Analysis of variance (ANOVA) was used to compare the means of different combinations. Where significant F-values were observed, differences between individual means were tested using Duncan's multiple range test at the 5% level of significance. The data were analyzed using SPSS 16.0 (SPSS Inc., Chicago, IL, USA) and the XLSTAT 2013 package.

3. Results

3.1. Characterization of the amendments used

Biofertilizers, being living organisms, were not analyzed for their physicochemical parameters. Chemical fertilizers were also not analyzed as the important chemical component contents were known. Farmyard manure and vermicompost prepared in-house and collected fly-ash used in the experiment were analyzed in the laboratory for their physicochemical parameters and the results are summarized in Table 1.

3.1.1. Farmyard manure

Farmyard manure was basic in nature with a pH of about 7.42 (Table 1). The manure has an optimum water-holding capacity of about 65.75, indicating its appropriateness for plant growth. High levels of nitrogen (N), phosphorous (P), and potassium (K) content were found in farmyard manure with available N ranging between 3115.3 and 3220.3 mg kg^{-1}, available phosphorous between 2038.03 and 2150.01 mg kg^{-1}, and available potassium between 5180.71 and 5444.31 mg kg^{-1}. Trace metal concentration (total) in farmyard manure showed the following trend: Fe > Mn > Zn > Cu > Cr > Ni > Co > Pb > Cd.

Table 1. Physicochemical properties of the amendments used.

Parameters	Units	Values (mean ± SD)		
		Farmyard manure	Vermicompost	Fly-ash
Moisture content (MC)	%	15.43 ± 0.51	16.30 ± 0.12	4.31 ± 0.02
Water holding capacity (WHC)	%	65.75 ± 0.5	66.75 ± 1.0	59.25 ± 0.5
Bulk density (BD)	g cm^{-3}	0.94 ± 0.02	0.84 ± 0	1.12 ± 0.04
Porosity	%	64.42 ± 0.18	68.19 ± 0.18	62.07 ± 1.45
pH	—	7.42 ± 0	7.75 ± 0.04	6.82 ± 0
Electrical conductivity (EC)	dS m^{-1}	2.63 ± 0.01	2.23 ± 0	0.25 ± 0
Organic carbon (OC)	%	21.96 ± 0.09	24.45 ± 0.38	1.67 ± 0.04
Organic matter (OM)	%	37.86 ± 0.16	42.15 ± 1.3	2.87 ± 0.06
Available N	mg kg^{-1}	3167.80 ± 52.50	4380.50 ± 60.86	0.00
Available P	mg kg^{-1}	2094.02 ± 55.99	3084 ± 82.99	60.52 ± 0.54
Available K	mg kg^{-1}	5312.51 ± 131.80	6599.77 ± 3.55	32.57 ± 2.68
Cation exchange capacity (CEC)	cmol(+) kg^{-1}	56.2 ± 0.11	75.38 ± 0.36	6.6 ± 0.02
Total trace elements				
Pb	mg kg^{-1}	9.43 ± 0.14	7.45 ± 0.23	23.5 ± 0.22
Zn		382.13 ± 088.66	431.61 ± 2.25	32.3 ± 9.85
Cu		136.13 ± 0.41	145.69 ± 15.09	42.85 ± 2.84
Fe		11,688.63 ± 215.24	11,135.88 ± 93.15	17,957.63 ± 26.03
Mn		239.05 ± 16.53	353.68 ± 10.97	217.26 ± 4.29
Ni		14.31 ± 0.48	14.74 ± 1.44	18.61 ± 0.51
Cd		1.48 ± 0.33	1.21 ± 0.01	0.95 ± 0.64
Co		12.09 ± 0.51	7.25 ± 1.71	11.13 ± 1.08
Cr		35.05 ± 1.88	42.61 ± 0.32	11.79 ± 1.73
DTPA available trace elements				
Pb	mg kg^{-1}	0. 90 ± 0.01	0.56 ± 0.01	0.40 ± 0.02
Zn		17.08 ± 0.01	29.12 ± 0.01	0.62 ± 0.01
Cu		2.34 ± 0.0	5.74 ± 00	0.85 ± 0.01
Fe		9.23 ± 0.01	9.34 ± 0.01	8.41 ± 0.85
Mn		6.92 ± 0.03	10.24 ± 0.03	1.22 ± 0-.64
Ni		0.22 ± 0.02	0.82 ± 0.08	0.21 ± 0.02
Cd		< 0.0004	< 0.0004	< 0.0004
Co		0.197 ± 0.04	0.24 ± 00	0.15 ± 0.04
Cr		< 0.003	< 0.003	< 0.003

3.1.2. Vermicompost

Vermicompost was found to have higher concentrations of N, P, and K of about 4380.50 mg kg^{-1} N, 3084 mg kg^{-1} P, and 6599.77 mg kg^{-1} K, respectively, thus proving it as a good fertilizer. Porosity of vermicompost was about 68.19%, thus leading to a lower bulk density of about 0.84 g cm^{-3}. Organic carbon ranged between 24.07% and 24.53%. Cation exchange capacity was found to be about 75.38 cmol kg^{-1}. In vermicompost, Fe concentration (total) was found to be highest, ranging between 11042.73 and 11229.03 mg kg^{-1}, followed by Zn and Cu having concentrations of about 431.61 and 145.69 mg kg^{-1}, respectively. Among DTPA available trace elements, Mn concentration was found to be highest at about 10.24 mg kg^{-1}, followed by Zn ranging between 9.33 and 9.35 mg kg^{-1} and Fe ranging between 29.11 and 29.13 mg kg^{-1}.

3.1.3. Fly-ash

Fly-ash has a very low moisture content of about 4.31 and low P and K contents of about 60.52 and 32.57 mg kg^{-1}, respectively. Nitrogen content was found to be negligible. Lower NPK content is generally unfavorable for plant growth. However, fly-ash is enriched in trace elements, with Fe (total) having a highest concentration of about 17957.63 mg kg^{-1}, followed by Mn > Cu > Zn > Pb > Ni > Cr> Cd. Among DTPA available trace elements, Fe had the highest concentration of about 8.41 mg kg^{-1}, followed by Mn, Cu, and other metals.

3.2. Physicochemical properties of mine spoil

Mine spoil was devoid of nutrients. It was of high bulk density, low moisture content, and low water-holding capacity and was deficient in nitrogen, phosphorus, and potassium (Table 2). The mean value of pH of the studied

Table 2. Physicochemical and biological properties of mine spoil samples.

Parameters	Unit	Mean value ± SD
Moisture content (MC)	%	4.14 ± 0.18
Water holding capacity (WHC)	%	29.03 ± 0.62
Bulk density (BD)	g cm^{-3}	1.45 ± 0.07
Porosity	%	45.46 ± 2.56
Sand	%	76.79 ± 1.70
Silt	%	14.47 ± 0.88
Clay	%	8.45 ± 0.93
pH	–	7.71 ± 0.13
Electrical Conductivity (EC)	dS m^{-1}	0.22 ± 0.05
Organic carbon (OC)	%	0.88 ± 0.07
Organic matter (OM)	%	1.52 ± 0.13
Available N	mg kg^{-1}	30.57 ± 2.20
Available P	mg kg^{-1}	1.95 ± 0.08
Available K	mg kg^{-1}	42.28 ± 1.88
Cation exchange capacity (CEC)	cmol (+) kg^{-1}	8.11 ± 0.78
Dehydrogenase activity	µg g^{-1} dry soil h^{-1}	3.99 ± 0.11
Total trace elements		
Pb		18.20 ± 0.72
Zn		128.25 ± 11.11
Cu		17.65 ± 0.81
Fe		12,779.50 ± 320.40
Mn	mg kg^{-1}	251.80 ± 8.75
Ni		23.34 ± 0.94
Cd		1.43 ± 0.34
Co		9.28 ± 0.71
Cr		28.61 ± 0.81
DTPA available trace elements		
Pb		2.82 ± 0.03
Zn		15.78 ± 0.05
Cu		2.98 ± 0.04
Fe		8.86 ± 0.06
Mn	mg kg^{-1}	10.28 ± 0.05
Ni		0.91 ± 0.10
Cd		0.06 ± 0.01
Co		0.60 ± 0.03
Cr		0.23 ± 0.00

overburden material was found to be slightly alkaline with a value of 7.71 ± 0.13. The mean value of electrical conductivity of the spoil sample was 0.22 ± 0.05 dS m^{-1}. The result of the spoil sample analysis for organic carbon was 0.88 ± 0.07%.

3.3. Effects of amendments on physicochemical properties of mine spoil

At the time of harvesting, the improvements in physicochemical and nutrient status of the mine spoil were analyzed and the results are given in Table 3. The bulk density of the mine spoil decreased from 1.41 ± 0.02 g cm^{-3} to 1.24 ± 0.00 g cm^{-3}. The decrease in bulk density will reduce the compaction, which facilitates the aeration and better penetration and spreading of plant roots, thereby making the rhizosphere favorable for massive root development. The addition of amendments also increases the porosity, water-holding capacity, moisture contents, and electrical conductivity. The organic carbon content also increased from 0.88 ± 0.06% to 1.27 ± 0.02 %, which might be due to high organic carbon content in the amendments.

Similarly, available nitrogen, phosphorous, and potassium also improved; biofertilizers might have improved the spoil material by fixing atmospheric nitrogen, solubilizing inorganic phosphorus, and mobilizing potassium.

3.4. Effects of amendments on trace metals of mine spoil

The total and DTPA available trace element concentrations in the spoil at harvest of *Cajanus cajan* in all treatments were found to be below their respective toxic levels (Table 4). It was observed that there were no significance differences between trace metals in the studied combinations of soil amendments. The concentrations of trace elements in seeds of *Cajanus cajan* were well within critical limits as per as per World Health Organization guidelines.

3.5. Effects of amendments on dehydrogenase activity of mine spoil

The dehydrogenase activity (DHA) of spoil in all treatments and in the control was observed at harvesting. The statistical analysis of DHA data showed that the DHA of spoil samples in all the treatments was significantly increased compared to the control after plantation of *Cajanus cajan*. The maximum value (10.15 ± 0.59 µg g^{-1} dry soil h^{-1}) of dehydrogenase activity in spoil sample was recorded in treatment C_1 with an increase of 147.97% over the control (Table 5).

3.6. Effect of different soil amendment on growth of *Cajanus cajan*

The statistical analysis suggested that the mine spoil being treated with different amendments enhanced the seed germination, plant height, total dry weight, number of leaves, root nodulation, and yield components significantly ($P \leq 0.05$) compared to the nonamended control (Figures 2 and 3). The combinations amended with biofertilizers were effectively improved in growth in comparison to other amendments. All the combinations of amendments used increased the percent of seed germination compared to the control, C_0 (mine spoil). Highest seed germination percentage was observed in C_5 and C_3, followed by C_8 and $C_{1.}$

3.7. Effect on yield components of *Cajanus cajan*

The yield components in terms of number of pods per plant, number of seeds per pod, weight per 100 seeds (grains), and weight of grains per pot were measured at harvest for all nine treatments and for the control to find out the effects of different amendments for *Cajanus cajan*. All the yield components were found to have higher values in all the treatments compared to those of the control (Table 6).

3.7.1. Comparison of yield components of the amendments

The statistical analysis of the data showed that the yield components of *Cajanus cajan* measured at harvest, except number of seeds per pod, were significantly ($P \leq 0.05$) increased in all the treatments compared to control. The combinations of biofertilizer, farmyard manure, vermicompost, and fly-ash were found to be better amendment combinations in terms of plant growth as well as grain yield. Combinations C_3 and C_8 showed the best results with respect to grain yield per pot of about 79.66 g in C_3 followed by combination C_8 with grain yield of about 79.09 g (Table 6). Combinations C_0 and C_4 showed poor grain yield of about 20.76–29.66 g in C_0 and 33.55–36.95 g in C_4. Number of pods per plant was highest with C_8 followed by C_3, i.e. 27.75 and 27.50, respectively, as compared to other combinations. The percentage increase in weight per 100 seeds was maximum with combination C_3 at about 15.45 g and minimum with combination C_0 at 9.53 g. All the yield components were found to have higher values in all the treatments compared to those of the control. The statistical analysis of the data showed that the yield components of *Cajanus cajan* measured at harvest, except number of seeds per pod, were significantly ($P \leq 0.05$) increased in all the treatments compared to control.

4. Discussion

For successful revegetation of the spoil material, addition of a suitable type and amount of fertilizers and amendments is required. Different types of amendment may be used to improve the fertility of mine spoil, bringing immediate

Table 3. Physicochemical properties of spoil samples at harvest of *Cajanus cajan*.

Properties	Moisture content	Water holding capacity	Bulk density	Porosity	pH	EC	OC	OM	Available N	Available P	Available K
Unit	%	%	g cm^{-3}	%	%	dS m^{-1}	%	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Combination	Values (mean ± SD)										
C_0	4.33 ± 0.05d	30.38 ± 0.15e	1.41 ± 0.02a	46.74 ± 0.80e	7.66 ± 0.04a	0.30 ± 0.03g	0.88 ± 0.06d	1.52 ± 0.06d	28.35 ± 2.39d	1.75 ± 0.04h	41.24 ± 0.11h
C_1	5.13 ± 0.13abc	34.58 ± 0.72a	1.27 ± 0.00de	52.25 ± 0.16ab	6.92 ± 0.18c	0.65 ± 0.01d	1.24 ± 0.01ab	2.13 ± 0.02ab	66.25 ± 1.75abc	5.56 ± 0.01a	54.38 ± 0.15c
C_2	4.84 ± 0.07c	33.74 ± 0.55b	1.28 ± 0.02d	51.77 ± 0.58b	7.13 ± 0.02b	0.92 ± 0.01b	1.24 ± 0.03ab	2.14 ± 0.05ab	64.75 ± 2.10bc	3.94 ± 0.06g	49.98 ± 0.66e
C_3	5.05 ± 0.10bc	34.95 ± 0.42a	1.28 ± 0.01d	51.86 ± 0.25b	7.18 ± 0.02b	0.53 ± 0.04e	1.22 ± 0.03abc	2.10 ± 0.05abc	66.85 ± 1.76ab	5.30 ± 0.06bc	56.48 ± 0.46b
C_4	5.08 ± 0.15bc	34.93 ± 0.29a	1.24 ± 0.00e	53.03 ± 0.14a	6.83 ± 0.11c	0.46 ± 0.01f	1.27 ± 0.02a	2.19 ± 0.04a	64.75 ± 0.70bc	4.61 ± 0.12e	48.15 ± 0.57f
C_5	5.38 ± 0.28a	34.56 ± 0.20a	1.24 ± 0.00e	53.08 ± 0.18a	6.78 ± 0.09c	0.52 ± 0.00e	1.23 ± 0.03ab	2.12 ± 0.05ab	67.20 ± 1.98ab	5.37 ± 0.05b	51.43 ± 1.03d
C_6	5.15 ± 0.37a	34.45 ± 0.17a	1.31 ± 0.01c	50.66 ± 0.36c	6.83 ± 0.11c	0.95 ± 0.01a	1.21 ± 0.02bc	2.09 ± 0.04bc	64.05 ± 1.34c	4.73 ± 0.19de	47.98 ± 0.33f
C_7	4.91 ± 0.12bc	32.89 ± 0.13c	1.35 ± 0.01b	48.96 ± 0.34d	7.11 ± 0.06b	0.89 ± 0.03c	1.17 ± 0.02c	2.02 ± 0.03c	64.70 ± 2.02bc	4.22 ± 0.04f	47.13 ± 0.48g
C_8	5.38 ± 0.15a	34.55 ± 0.33a	1.32 ± 0.05c	50.37 ± 1.89c	6.77 ± 0.12c	0.51 ± 0.04e	1.21 ± 0.02bc	2.09 ± 0.04bc	67.55 ± 1.34a	5.16 ± 0.13c	58.33 ± 0.13a
C_9	4.91 ± 0.11bc	32.28 ± 0.49d	1.35 ± 0.01b	49.08 ± 0.31d	7.09 ± 0.14b	0.66 ± 0.01d	1.18 ± 0.02c	2.03 ± 0.04c	64.75 ± 0.70bc	4.81 ± 0.14d	47.23 ± 0.26g

Means (±SD; n = 4) followed by different letters in the same column are statistically different according to Duncan's multiple range test at P ≤ 0.05.

Table 4. DTPA available trace elements in mine spoil samples at harvest of *Cajanus cajan*.

Trace elements	Pb	Zn	Cu	Fe	Mn	Ni	Cd	Co	Cr
Unit	mg kg^{-1}								
Combination	Values (mean ± SD)								
C_0	2.78 ± 0.05a	15.58 ± 0.53	2.93 ± 0.05*	8.76 ± 0.18a	10.28 ± 0.06a	0.85 ± 0.17a	0.06 ± 0.01a	0.59 ± 0.02a	0.23 ± 0a
C_1	2.21 ± 0.06c	17.13 ± 0.04a	2.53 ± 0.55*	8.8 ± 0.07a	9.79 ± 0.28c	0.69 ± 0.15b	0.05 ± 0.02abcd	0.14 ± 0.01e	0.24 ± 0.04e
C_2	2.77 ± 0.05a	15.24 ± 0.12bc	2.53 ± 0.31*	8.39 ± 0.23abc	9.78 ± 0.29c	0.64 ± 0.01bc	0.02 ± 0.00de	0.35 ± 0.01c	0.23 ± 0c
C_3	2.52 ± 0.34ab	14.79 ± 1.72bcd	2.55 ± 0.23*	7.86 ± 0.44cd	9.59 ± 0.36cd	0.63 ± 0.01bc	0.03 ± 0.01bcde	0.34 ± 0.02c	0.19 ± 0.05d
C_4	2.73 ± 0.19a	14.86 ± 0.16bcd	2.82 ± 0.06*	7.33 ± 1.15d	9.5 ± 0.06cd	0.44 ± 0.03d	0.03 ± 0.00bcde	0.15 ± 0.02e	0.41 ± 0.03e
C_5	2.75 ± 0.09a	13.99 ± 0.93de	2.41 ± 0.78*	7.62 ± 0.24cd	9.6 ± 0.15cd	0.54 ± 0.02cd	0.03 ± 0.01de	0.21 ± 0.05de	0.3 ± 0.13d
C_6	2.2 ± 0.04c	15.29 ± 0.71bc	2.59 ± 0.08*	8.44 ± 0.2a	9.31 ± 0.24d	0.51 ± 0.05cd	0.06 ± 0.00abc	0.28 ± 0.05cd	0.11 ± 0.01cd
C_7	2.34 ± 0.17bc	14.3 ± 5.53cd	2.75 ± 0.34*	7.83 ± 2.64cd	9.83 ± 3.5bc	0.55 ± 0.66cd	0.03 ± 0.88cde	0.29 ± 0.77cd	0.36 ± 0.73cd
C_8	2.4 ± 0.42bc	13.11 ± 0.43e	2.71 ± 0.08*	8.42 ± 0.07a	10.13 ± 0.2ab	0.45 ± 0.05d	0.06 ± 0.02ab	0.46 ± 0.16b	0.23 ± 0.01b
C_9	2.32 ± 0.07bc	12.86 ± 0.69e	2.66 ± 0.10*	9.04 ± 0.69a	9.53 ± 0.17cd	0.07 ± 0.01a	0.07 ± 0.06a	0.24 ± 0.02de	0.24 ± 0.02cd

Means (±SD; n = 4) followed by different letters in the same column are statistically different according to Duncan's multiple range test at $P \leq 0.05$.
*: Nonsignificant.

Table 5. Analysis of dehydrogenase activity (DHA) of soil at harvest and its % increase over control of *Cajanus cajan*.

Combination	Dehydrogenase activity ($\mu g\ g^{-1}$ dry soil h^{-1}) values (mean ± SD)	% increase of DHA over C_0
C_0	4.09 ± 0.20d	00.00
C_1	10.15 ± 0.59a	147.97
C_2	9.16 ± 0.29bc	123.74
C_3	9.51 ± 0.18ab	132.49
C_4	9.18 ± 0.52bc	124.26
C_5	9.69 ± 0.34ab	136.71
C_6	9.13 ± 0.49bc	123.09
C_7	9.06 ± 0.65bc	121.39
C_8	9.55 ± 0.17ab	133.27
C_9	8.54 ± 0.32c	108.64

Means (± SD; n = 4) followed by different letters in the same column are statistically different according to Duncan's multiple range test at $P \leq 0.05$.

change both in its physical and chemical characteristics. The amendment can alter the unfavorable physical characteristics of mine spoil to favorable ones in terms of its texture, moisture, bulk density, pore space, etc.

Statistical analyses suggested that the mine spoil significantly ($P \leq 0.05$) improved in terms of physicochemical/ biological properties in all the combinations compared to the control (Table 3). Biofertilizer-amended combinations were found to be more effective than other amendments in terms of nutrient status. This might be due to the incorporation of the amendments as they stimulate the microbial activity, which enhanced the nutrients (N, P, K) and organic matter in the spoil material and maintained a healthy positive nutrient balance since the mine spoil was deficit in macronutrients, i.e. nitrogen, phosphorous, and potassium. The poor availability of nitrogen in the mine spoil may be due to the lack of mineralizable organic nitrogen, lower mineralization rates, and the fact that mine spoils are mainly composed of sandstone, shale, clay, etc., which lack in microbial activity and accumulation of organic matter.

The higher values of pH in the overburden material may be due to the geological formation in the studied area and to leaching, leading to accumulation of basic cations such as carbonates (CO_3^{-2}) and bicarbonate (HCO_3^{-}). High values of organic carbon in the spoil samples may be due to the fact that the dump materials also contain disintegrated coaly shale and other coaly matters. In the present study, decrease in pH was found in the biofertilizer-treated mine spoil at harvest, and this may be due to secretion of organic acids by phosphate-solubilizing bacteria. Pore space was similar to the typical percentage of air and water space suitable for plant growth in well-formed soil (Brady and Weil, 2002). The high bulk density of mine spoil, which is due to massive compaction, might have been decreased due to application of farm yard manure and other organic amendments. Similar results were noticed by Juwarkar and Jambhulkar (2008).

The organic manures (farmyard manure and vermicompost), and especially vermicompost, slowly release their nutrients in higher quantities. Conjunctive use of *Rhizobium* and phosphate-solubilizing bacteria and potash-mobilizing bacteria with organic manures possibly increased the plant biomass and other parameters in comparison with the control (Davari et al., 2012). Application of farmyard manure might have improved the soil physical conditions and N, P, and K contents of the soil, thereby increasing the yield and yield attributes. Several researchers also reported favorable effects of farmyard manure on the seed yield of red gram. Seed inoculation with biofertilizer treatments might have also influenced the grain yield significantly. The DHA of the spoil at harvest in all the treatments was found to be more than in the control. This was possibly due to the presence

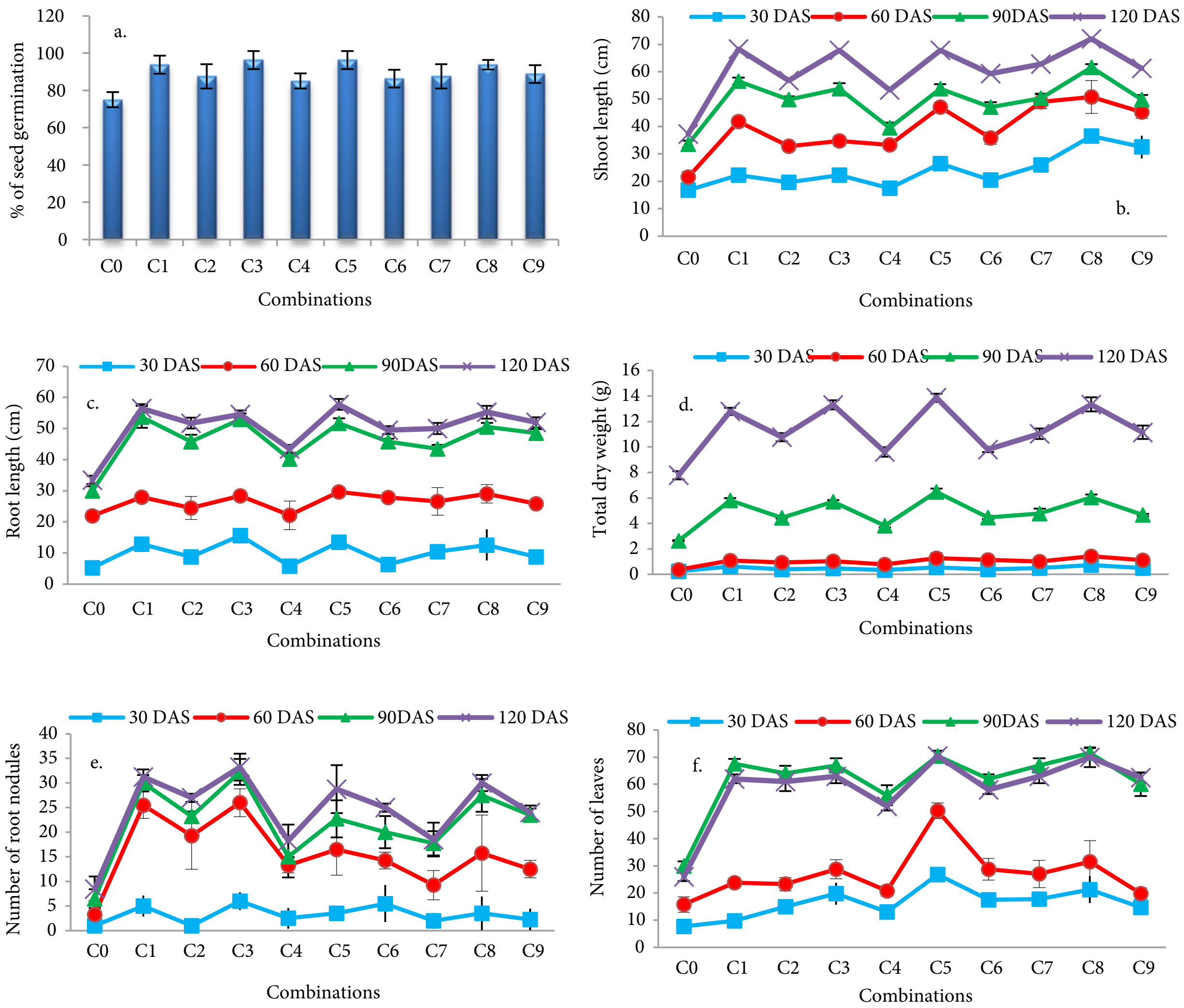

Figure 2. Effect of various soil amendments on growth parameters: a- percent seed germination, b- shoot length, c- root length, d- total dry weight, e- number of root nodules, f- number of leaves (DAS = days after sowing).

of one or more of farmyard manure, vermicompost, and biofertilizers in the treatments.

The improvement in growth parameters and yield components may not be solely due to the inoculation of seeds with biofertilizers but also because of several other factors such as release of growth-promoting substances, suppression of plant pathogens, and proliferation of beneficial microbes in the rhizosphere (Kundu and Guar, 1980; Goud and Kale, 2010). Number of root nodules and plant biomass were increased in the combinations made up of biofertilizers, vermicompost, and fly-ash and farmyard manures, possibly combining the effects of all amendments. Biofertilizers enhanced the growth parameters. Roots are the sites of microbial infection, so well-infected roots increase the number of nodules (Selvakumar et al., 2012).

The combinations prepared with biofertilizers along with farmyard manure and fly-ash induced the best growth. This is most likely because the microorganisms used as biofertilizers stimulated plant growth by providing necessary nutrients as a result of their colonization at their rhizosphere or by symbiotic association. Similar effects were reported in earlier studies (Varma and Shuepp, 1995; Juwarkar and Jambhulkar, 2008; Thenmozhi et al., 2010).

From the experimental results, it may be concluded that the successful growth of the studied pulse crop in these barren, recalcitrant overburden dump materials is possible with the application of suitable amendments.

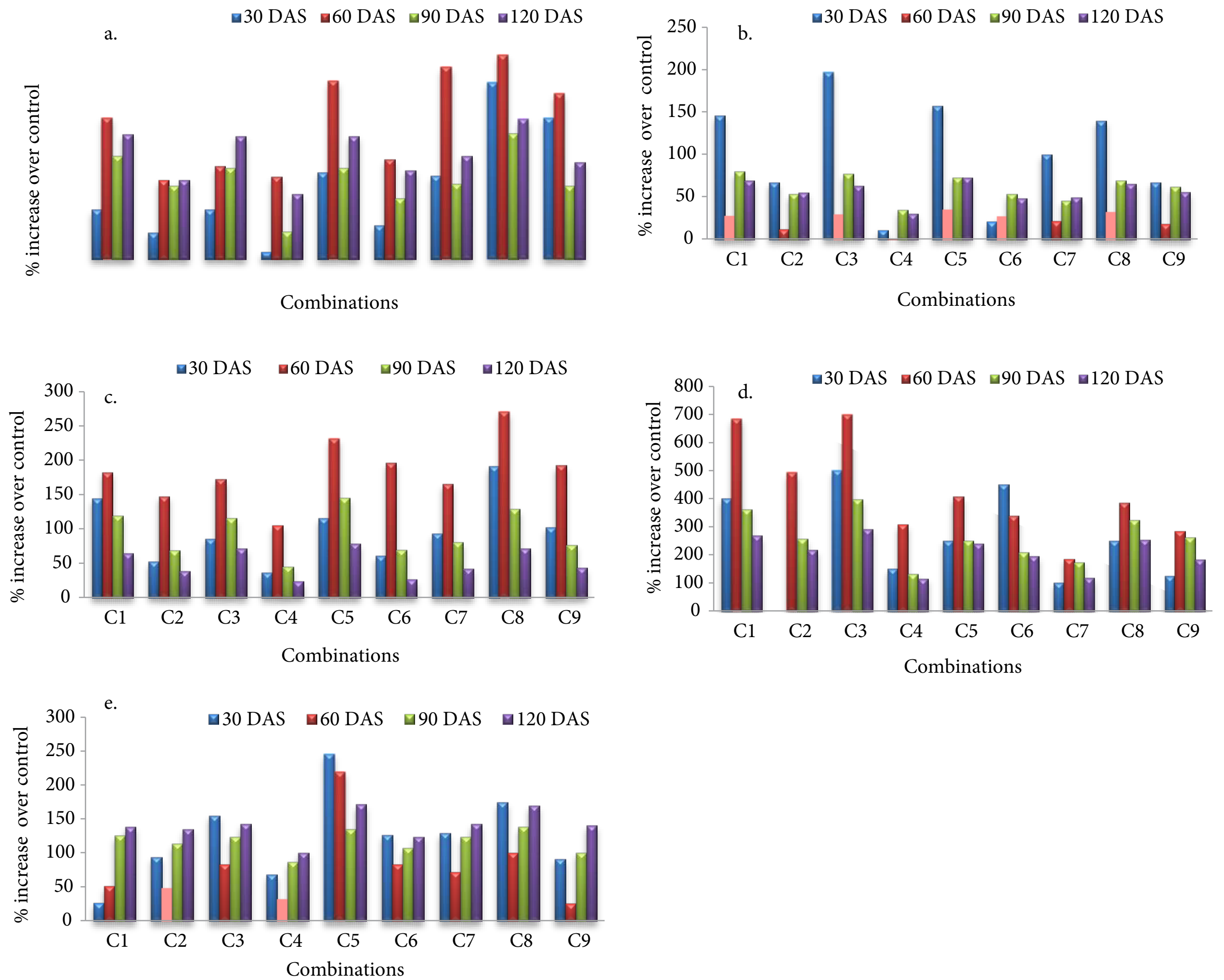

Figure 3. Percentage increase in different parameters over control: a- shoot length, b- root length, c- total dry weight, d- number of root nodules, e- number of leaves (DAS = days after sowing).

To enhance the fertility of spoil samples for revegetation, different amendments (farmyard manure, vermicompost, biofertilizers, and chemical fertilizers) may be used. For restoration, it is necessary to have a cover on the top and sides of the dump that is rich in nutrient and organic matter content and capable of retaining moisture. The appropriate proportions of chemical fertilizers, organic fertilizers, vermicompost, biofertilizers, and fly-ash can be used as soil amendments and *Cajanus cajan* L. can be used in restoration of coal mine dumps. The findings of this study can be utilized by mine management in the large-scale revegetation of several adjacent coal mining overburden dumps for ecofriendly mining. The study thus found that fly-ash along with soil amendment by farmyard manure and biofertilizers is the most potent combination to support vegetation of mine-degraded land.

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Table 6. Effect of amendments on yield components of *Cajanus cajan*.

Combination	No. of pods per plant	No. of pods per plant (%↑)	No. of seeds per pod	No. of seeds per plant (%↑)	Weight per 100 seeds (g)	Weight per 100 seeds (g) (%↑)	Grain yield per pot (g)	Grain yield per pot (%↑)
C_0	19.25 ± 1.50c	0.00	2.75 ± 0.50*	0.00	9.53 ± 0.13g	0.00	25.21 ± 4.45d	0.00
C_1	26.50 ± 1.29a	37.66	3.75 ± 0.50*	36.36	13.97 ± 0.54c	46.61	69.39 ± 6.96a	175.22
C_2	21.00 ± 0.82b	9.09	3.50 ± 0.58*	27.27	12.67 ± 0.05de	33.02	46.57 ± 6.36b	84.69
C_3	27.50 ± 1.29a	42.86	3.75 ± 0.50*	36.36	15.45 ± 0.13a	62.19	79.66 ± 10.05a	215.95
C_4	20.00 ± 0.82bc	3.90	3.00 ± 0.00*	9.09	11.75 ± 0.37f	23.35	35.25 ± 1.70c	39.80
C_5	27.75 ± 0.50a	44.16	3.75 ± 0.50*	36.36	14.60 ± 0.18b	53.26	75.97 ± 10.30a	201.28
C_6	20.25 ± 0.50bc	5.19	3.50 ± 0.58	27.27	13.15 ± 0.44d	38.04	46.60 ± 8.64b	84.82
C_7	20.75 ± 0.50b	7.79	3.75 ± 0.50*	36.36	12.10 ± 0.47f	27.02	47.08 ± 1.94b	86.71
C_8	27.75 ± 0.50a	44.16	4.00 ± 0.00*	45.45	14.25 ± 0.20bc	49.59	79.09 ± 0.00a	213.66
C_9	20.50 ± 0.58bc	6.49	3.50 ± 0.58*	27.27	12.63 ± 0.46e	32.53	45.29 ± 6.90bc	79.63

Means (±SD; n = 4) followed by different letters in the same column are statistically different according to Duncan's multiple range test at $P \leq 0.05$.
*: Nonsignificant; (%↑): percentage increase.

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