The DTPA extractable metals were analyzed to know whether plants are exposed to any metal toxicity in this particular overburden dump or not. Cu, Zn, and Mn were satisfactorily high when compared to Table 4.4. The overburden dump had inadequate iron. The soil was found to be unpolluted when soil pollution index was calculated (Table 4.5). Slight pollution was observed in the case of Zinc. Soil pollution index was very helpful to know the actual pollution status which would otherwise have been very difficult to actually evaluate the magnitude of the data generated.

Table 4.4 Determination of soil pollution index in the overburden dump of Bastacola (Alloway, 1990)

Heavy Metals (ppm)	Concentration at Study Area	Lower Critical Soil Concentration	Soil Pollution Index	Degree of Pollution
Cu	0.43	60	0.72	Unpolluted
Mn	3.24	1500	0.22	Unpolluted
Zn	11.44	70	16.34	Slightly polluted
Ni	0.13	100	0.13	Unpolluted
Cd	0.19	3	6.33	Unpolluted
Pb	0.82	100	0.82	Unpolluted

The soil was found to be slightly acidic, as shown in the Table.4.2, with high bulk density and low clay, showing that soil is in its developmental stage (Ramsey et al., 2001). The XRD peaks of palygorskite and kaolinite were also identified at 2θ~20.9 and 35.1º, respectively. Kaolin-based minerals do not expand, and they have a lower number of active surface charge sites (Markis, 2003). Furthermore, very small XRD peaks, related to hematite and mullite, were observed at 39.5 and 40.36º. It is worth to mention that high clay fraction can be characterized with the high illite, palygorskite and kaolinite contents.

Soil organic matter is a key for sorbing metals. Organic matter is important for the retention of metals by soil solids, thus decreasing mobility and bioavailability (Sherene, 2010). Since in the present study, the organic carbon and matter are low hence mobility and bioavailability will also be low. However, since pH is a very important factor as low pH may influence the availability of metals. The pH was found to be low hence some metals were present in sufficient amount. Lack of Fe was due to the scarcity of iron mineral as depicted in XRD study. The low quantity of heamatite is thus responsible. In an early study by Khan (1979), it was depicted that Iron extracted from clay fractions was significantly higher than that extracted from sand. Soil micro-aggregates (≥250 mm in diameter) consisting largely of clay and humified organic material contain higher amounts of DTPA-extractable Fe, Zn, and Cu. The higher amounts of DTPA-extractable Fe, Zn, and Cu in clay fractions of soil also imply that clay fractions have higher intensity and capacity factors for these metals, since DTPA micronutrient test measures both the intensity and capacity factors. Therefore, clay fraction in a given soil is the most important labile source of micronutrients in soils. Here the lack of clay fraction is an important reason for not having metals in huge quantities.

Smolders et al. (1998) found that Pb may also form complexes more readily with $NO^{-}{}_{3}$. As shown in the present findings, available nitrogen is quite low hence lead is not chelated. Khan et al. (1991) indicated the presence of NH_4^+, Na^+, K^+ and Ca^{++} as cations and NO_3^-, Cl^-, SO_4^{2-} and PO_4^{3-} as anions released from applied fertilizers could be regarded to play a dominant role in mobility of Pb and Ni in soil because of blocking of adsorptive site by the above said ions. Also, no fertilizer has been added to the overburden dump spoil in mining area as agriculture is usually never practiced in such disturbed sites, therefore, presence of Pb and Ni is rare. Also, Pb is poisonous, with no major metabolic function in plants or animals, but high persistence in soils, lead has a long-term tendency for accumulation in the food chain. Thus the lack of Pb in the current study is a boon. Moderately poisonous, Nickel is also an essential micronutrient of animals and plants but required in traces. Additionally, several metal contaminants have the capacity to inhibit or prevent plant growth. In many cases, the level for phytotoxicity is well below that which might harm humans. The main phytotoxic elements are zinc, nickel, copper and boron. Mn is an important plant nutrient. In regions of high background Mn, toxicity may develop at levels ranging from 80-5000 ppm (300-000 mg/kg in the plant tissue dry matter). Zinc is an essential micronutrient for animals and higher plants. In humans, it affects enzyme activity, growth, and appetite (Haigh, 1995). Plants become zinc deficient at levels of 10 - 20 mg/kg dry matter and Zn is toxic where greater than 400 mg/kg (Alloway, 1990; Brady, 1984). Cadmium is extremely poisonous. Cadmium has no essential biological function and is highly toxic to plants and animals.

Our finding contradicts the finding of a study on Jaintia coalmines by Makdoh and Kayang (2015) who reported significantly higher concentrations of heavy metals in mine overburdens. This may be due to the different geology of the area. Kabata-Pendias and Pendias (1984) considered the following values of the critical soil data: 1500–3000 mg kg^{-1} (Mn), 60-125 mg kg^{-1} (Cu), 70–400 mg kg^{-1} (Zn), 100 mg kg^{-1} (Ni), 100– 400 mg kg^{-1} (Pb) and 3–8 mg kg^{-1} (Cd). The present findings are in agreement with that of Maiti (2007) where critical metal concentrations in the Jharia coalmine overburden dumps have been reported. In another research by Tripathy et al., (2009) slight metal pollution was found in the soil of Bastacola mines, Jharia, which also matches with some of our findings. Finally, since in the study area no metal toxicity was seen, thus it is open to extensive options of additives for land reclamation. In fact, the soil is deficient in terms of heavy metals. Application of vescicular arbuscular mychorhiza along with organic manure is highly recommended to boost up the soil fertility.

4.5. Plant biomass study

The surviving plants were counted to know the percent survival in each plot. Due to stressed condition, control plot could support only 54% while OBM plot supported 90% survival due to addition of cow dung (Fig. 4.3.). When species survival was estimated, *D. strictus* proved to be the best survivor (Fig. 4.4). The growth of the plants was monitored and recorded. Parameters like shoot length, root length, circumference, height, were taken into account (Fig. 4.5 and 4.6).

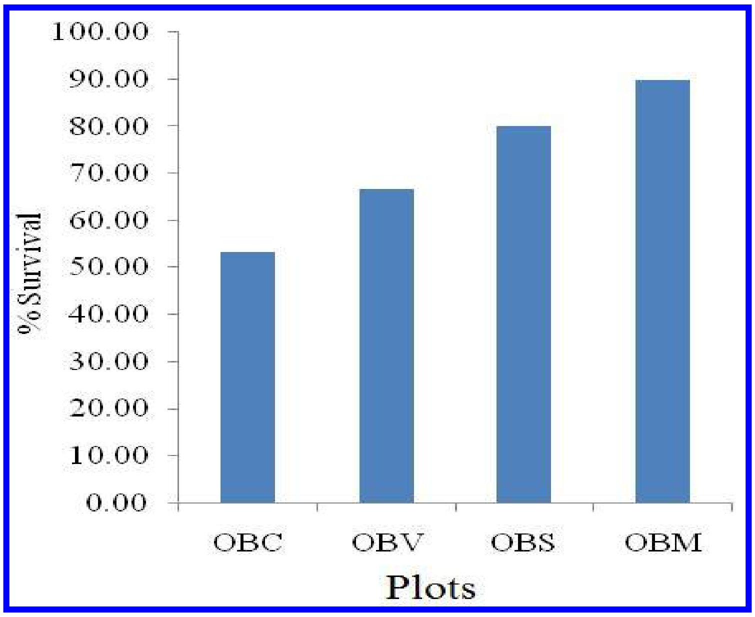

Fig. 4.3 Percent survival of the total number of plants in various plots

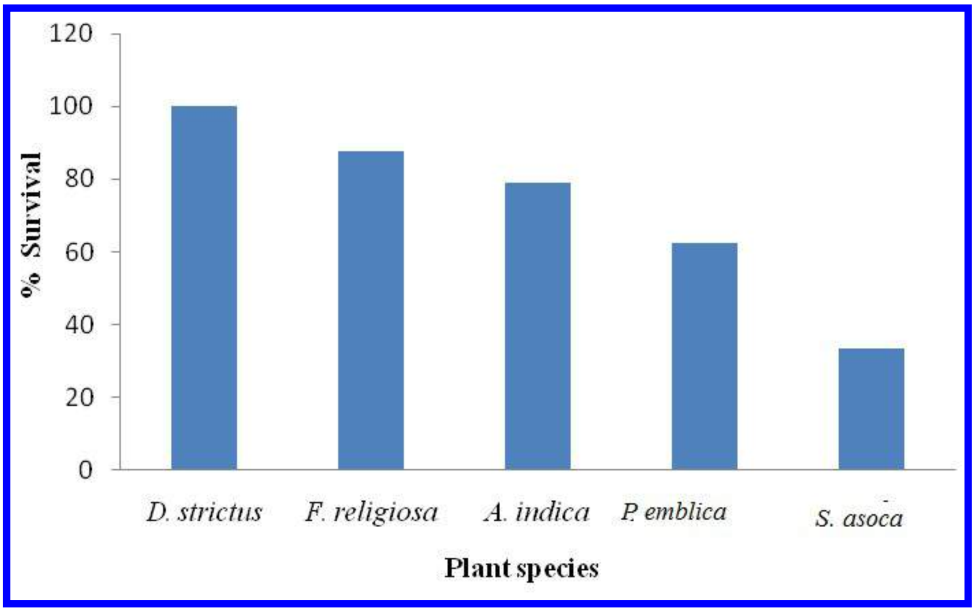

Fig. 4.4 Percent survival of the total number of individual plant species in all the plots taken together

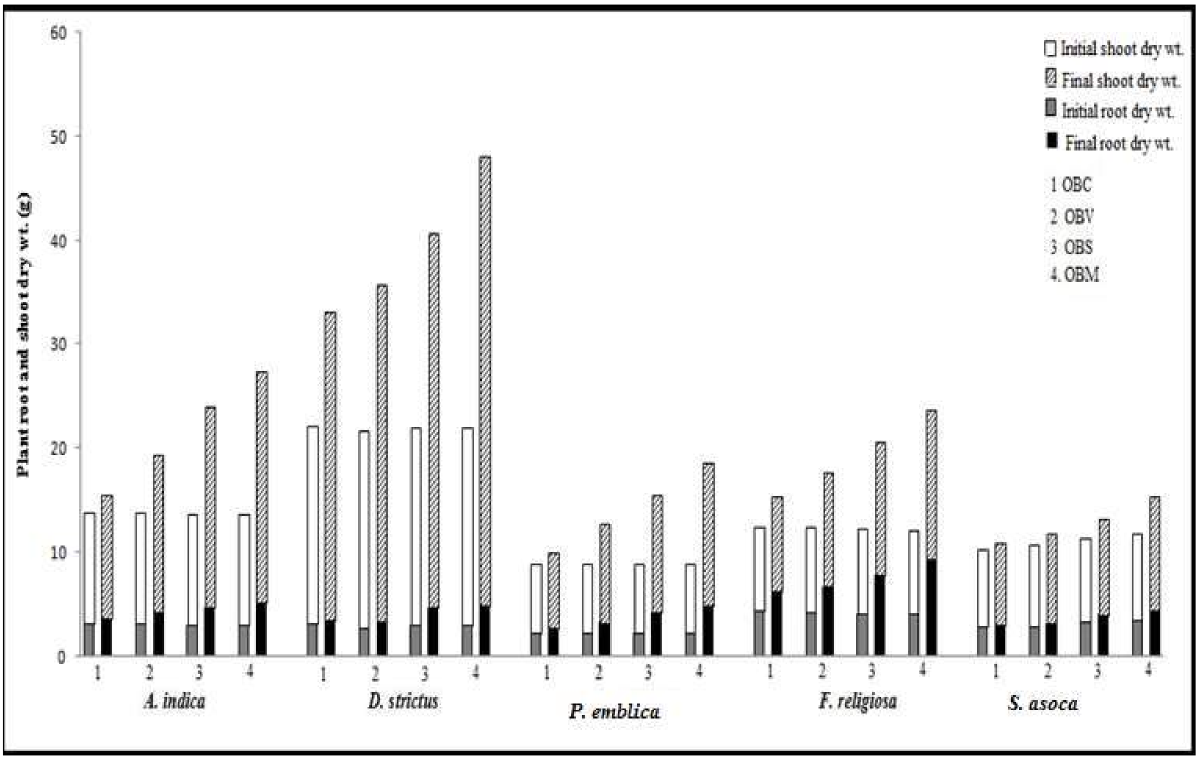

Fig. 4.5 Initial (2 months old individuals) and final (two years old) root and shoot biomass (dry weight, g) in control and treatment plots

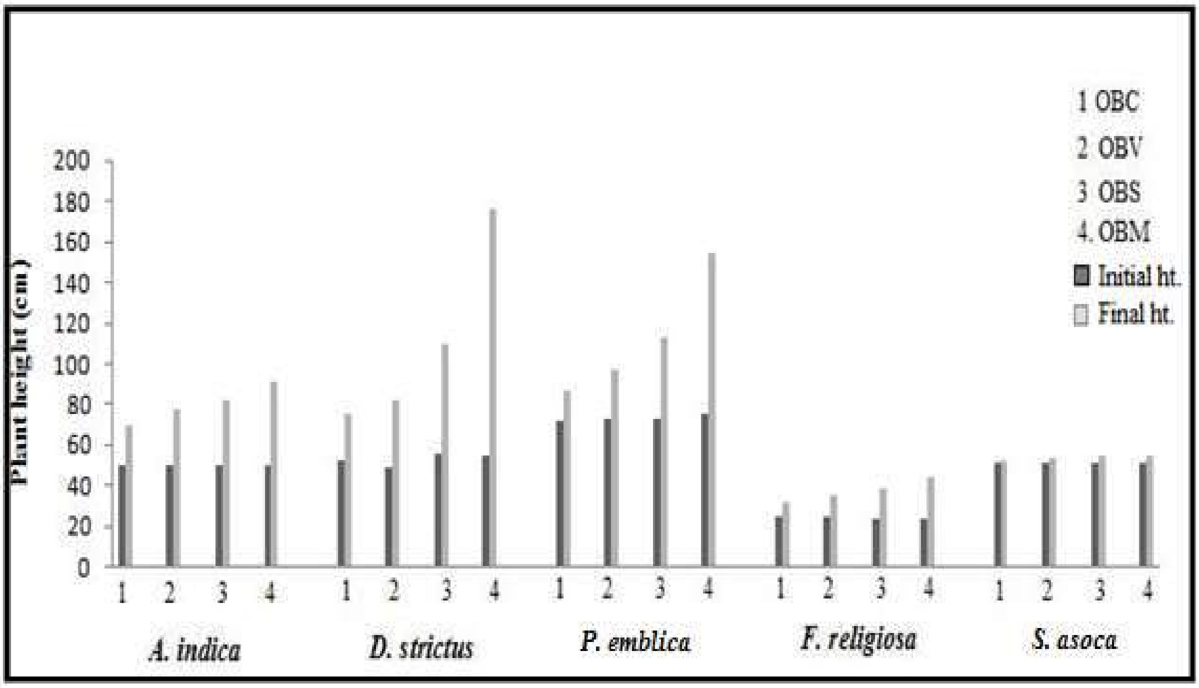

Fig. 4.6 Initial (2 months old individuals) and final (two years old) height (cm) in control and treatment plots

The ANOVA revealed significant treatment impact on seedling growth performance, which varied considerably from species to species. Furthermore, the organic manure addition improved the mine spoils fertility status by 2-10 times more than VAM treatment and 1-2 times more than agricultural soil amendments. Changes in mine spoil characteristics revealed that the spoil amendments (VAM, agricultural soils, and organic manure) enhanced the spoil fertility by increasing pH. The high CEC showed retention of essential nutrients in the rhizosphere after decomposition of organic matter while decreased bulk density leads to reduced compaction, facilitated aeration, better penetration and spreading of roots, thereby making the rhizosphere favorable for massive root development.

This gradual increase in favorable physicochemical properties and nutrient availability in the sequence OBC<OBV<OBS<OBM plots facilitated the growth of the plant. The significant increase in shoot biomass was observed for *D. strictus* irrespective of plots while the seedlings of *F. religiosa* showed maximum root biomass (Table 4.7). The high shoot biomass of *D. strictus* saplings can be attributed to significant increase in the height. Moreover, the significant shoot biomass in the OBV compared to OBC plot for most the saplings indicate that VAM could have resulted in an increased nutrient uptake by merely shortening the distance that the nutrients had to diffuse from the soil to the roots. Many studies showed a positive relationship between dry matter yield increment and VAM inoculations (Chulan and Martin, 1992). Li et al. (1991) showed that when root exploration is restricted, up to 80% of the plant phosphorus can be delivered by the external VAM hyphae to the host plant over a distance of more than 10 cm from the root surface.

Table 4.7. Percentage increase in root biomass, shoot biomass, circumference, and height of the plants under the control and treatment plots

Plant species	OBC	OBV	OBS	OBM	% Increase in Parameters
A. indica	18.96	42.57	58.68	72.70	Root Biomass
E. officinalis	27.84	49.11	97.34	125.43	
D. strictus	12.77	25.49	55.94	65.57	
F. religiosa	46.25	61.10	91.55	133.59	
S. asoca	8.80	13.44	21.57	32.91	
A. indica	11.57	41.56	82.25	109.25	Shoot Biomass
E. officinalis	7.42	45.51	71.22	107.44	
D. strictus	56.12	70.77	89.94	127.89	
F. religiosa	12.95	35.95	58.53	77.43	
S. asoca	5.74	10.27	15.04	31.17	
A. indica	10.45	13.43	85.08	116.59	Circumference
E. officinalis	10.85	15.14	27.08	28.94	
D. strictus	13.99	27.76	30.63	44.68	
F. religiosa	13.43	17.95	36.08	76.49	
S. asoca	0	1.96	7.69	7.51	
A. indica	39.88	55.77	64.02	83.01	Height
E. officinalis	20.79	31.37	56.38	104.69	
D. strictus	44.54	68.34	98.77	221.93	
F. religiosa	26.97	43.81	60.64	83.29	
S. asoca	3.15	3.49	5.68	6.12	

The circumference showed descending trend as *F. religiosa* > *A. indica* > *D. strictus* > *P. emblica* > *S. asoca*. The H: D ratio revealed that all seedlings showed maximum responses to treatments in terms of height growth (i.e. increased H:D ratio) except *F. religiosa* where amendments resulted in more resource allocation in fine root and circumference development (i.e. decreased H:D ratio) as observed in table 4.8. Consequently, the relationship between annual increment in height and circumference was highly positive in *F. religiosa* while the disproportionately large increase in height with respect to circumference may be responsible for poor R^2 value in *D. strictus*.

Singh et al. (2000) observed a similar response to nutrient enrichment for non-leguminous species planted on mine spoils. Generally, the trees that allocate comparatively fewer resources to stem per unit of height growth are assumed to grow taller than those that distribute more (King, 1981; Lawton, 1984; Singh et al. 2000). Further, the low annual increment in height i.e. decreased Relative Growth Rate in Height (RGRH) and significant annual increment in circumference i.e., increased Relative Growth Rate in Circumference (RGRC), support versatile nature of *F. religiosa* in terms of better spoil binder, lesser chances of getting uprooted in stress conditions, control spoil erosion and water body siltation and promote slope stabilization. The plants in the rooted conditions are shown in plates 4.1, 4.2 and 4.3. After uprooting them for the biomass study, the same have been shown in plate 4.4 collectively.

Plate 4.1 The growth of *Azardiracta indica* in the experimental plot

Plate 4.2 i and j show the growth of *Dendrocalamus strictus* on the experimental plot

Plate 4.3 k and l show the growth of *F. religiosa* on the experimental plot

Plate 4.4 m, n, o, p,depict the plants after being uprooted, for various biomass measurements

Table 4.8 H: D ratio, Relative Growth Rate in height (RGRH, cm/month) and circumference (RGRC, cm/month), annual increment in height (cm) and circumference (cm) in control and experimental plots

Plant species	OBC	OBV	OBS	OBM	Parameter
A. indica	77.15±13.40	78.32±6.71	63.30±2.45	60.51±3.38	H:D ratio
E. officinalis	157.78±12.83	149.48±6.03	187.12±25.94	230.31±13.11	
D. strictus	108.48±7.57	117.92±7.65	166.03±32.98	231.34±18.24	
F. religiosa	51.23±9.84	54.65±4.86	54.92±4.68	47.63±1.10	
S. asoca	98.19±10.70	97.57±12.30	107.56±4.28	117.61±12.04	
A. indica	0.026±0.008	0.034±0.004	0.038±0.006	0.047±0.005	RGRH (cm/month)
E. officinalis	0.0145±0.0029	0.021±0.00	0.034±0.008	0.056±0.002	
D. strictus	0.029±0.002	0.032±0.001	0.052±0.001	0.09±0.002	
F. religiosa	0.018±0.01	0.028±0.005	0.037±0.002	0.047±0.007	
S. asoca	0.002±0.00	0.002±0.00	0.004±0.007	0.004±0.00	
A. indica	0.008±0.003	0.01±0.00	0.0469±0.0098	0.056±0.001	RGRC(cm/month)
E. officinalis	0.008±0.003	0.01±0.002	0.0183±0.0056	0.011±0.003	
D. strictus	0.01±0.002	0.019±0.007	0.0205±0.0016	0.029±0.008	
F.religiosa	0.01±0.002	0.012±0.005	0.0235±0.0068	0.043±0.003	
S. asoca	0	0	0.0070 ±0.0082	0.006±0.006	
A. indica	18.11±5.03	25.67±2.32	29.72±3.90	38.32 ± 2.97	Annual increment in height (cm)
E. officinalis	13.88 ± 3.30	21.38±0.84	37.68±8.34	72.78±1.94	
D. strictus	21.60± 1.25	26.25 ± 1.24	50.67±2.10	112.39 ± 0.40	
F.religiosa	6.24±3.40	9.94±1.24	13.76±1.71	18.60±2.22	
S. asoca	1.48±0.40	1.67±0.42	2.72 ± 0.43	2.92±0.58	
A. indica	0.24±0.10	0.33±0.05	1.72±0.32	2.37±0.23	Annual increment in circumference (cm)
E. officinalis	0.15±0.05	0.24±0.05	0.37±0.09	0.43±0.05	
D. strictus	0.24±0.05	0.43±0.10	0.46±0.09	0.67 ± 0.19	
F.religiosa	0.21±0.05	0.27±0.09	0.55±0.19	1.17±0.05	
S. asoca	0	0.0	0.09±0.016	0.09 ± 0.003	

4.6. Phosphorus fractionation

The various phosphorus fractions obtained in the overburden mine spoil samples through SEDEX method has been depicted in figure 4.7. The X-ray diffraction technique was employed for the mineralogical analyses and the corresponding XRD has been shown in Fig. 4.8. As seen from the XRD graph, the elements were bound in form of different compounds. Quartz, $CaCO_3$ (calcite, vaterite, and dolomite), $CaPO_4$, $Ca_3(PO_4)_2$, ZnO and clay related minerals were mainly identified via the XRD analyses. Stronger XRD peak located at $2\theta \sim 27^o$ of quartz indicated large fraction of quartz in the sample. Such observations also indicated that the clay fraction was low.

The lower clay fraction could also be visualized via the small peak intensity of illite mineral located at $2\theta \sim 8.8$ and 17.75^o. The XRD peaks of palygorskite and kaolinite were also identified at $2\theta \sim 20.9$ and 35.1^o, respectively. Kaolin-based minerals are not expandable, and they have a lower number of active surface charge sites (Markis, 2003). Furthermore, very small XRD peaks related to hematite and mullite were observed at 39.5 and 40.36^o. It is worth to mention that high clay fraction can be characterized with the high illite, palygorskite and kaolinite contents. The available phosphorus is correlated with the clay particle. Since clay is very less thus phosphorus availability was low (Andrieux et al., 2001; Koch et al., 2001). It was also known that the phosphate buffering capacity of sand is less (Sanyal et al., 2015).

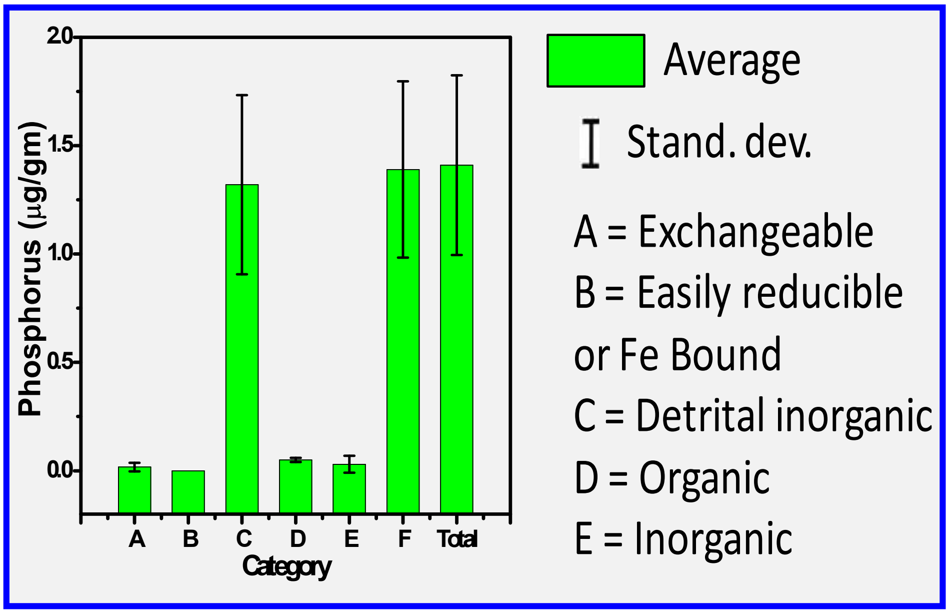

Fig. 4.7. Phosphorus fractions found in the overburden dump samples

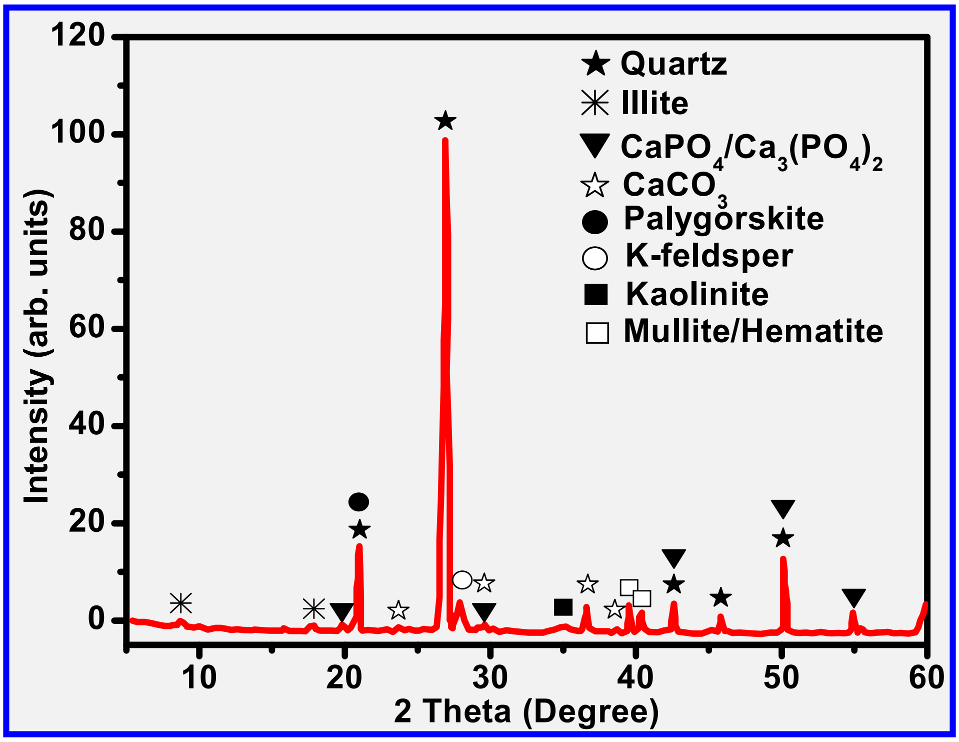

Fig. 4.8. XRD report of the overburden dump samples

According to the XRD pattern, loosely sorbed phosphorus was not found as this fraction is labile. Labile forms are usually available to the plant. In the newly formed dump, the plant available labile forms are not obtainable. This is because of the fact that the microbial population usually do not establish in such a harsh condition. Further, easily reducible or reactive ferric-Fe bound phosphorus and the detrital, as well as inorganic fractions, were also found to be absent. However, minor fractions of calcium bound phosphorus (1.8 µg/g) were observed, but, in small quantity, as indicated in the XRD pattern. The XRD analysis showing the small XRD peaks corresponding to calcium phosphates located at $2\theta \sim 19.8$, 29.5, 42.6, 50.22 and 54.93º. Also, calcium carbonates which adsorb phosphorus are present as minerals in the dump samples as indicated by the corresponding XRD peak located at $2\theta \sim 24$, 29.58, 36.62 and 38.7º. Thus phosphorus is present only in forms adsorbed on calcium compounds. Also, Walker and Syers (1976) put forth a model of soil phosphorus transformation during the soil development that provides a useful starting point for investigating P dynamics at different stages in the soil development. The model depicts that all the soil P is in the primary mineral form (mainly as calcium apatite minerals) at the beginning of the soil development which coincides with the beginning of primary succession. Such a study has been done by Simmons and Currie (2005) in Western Maryland, USA.

It is worth to be mentioned that if the soil is rich with calcium carbonates then that may lead to the formation of Ca–P precipitates in the soil (Siddique and Robinson, 2003) and may be followed by formation of secondary P minerals and calcium–phosphorus complexes. Calcium bound phosphate is found more in soil than other fractions (Srilatha and Sharma, 2015). In the present study, the content of calcium carbonates in the sample was low due to which some Ca complexes or precipitates may be produced and P may be preserved. On the other hand, the addition of organic manure may be useful for the enhancement in P fraction (Anetor et al., 2015). As indicated in Table 4.2, the soil was found to be slightly acidic. It is worth to state that the acidic medium is known to delay the crystallization and formation of Ca–P complexes and Ca–P minerals. Since the pH of the spoil material was acidic thus the chemical environment is responsible for favoring phosphorus availability (Ch'ng et al., 2014). Further, detrital P was mainly igneous or metamorphic origin (Lukkari, 2008), so the absence of this fraction is obvious in the sedimentary origin of mine spoils. Such studies are even important because Jharia coalfield is a place of constant land deformation (Prakash et al., 2010). Thus restoration activities are required at a faster and larger scale.

4.7. Litter decomposition study

Leaf litter decomposition study was undertaken to know the status of litter decay of each plant species. This study was done with an objective to recommend plant species for quick restoration.

4.7.1. Chemistry of litter

The nitrogen, phosphorus and potassium contents of the initial litter material varied markedly among the five plant species (Table 4.9). *D. strictus* had highest NPK; *P. emblica* had the least nitrogen, moderate K and P; *F. religiosa* showed low P, higher N and K; *S.asoca* had the least K content while *A. indica* had moderate amount NPK amongst the five species.

Table 4.9 Initial chemical composition of leaf litter of the five plant species

Parameters	*D. strictus*	*S. asoca*	*A. indica*	*E.officinalis*	*F. religiosa*
N (mg/g)	14.11±0.029	12.08±0.017	11.18±0.023	10.24±0.038	12.24±0.134
P (mg/g)	0.28±0.001	0.191±0.002	0.24±0.005	0.17±0.008	0.11±0.003
K (mg/g)	4.84±0.134	2.05±0.022	2.19±0.025	3.19±0.013	3.99±0.002

4.7.2. Weight loss

The decomposition time (t50 and t99) of all the species was found to differ from plot to plot and followed a trend in decreasing order of decay time as OBM>OBS>OBV>OBC (Fig. 4.9).

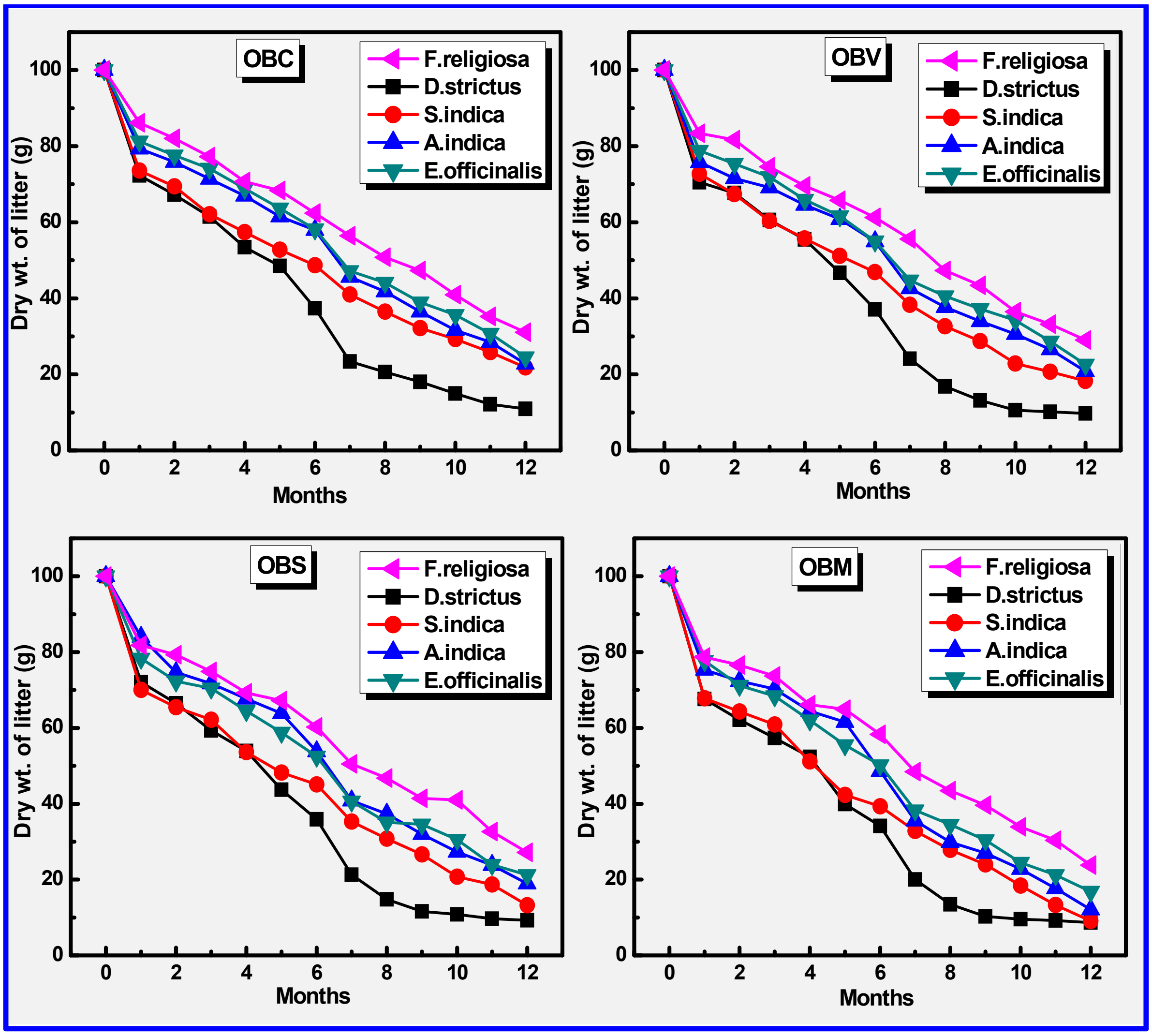

Fig. 4.9 Mass loss of litter of the five species with time in the four plots

The treatments had a significant impact on t50 and t99. As evident from our result, OBM reduced t50 of *F. religiosa* by 40 days and t99 by 289 days than the control plot. A lag phase in the decay of *F. religiosa* litter was observed in later months which delayed the decomposition process. The time taken by *D. strictus* to attain t99 was 745 days in OBM which was much faster compared to that in OBC (825 days). Initially, there was a rapid decay in the first month of about 14-28% in OBC; 14-30% in OBV; 19-28% in OBS and 22-33% in OBM with the actual values. The rapid decline in residual weights was noticed during the rainy months of June-July. The time is taken for 50% and 99% weight loss varied with the species (Table 4.10).

Table 4.10 Daily decay rate coefficient of litter decomposition (k_d), time required in days for 50% (t50) and 99% (t99) weight loss and N (k_N), P (k_P), and K (k_K) losses of 5 plant species in 4 plots

Treatments	k_d	k_N	k_P	k_K	t50	t99	Species
OBC	0.0061	0.0055	0.0038	0.0058	114	825	*D. strictus*
OBV	0.0064	0.0063	0.0050	0.0076	109	784	
OBS	0.0065	0.0072	0.0054	0.0082	106	766	
OBM	0.0067	0.0079	0.0069	0.0109	103	745	
OBC	0.0042	0.0040	0.0029	0.0043	166	1200	*S. indica*
OBV	0.0047	0.0048	0.0036	0.0046	149	1074	
OBS	0.0055	0.0054	0.0046	0.0062	125	901	
OBM	0.0066	0.0059	0.0052	0.0073	106	761	
OBC	0.0041	0.0037	0.0034	0.0044	171	1235	*A. indica*
OBV	0.0043	0.0049	0.0041	0.0051	161	1163	
OBS	0.0046	0.0053	0.0047	0.0055	152	1096	
OBM	0.0058	0.0057	0.0053	0.0069	120	863	
OBC	0.0039	0.0034	0.0031	0.0037	180	1298	*E.officinalis*
OBV	0.0041	0.0042	0.0045	0.0045	170	1227	
OBS	0.0042	0.0045	0.0043	0.0051	163	1177	
OBM	0.0049	0.0049	0.0046	0.0066	142	1025	
OBC	0.0032	0.0026	0.0024	0.0034	216	1561	*F. religiosa*
OBV	0.0034	0.0030	0.0048	0.0042	205	1476	
OBS	0.0036	0.0038	0.0037	0.0047	194	1400	
OBM	0.0039	0.0043	0.0041	0.0062	176	1272	

4.7.3. NPK contents of residual litter

In all the five plant species, a decline in NPK content was seen, though the rate of decline was rapid initially and turned gradual during the last months, with a significantly regular decrease in NPK content in *D. strictus*. The constant release of nutrients was observed throughout. K was more easily decomposed as compared to N and P. The order of mobility remained K>N>P in all the plots. Overall NPK stock loss was slower than the mass loss in all species. The nutrient release was higher in the rainy months of June-July. The regular decline in NPK stock in all the five species revealed net mineralization of nutrients from the beginning.

4.7.4. Nutrient stock

There was constant release in nutrient stock and no nutrient arrest was observed. At the end of the experiment, about 0.48 % of the nutrient stock of *D. strictus* was left in OBM plot while in OBC plot it was 1.43% (almost 3 times). *F. religiosa* showed maximum nutrient remaining at the end which was 12.20% in OBC plot and 4.89 % in OBM plot.

4.7.5. ANOVA

There was a significant difference in the litter when placed in different plots. Tuckey's HSD was performed and a significant difference was observed in the means of all the plant species. OBM had the maximum k_d values for all the five species followed by OBS, OBV and OBC (Table. 4.11). Similar results were also observed for k_N, k_P and k_K values. It was indicated that addition of soil amendments augmented the decay rates and nutrient release of a litter of the same five species.

Table 4.11. F values for k_d, k_N, k_P and k_K at 5 % level of significance

Species	F (k_d)	F (k_N)	F (k_P)	F (k_K)
D. strictus	15.43	97.43	369.19	508.03
S. indica	1178.32	245.26	1198.92	1906.47
A. indica	319.04	281.87	109.82	294.85
E.officinalis	79.13	256.03	140.73	5547.43
F. religiosa	141.94	244.73	104.45	3373.54

4.7.6. General discussion

Early studies were done by Jamaludheen et al. (1999) on quality, decay rates and release of nutrients in Kerala. Another study on Kerala was done by Isaac and Nair (2005) and they reported that the litter of *Mangifera indica* with a half-life period of 3.2 months showed the fastest decay as compared to other two species, *Artocarpus heterophyllus* and *Anacardium occidentale* in the warm humid tropics of Kerala. Yadav et al. (2008) evaluated the total litter production and reported *Prosopis cineraria* to have highest NPK concentration in the litter. In another study in Nandapha National Park, Arunachal Pradesh the initial N and P content were significantly positively correlated with decay rates (Barbhuiya et al., 2008). Bargali et al. (2015) have also done some exclusive studies on single leaf litter.

In the present study, a rapid initial decay in the first month was the net effect of a large number of processes such as upake of readily available energy sources by microbes, loss of water-soluble components and non-structural carbohydrates which are simply leachable forms, from the leaf litter as reported by Kuruvilla et al. (2016). Removal of litter particles by soil microfauna (Meixiang et al., 2012) and also macrofauna (Riutta et al., 2012) a potent reason. The higher leaf litter decomposition in the rainy months of June-July reflects the favorable effect of rainfall. This is related to the pleasant conditions for the decay of litter and soil moisture contents, high relative humidity and congenial atmospheric temperature, all indirectly favored the soil biological activity. The higher decay rates in the wet months also accord with the results of Pandey and Singh (1982). The decay rates slowed down as winter approached. The reason may be due to low soil moisture and low temperature affecting adversely the activity of the decomposer organisms (Maithani et al., 1996; Singh et al., 1999). A decline in the decomposition rate after the rapid phase of decay may also be attributed to a higher percentage of recalcitrant fractions like cellulose, lignin, and tannin during the advanced stage of leaf decay (Talbot and Treseder, 2012).

The decay constant k_d for the five species in control plot (0.0032 – 0.0061) which is lower than the results of Singh et al., (1999) as because our study was done on a fresh dump while theirs was done on a 5-year-old dump and the decomposer population increased with the age of the dumps (Ghosh, 2001). The dump was devoid of organic matter and the development of soil organic matter has been found to be essential in leaf litter decomposition (Aubert et al., 2010). t50 value is an indicator of the persistence of the litter on the soil. The elevated t50 value indicates longer stay of the litter. Thus, *F. religiosa* proved to be a durable soil cover in the long term than other species as species that produce low-quality litter play an important functional role in ecosystem by promoting nutrient retention (Ball et al., 2008) while *D. strictus* would meet the immediate requirements of soil microbes boosting the fertility status of the impoverished spoils. Such studies have been conducted on bamboo species by Nath and Das (2011).

The delayed decay of *F. religiosa*, indicate the presence of prominent midribs and veins in the leaves as reported by Chandrashekar (2011). The C/N also imparts speed to the litter decay rates as it is required by the microbes for their sustenance. C/N of soil microbes is 8:1 (USDA NRCS, 2011). They have to acquire enough carbon and nitrogen from the soil to maintain that ratio of carbon and nitrogen in their bodies. Since the soil of the overburden dump is impoverished so it is unable to provide the required C/N ratio to the microbes. Thus the decay rates are very slow in the overburden dumps as carbon was slowly released by the microbial decay of the litter.

D. strictus with the highest initial N content decomposed fastest while *F. religiosa* with the least initial N content, decomposed at the slowest rate among the five species irrespective of plots which are in accordance with the findings of Barbhuiya et al. (2008). Greater initial N in the foliage leads to faster decomposition and vice-versa. Van Huysen et al. (2013) also reported that the initial N can be well correlated with weight loss. As decomposition proceeds, the composition of litter continually changes, creating new conditions for the decomposing organisms (Prescott et al., 2004).

Nutrient return through litter is a debatable topic. However, it has also been recorded that substantial portion of nutrients is returned to the soil through the decay of plant litter (Yang et al. 2004). Litter production in forest ecosystem is determined by climate, species composition, and succession stages (Vogt et al., 1986; Sundarapandian and Swamy, 1999). It has been observed that N and P are the major limiting nutrients for tree growth in many subtropical forests because of high soil acidity. A notable research revealed that broadleaved species gave higher return of N and P through litters over conifers trees, especially in the surface soil horizons (Yang et al. 1993). Nutrient concentrations are known to vary to some extent during the decomposing period and between leaf litter types (Blair 1998; Bubb et al., 1998; Palm et al., 1990).

Silicon has special importance in the defense mechanism of plants, particularly against big ungulate herbivores (McNaughton and Tarrants 1983; McNaughton et al. 1985), herbivorous rodents (Soininen et al. 2013), and insects (Massey and Hartley, 2009), and it is evident that silica in plants is effective against fungal infestation (Fauteux et al. 2005). Deterrent properties of Si are likely to remain effective even after plant death (Schaller et al., 2014). This is in reference to high Si content in bamboo leaves, used in our present study. Thus this finding can help to plant more bamboos in mined out area as it will be protected from grazers due to high Si content. However, it is not always necessary that Si content in litter will give resistance to litter decay. The influence of Si on decomposition mostly depends upon litter tissue type. Only sheath decomposition was seen to accelerate in the study conducted by Schaller et al. (2014) on *Phragmites australis*. This has also been earlier observed in another research (Schaller and Struyf, 2013) and the reason might be high accumulation of Si in sheath tissue (Schaller et al. 2013). It was also observed that the stimulation of sheath decomposition is at variance with the common explanation that higher Si concentrations in plants act as a defense mechanism (Fauteux et al. 2005), which should remain functional even after plant death (Cornelissen et al. 2004) and thus reduce microbial decomposer activity. A possible explanation for this apparent inconsistency is that high Si concentrations shift the result of competitive interactions between fungi and bacteria (Mille-Lindblom and Tranvik 2003) in favor of bacteria (Wainwright et al. 1997, Tian et al. 2012). Such a shift could be facilitated by an increase in the surface area of litter available for bacterial colonization when phytoliths and amorphous silica deposits are partially solubilized or mechanically removed during decomposition (Holstein and Hensen 2010). Such a surface area effect could also explain the absence of influence of Si on the mass loss of leaf blades and culms, because silicon contents and condensation state of these litter types are lower than that in the sheaths (Schaller et al. 2013). Importantly, fungi are unlikely to benefit in similar ways from surface-area enlargements, because their hyphae enter the litter surface to expand their mycelial network within the decomposing plant tissue (Newell et al. 1996).

Research revealed that Si increases plant resistance to biotic stresses, such as fungal and insect pests, as well as to abiotic stresses, such as rain, wind, and salinity (Guntzer et al. 2012). Sometimes rice farmers remove part of the straw after harvest permanently from the field; others leave it in the field (Klotzbücher et al. 2014). Deposition of crop residues is a crucial factor for Si balance of rice fields (Klotzbücher et al. 2015). Si fertilizers is added externally in few cases to increase the yield. In some bamboo species like *P. pubescens* and *P. bambusoides*, most of the absorbed silica is accumulated in the leaves (Ueda and Ueda 1961), so it can be assumed that bamboo forests return substantial amounts of silica to the soil through litterfall, especially when compared with broad-leaved forests and coniferous forests. Silica plays a very vital role in the global carbon (C) cycle through silicate weathering processes and silica fluxes that are delivered to the oceans as part of the global silica cycle (Conley 2002; Sommer et al. 2006). Bamboo species like *Phyllostachys pubescens* and *P. bambusoides* are silica accumulators which take up silica actively from the soil (Ma and Takahashi 2002). In a study by N. Ikegami et al. (2014) showed contribution of bamboo leaf litter to Si content in forest soil by the same plant species. All the above findings propose that tough bamboo leaves are rich in Silica but that does not hinder litter decay. On contrary, presence of Silica hastens litter decay.

Based on the percent release of different nutrients, the relative mobility of the elements can be arranged as K > N > P. Hasanuzzaman and Hossain (2014) reported that K being highly mobile is lost mainly by leaching. Our results are in agreement with the findings of Das and Chaturvedi (2005) and Yadav et al. (2008). A constant release pattern in NPK was observed in all the plots and for all the species depicting a complete lack of immobilization. This may be due to mineralization by the microbes through utilization of easily available energy sources and removal of litter particles by soil micro and macro fauna. Ha¨ttenschwiler et al. (2005) reported that microbial succession with changing enzymatic capabilities enhances decomposition, whereas antagonistic interactions among fungi that compete for similar resources decelerate litter decay. Thus the process becomes complicated. The nutrient release patterns increased with improvement in soil amendments. Cow dung and agricultural soil had a high nutrient quality which harboured and boosted micro flora and fauna which further increased the decay rates. The decay rate was highest in OBM plot which conforms the finding of Sannigrahi (2009). Litter decomposition rates are largely determined by the traits of the living plants (Tilston et al., 2013). The decay rates also improved with the addition of VAM in OBV as compared to OBC plot as VAM encourages the growth of beneficial microbes and it itself is a potent litter decomposer (Midgley et al., 2015).

Another aspect to be considered for litter decay is erodability of the soil. This factor depends on the texture of the soil. Maiti (2013) has described that sandy soil has low probability. Thus it is an advantage for the overburden soil which is dominated by sand. But low organic carbon content increases erosion. Wind Speed was low so litter erosion did not take place and thus litter decay continued with minimum disturbance. With regard to economy and species selection for restoration activity, it is one among the bamboo species which is closely linked with rural mass. It has been utilized in the manufacture of umbrella handles, walking sticks, furniture and also as a support for betel plants. Bamboos are fast growers and it is said that vegetation development increases the microbial biomass in soils (Knelman et al., 2012) and tends to increase the fungal to bacterial biomass ratio. The litter of *F. religiosa* can be as a mulch material because of slow decay.

4.8. Soil enzyme activities

Soil enzymatic activity gives the picture of soil health. There are many soil enzymes. However, in the present research, dehydrogenase and catalase activities have been studied as these are broader enzymes which collectively reflect the soil health. Since the study was done on a quick and small scale thus other enzymes could not be studied.

4.8.1. Dehydrogenase activity

Changes in the physicochemical properties of coal mine spoil were evaluated annually for three consecutive years which are given in Table 4.5. OBS and OBM treatments improved the mine spoil characteristics as seasonal changes in mine spoil characteristics revealed that the spoil amendments (VAM, agricultural soils, and organic manure) enhanced the soil fertility by increasing pH. The high cation exchange capacity showed retention of essential nutrients in the root zone after decomposition of organic matter while decreased bulk density led to reduced compaction, facilitated aeration and better penetration and proliferation of roots, thereby making the rhizosphere favorable for massive root development. This gradual increase in favorable physicochemical properties and nutrient availability in the plots as sequenced OBC<OBV<OBS<OBM plots facilitated DHA activity to increase as depicted by ANOVA. This is as per the findings of Liang et al. (2014). Correlation of DHA activity with the soil characteristics was not observed.

The DHA activity was highest in *F.religiosa* followed by *D. strictus* (Table. 4.12) while *S.asoca* showed the least activity in all the experimental plots. However, there was a significant difference at 0.01% level of significance in the dehydrogenase activity in various plots in one particular season. Among the plots, OBM depicted the highest DHA activity due to the positive effect of organic manure on DHA production Control Plot, OBC depicted 5.28 to 14.33 µg/g/hr DHA activity. The same was true for agricultural soil addition. Application of VAM increased the DHA activity noticeably in OBV plot. ANOVA showed a significant variation in the plots and among the plant species. DMRT further ranked the plants and the rhizosphere soil of *F. religiosa* performed best in terms of DHA activity.

Table 4.12 Seasonal variation in DHA activity (µg/g/hr) in the rhizosphere of five plant species along with their F values and outcomes of DMRT

Plant Species	**Plots**			
A. indica	***OBC***	***OBV***	***OBS***	***OBM***
M (F=52.24)	1.34 (c) ± 0.10	2.03 (c) ± 0.38	3.40 (b) ± 0.73	8.00 (a) ± 0.59
W (F=28.29)	3.60 (c) ± 0.95	5.88 (bc) ± 0.80	8.03 (ab) ± 1.56	13.28 (a) ± 1.72
S (F=174.20)	2.94 (c) ± 0.57	4.07 (bc) ± 0.93	6.21 (b) ±1.02	10.58 (a) ± 1.61
E. Officinalis	***OBC***	***OBV***	***OBS***	***OBM***
M (F=740.53)	1.17 (d) ± 0.80	1.99 (c) ± 0.63	2.82 (b) ± 0.63	5.41 (a) ± 0.69
W (F=28.07)	2.14 (c) ± 0.57	3.73 (bc) ± 0.92	5.47 (b) ± 0.92	8.74 (a) ± 1.38
S (F=56.48)	2.52 (c) ± 0.4	3.20 (c)± 0.91	5.54 (b) ±1.21	9.56 (a) ± 1.19
D. strictus	***OBC***	***OBV***	***OBS***	***OBM***
M (F=837.34)	1.34 (d) ± 0.51	2.83 (c) ± 1.51	4.39 (b) ± 1.22	12.74 (a) ± 2.19
W (F=214.29)	4.42 (c) ± 1.19	6.37 (c) ± 1.73	9.99 (b) ± 2.17	19.77 (a) ± 2.18
S (F=200.09)	4.01 (c) ± 1.04	5.66 (c) ± 1.29	8.35 (b) ± 1.92	16.55 (a) ± 1.87
F. religiosa	***OBC***	***OBV***	***OBS***	***OBM***
M (F=424.08)	1.26 (d) ± 0.19	2.80 (c) ± 1.77	2.80 (b) ± 1.92	13.90 (a) ± 3.17
W (F=117.61)	5.77 (c) ± 1.16	8.59 (c) ± 2.18	8.59 (b)± 1.94	22.98 (a) ± 4.11
S (F=146.40)	4.75 (c) ± 1.97	6.03 (c) ± 1.39	6.03 (b) ± 2.18	19.58 (a) ± 2.72
S. indica	***OBC***	***OBV***	***OBS***	***OBM***
M (F=102.38)	1.17 (c) ± 0.72	1.99 (bc) ± 1.42	2.82 (ab) ± 2.18	5.41 (a) ± 1.59
W (F=36.53)	2.14 (c) ± 0.95	3.73 (bc) ± 1.33	5.47 (b) ± 1.18	8.74 (a) ± 3.28
S (F=15.79)	2.52 (b) ± 0.38	3.20 (b) ± 1.91	5.54 (b) ± 1.55	9.56 (a) ± 3.17

Note: M = monsoon, W = winter and S = summer

4.8.1.1. Seasonal variation in DHA activities

All the plant species had considerably higher DHA activity in their respective rhizosphere as compared to the control plots in all the seasons (Table. 4.12). A significant difference was observed in the DHA activity amongst the three seasons. The initial enzyme activity was low in all the plots. However, an increase was observed in the winter season which was 57 to 211% more than monsoon season, followed by a decrease of about 14 to 38% in the summer months. The observed increase in DHA from monsoon to winter can be due to litter decomposition process. The decay of litter in the plots, through the litter bag experiment, was conducted for the different study. The litter addition favored the overall soil oxidative activity. As the litter underwent decay, smaller and simpler organic molecules were leached down from the litter layer to the surface soil horizon in the form of water-soluble organic matter, thus imparting a labile organic substrate for soil microorganisms (Görres et al., 1998). The decrease in DHA activity in summer season may be due to the decrease in moisture content which would have led to the decline in microbiological activity. Garcia et al. (1994) found that the rainy season enhanced the enzyme activity (DHA) of soils in the southeast arid region of Spain. Banerjee et al., (2000) also found an increase in microbial activity in forest and grassland soils due to higher soil moisture contents. Soil with low moisture level has shown DHA activity even close to zero (Marzadori, 1998). As soils dry, the water potential increases, and as well microbial activity as intracellular enzyme activity slows down (Mukhopadhyay and Maiti, 2010). In the present study, the highest DHA activity was reported in the rainy season and lowest in winter. Soil DHA was positively and significantly correlated with soil pH, Ca, Mg, K, and water content in a study by Kumar et al. (2010) on Jharia coalfields.

4.8.1.2. Relationships with soil variables

Many researchers expressed positive correlation between some soil properties and DHA activity (Leirós et al., 2000). However, it must be taken into consideration that these findings hold good only for stable soil like forests and our study was done on OB dumps which is just weathered rocks particles and thus far from equilibrium. It is also recognized that statistical analyses act only as a guide for the result interpretation and some of the significant correlation may be of doubtful biochemical significance. Present findings are in accordance with that of Nannipeiri et al. (2003) who found no consistent relationship between microbial diversity and soil functions. Due to complex dynamics of soil ecosystem, no single property is sufficient for the study of microbial activity (Garcia et al., 1998). Establishing correlation between parameters in a completely disturbed ecosystem is not a good tool for inferences. Further, the relationship between an individual biochemical property and the total microbial activity is not always observable, especially in the case of complex systems like soils, where the microorganisms and processes involved in the degradation of the organic compounds are highly diverse. Low DHA activity observed throughout the control plot was due to poor fertility status of spoil especially due to lack of soil organic matter (Mummey et al., 2002b). The presence of many aromatic organic pollutants in the coal mine spoils hamper rhizospheric soil microbial activity (Kumar et al., 2010).

However, OBM showed the maximum DHA activity this can be supported by the fact that fresh organic matter contributes to a significant increase in microbial metabolism (Joshi et al., 2010). The present research also supports the finding of Jarvan et al. (2014) who added cattle manure and observed improved DHA activity in agro-ecosystem. There was an active increase in DHA activity with the application of organic fertilizers in the experiment of Zhang et al. (2009). Poor DHA activity is an indicator of soil degradation (Garcia et al., 1997). In general, fine-textured soils have more micropores than sandy soils. Soil micropores protect mineralising microorganisms against grazers (Killham, 1994) and this can be one of the reasons for the higher enzyme activity in OBS plot.

Vesicular-Arbuscular Mycorrhizal (VAM) fungi also hold promise to increase plant yield and nutrient dynamics as they represent both a conduit for better nutrient uptake and site for accumulation of nutrients in the ecosystem. VAM also affects the enzyme activity by influencing the root exudation and microbial community (Wamberg et al., 2003) and consequently enzymatic activity. Similar results have been depicted by Acosta-Martinez et al., (2008) who reported a decline in DHA activity of cultivated land with a comparison to undisturbed land. This shows that since mining area are disturbed so the DHA activity has shown a decrease. Verma et al. (2014) reported very low DHA activity in overburden dumps (0.1625 μg/g of soil). However, our findings are more than that of Verma et al. (2014) because in our study rhizospheric soil was taken. Most importantly, the soil C/N ratio was so less that it could not provide a conducive environment for the microbes to survive which is a very significant cause for the low DHA activity (USDA NRSC, 2011).

Heavy metals can reduce enzyme activity by interacting with the enzyme-substrate complex, denaturing the enzyme protein or interacting with the protein-active groups, they could also affect the synthesis of enzyme microbial cells (Pan and Yu, 2011). Xie et al. (2009) noted that Cu of 100 mg kg^{-1} could suppress DHA significantly, while Cd of 5 mg kg^{-1} had a relative greater influence on soil microbial diversity. However, in our study heavy metals were not found in such a high amount. Thus low DHA activity was not affected due to of heavy metal toxicity in the current study.

4.8.1.3. Plant species wise DHA activity

Sinha et al. (2009) did a remarkable study on Jharia Coalmines and reported 93.3 μg TPF/g/hr in the rhizosphere soil of *Aegle mermalos*. Their research highlighted that the microbial activity of the tree root zone is important for selecting plant species for reclaiming the coal mines spoils. In the present study, the maximum DHA activity has been found in the rhizosphere of *F. religiosa* which may be due to higher root proliferation and exudates. *F. religiosa* has been found to have the highest root biomass and a potent grower in poor spoils. *D. strictus* is also a fast grower and its association with VAM has been found to be about 32% in the control sites. There is supportive research work that mycorrhiza affects the growth, composition, and activity of microbial communities by altering root exudation (Prasad and Mertia, 2005). Thus VAM has been found to considerably increase the dehydrogenase activity (Alguacil et al., 2005).

During the present study, a new observation was marked. Higher DHA activity does not always refer to the good health of the plant. Such an observation was highlighted in the case of *S. asoca* which showed death and very poor growth performance. Its root exudation stopped and dead root material was available for decay to the soil microbes as some *S. asoca* plants wilted. This shift in carbon availability probably resulted in the growth of saprotrophic fungi and bacteria that replaced micro-organisms living on water soluble carbohydrates from the living roots and hence increased the DHA activity (Wamberg et al., 2003).

The initial DHA activity was more or less similar amongst the plants because they were not very well acclimatizing to the adverse condition of the dump spoil. Variation was seen afterward when the plants started growing and as per there growth response, root exudation was also different. The complexity of the interaction between different tree species and micro flora is too enormous to be generalized (Pellisier and Souto, 1999). Soil chemical changes related to the release of organic and inorganic compounds, and the respective products of their microbial metabolism are important factors affecting microbial populations, availability of nutrients, the solubility of toxic elements in the rhizosphere, and thereby the ability of plants to survive in adverse soil chemical conditions (Pandey and Palni, 2007).

4.8.2. Catalase activity

The average value of pH of the mine spoil was slightly acidic (5.67), poor electrical conductivity (0.07mmhos/cm) and high bulk density (1.45 g/cc) revealed dominance of sand particles (Table 4.13), which might be further responsible for low moisture content, water holding capacity, organic carbon, available nutrients and microbial activity. No heavy metal toxicity was observed in treatment and control plots. The gradual increase in favorable physicochemical properties and nutrient availability in treatment plots facilitated catalase activity (CAT) to increase as depicted by ANOVA. The CAT activity was maximum in *Ficus religiosa* rhizospheric soil followed by *Dendrocalamus strictus* while *Saraca asoca* showed the least activity in all the plots (Table 4.10). Among the plots, OBM depicted the highest CAT activity. ANOVA showed a significant difference in the plots and among the plant species.

Initial Catalase activity was very low due to impoverished soil conditions which resulted in poor growth of microbes. The soil catalase is concerned with soil organic matter so low catalase activity can be due to low organic matter in the dump (Li-Hua et al., 2007). Besides total K and available N, most nutrients are significantly positively correlated with catalase (Nan et al., 2006). Also, the saplings were acclimatizing with the stressed condition of the dump. Trees have canopy cover which provides a microclimate favorable for the soil microbes (Berg, 1998). But such a condition lacked in our study. Generally, positive correlations of canopy openness with soil moisture and microbial activity parameters in the A horizon may be related to a higher input of precipitation water and radiation (meaning a higher soil temperature) under open canopy (Buchmann, 2000; Stoyan et al., 2000). Soil microclimate oscillations related to the radiation influx through canopy gaps may be the reason for nil or negative correlations between canopy openness and microbial activities in the organic horizons. However, such a condition was lacking in the present study and the conditions were harsher.

Sometimes heavy metal toxicity increases catalase activity. The increase in catalase and peroxidase is strongly correlated with metal ion concentration. Metals were not present in high concentration in the study area of Jharia. Seasonally, the enzymes showed increased in later stages of the study i.e., in the summer season. This is because of time advancement and growth of the roots of the plants. Because of increase in root exudation the activity of the enzyme increased. It was observed that *Ficus religiosa* showed very good enzymatic activity in its rhizosphere. Thus this species can be strongly recommended for restoration activity. This is a new study which was done on a completely denuded dump to understand the response of the individual plant species. Thus previous data on such studies are scanty. Gömöryová et al. (2006) have reported catalase activity as high as 73.9 mol $KMnO_4$ g^{-1} in the well-defined soil. Our finding show meager amounts of catalase (1.60±0.46 ml $KMnO_4$/g) which may be due to poor soil structure. Further long-term research in this field is necessary for better understanding of the enzymatic activity in such stressed condition in mining areas in a better way.

Table 4.13 Seasonal variation in catalase activity (ml $KMnO_4$/g) in the litter of five plant species along with their F values

Plant Species	**Plots**			
A. indica	***OBC***	***OBV***	***OBS***	***OBM***
M (F=174.20)	1.60±0.46	1.63±0.38	2.43±0.42	2.97±0.12
W (F=28.29)	2.07±0.25	3.43±0.55	4.67±0.40	6.57±0.29
S (F=52.24)	2.37±0.46	3.70±0.56	6.23±0.23	7.23±0.15
E. Officinalis	***OBC***	***OBV***	***OBS***	***OBM***
M (F=740.53)	1.80±0.70	2.00±0.85	2.43±0.25	2.70±0.26
W (F=28.07)	2.67±0.45	3.33±0.51	4.60±0.26	5.77±0.50
S (F=56.48)	3.53±0.40	4.00±0.17	5.63±0.25	6.33±0.50
D. strictus	***OBC***	***OBV***	***OBS***	***OBM***
M (F=837.34)	1.53±0.31	2.43±0.32	2.53±0.32	3.27±0.21
W (F=214.29)	3.47±0.51	4.37±0.38	5.93±0.40	7.23±0.15
S (F=200.09)	4.23±0.35	5.90±0.26	6.33±0.15	8.60±0.36
F. religiosa	***OBC***	***OBV***	***OBS***	***OBM***
M (F=424.08)	1.40±0.44	2.40±0.35	2.93±0.15	3.60±0.17
W (F=117.61)	2.23±0.42	3.77±0.35	6.60±0.26	8.17±0.81
S (F=146.40)	4.87±0.45	6.17±0.31	8.13±0.21	9.93±0.85
S. asoca	***OBC***	***OBV***	***OBS***	***OBM***
M (F=102.38)	1.07±0.06	1.37±0.31	2.10±0.20	2.43±0.31
W (F=36.53)	1.70±0.26	1.90±0.20	2.80±0.52	3.83±0.35
S (F=15.79)	2.00±0.44	2.37±0.31	2.77±0.06	4.53±0.40

4.9. VAM Root Infection

There was no infection found in the control plot as expected. In the treatment plots VAM infection in *Azardirachta indica* (Neem), *Dendrocalamus strictus* (Bamboo), *Phyllanthus emblica* (Amla), *Ficus religiosa* (Peepal) and *Saraca asoca* (Ashok) was about 16%, 32%, 16%, 40% and 10% respectively. Arbuscules, vesicles and hyphae were observed in *D. strictus* (Table 4.14).

Table 4.14 Percent root infection of VAM with the five plant species

S.N.	Name of the plants	% of root length colonized	Remarks
1	*Azardirachta indica*	12-16	Vesicles and hypha are observed
2	*Dendrocalamus strictus*	20-32	Hyphae, Vesicles and Arbuscules were observed
3	*Emblica officinalis*	10-16	Hyphae were observed
4	*Ficus religiosa*	35-40	Hyphae were observed
5	*Saraca asoca*	6-10	Hyphae have been observed

Maiti (2013) collected spores in restored dumps of Jharia coal mines and found *Glomus* species to dominate. Thus, in our study *Glomus* species have been used which imitates the natural occurrence in restored mines. Similar studies have been done by Kumar et al. (2003) on Jayant Coalmines, Madhya Pradesh. They found high percent colonization of *A. indica* (about 70%) which does not match with our findings. Kumar et al. (2010) found low percent infection in *A. indica* in another study which supports our findings. Similarly, we found moderate infection for *D. strictus* which corroborates the research of Kumar et al. (2003). Bamboo's root infection by vesicular-arbuscular mycorrhiza (VAM) has also been studied by Jiang et al. (2013). Rajeshkumar et al. (2012) found 45 % root colonization in *S. asoca*. *S. asoca* failed to grow vigorously which may be correlated to its poor association with VAM. Research on *S. asoca* infection studies by VAM is rare in India. Therefore, our finding may be fruitful in this aspect.

The presence of arbuscules is normally used to designate VAM association (Smith and Gianinazzi- Pearson, 1988). However, the presence of hyphae or vesicles alone has also been used as evidence for these associations. Arbuscules are ephemeral structures which may be absent if samples are collected when roots are inactive, whereas vesicles are considered as storage organ produced in the older region of infection. The condition indicates that roots of the majority of the plants colonized are not mature.

Gould et al. (1996) have reported that mycorrhizal inocula in spoil during the first year following dumping chiefly consisted of spores; following the first spring after reclamation other forms of mycorrhizal inocula were enhanced in a revegetating coal mine spoil. As the succession commences at the distressed site, there is an increase in VAM inoculums level and as plant root system matures and expands the association also increases. The plants were juvenile so high association at this stage is not expected. Association also varies from soil to soil. In forest, *P. emblica* root infection was found as high as 64% (Pindi, 2011). The impoverished soil condition is a potential cause for slow root development of the plants and hence colonization. *F. religiosa* showed good root growth which may be boosted up by its association with the VAM. Thus *F. religiosa* and *D. strictus* can be promoted as good growers in such stressed sites of Jharia Coalfields.