Article

Reclamation of fly ash dykes using naturally growing plant species

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Abstract

The present study was conducted over a period of three years on fly ash dyke. The physicochemical analysis of fly ash (pH, WHC, BD, porosity, EC% OC & available P, heavy metal content etc) was performed before and after the growth of plant species. Fly ash was analyzed after concentrated nitric acid digestion by atomic absorption spectrophotometer AAS-7000 (Shimadzu) for heavy metals. The dyke was colonized by the propagules of native species over a period of time and it was observed that fly ash was contaminated by heavy metals and plants were able to ameliorate the metal concentration of dyke. The growth of plant species also improved the condition of fly ash so that it can be used for agricultural purposes. Phytosociological studies of the fly ash dyke were performed so that these plants may be used for reclamation of fly ash for subsequent use in agriculture.

Keywords reclamation; fly ash; IVI; phytosociology; heavy metals.

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1 Introduction

Fly ash dumpsites called fly ash dykes have been recognized as a major environmental threat which is the results of coal combustion by thermal power plants. In India, fly ash generation is increasing day by day and was expected to be 300–400 million tons per annum by 2016–2017 (FAU, 2013). Therefore, for the proper disposal of fly ash, sufficient land is needed nearby thermal power plants for the construction of dykes. The fly ash causes particulate due to re-suspension of fly ash from dykes during the summer season by wind, presence of heavy metals/metalloids in fly ash and fly ash leachates leads to heavy metal pollution which is deleterious to the ecosystem (Haynes, 2009). There are many human health reported problems due to fly ash such as lung problems, skin disease, eye irritation, etc (US EPA, 2007; Dellantonio et al., 2009; Ruhl et al., 2010). And therefore fly ash dykes are recognized as potential hazardous sites in the vicinity of coal fired thermal power plants and exerting adverse impacts on the surrounding ecosystems (Rau et al., 2009). Bio-stabilization of fly ash dykes using naturally growing plant species on dykes can be used to alleviate all environmental problems associated with fly ash in India and countries operating coal fired thermal power plants. Krzaklewski et al. (2012) have suggested bio-stabilization of fly ash dykes using Black alder. Presence of various essential plant nutrients in fly ash and its ameliorating effect on physico-chemical and microbial properties of soil make it a useful soil modification agent for biomass production (Pandey and Kumar, 2012). Meravi and Prajapati (2014) have shown that the dust of fly ash is contaminated by heavy metals and it was contributing to the metals present in the soil surrounding to thermal power plant.

He et al. (2018) have performed extraction of rhenium by *Medicago sativa* and erect *Astragalus adsurgens* from alkaline soils amended with coal fly ash. It has been shown that vermin composted fly ash enhanced soil fertility, plant growth promotion and microbial enzymatic activities (Usmani et al., 2019). Several reports are there for the bio-stabilization of fly ash and many researchers have made efforts for the restoration of fly ash dykes through biological interventions (Babu and Reddy, 2011; Hrynkiewiez et al., 2009; Juwarkar and Jambhulkar, 2008). Kisku et al. (2018) have characterized coal fly ash and used plants growing in ash pond for phytoremediation of metals from contaminated agricultural land. The plant species growing on the dykes are able to accumulate the heavy metals present in fly ash and therefore can be used for bioremediation purposes also (Gupta and Sinha, 2008; Maiti and Jaiswal, 2008; Kumari et al., 2013). There are studies and report regarding natural vegetation on fly ash worldwide (Mulhern et al., 1989; Shaw, 1992; Chu, 2008; Mustafa et al., 2012) and the plants were able to successfully ameliorate many problems associated with the fly ash. The bio-stabilization of fly ash dyke using naturally growing plants is an effective solution against environmental pollution (Krzaklewski et al., 2012). Therefore, naturally growing plant species on the fly ash dykes seem to be a potential tool for the restoration because these plants can respond better and can survive easily in comparison to exotic species (Yoon et al., 2006; Pandey and Singh, 2011). Metal remediation potential of early successional pioneer plant species *Chenopodium album* and *Tripleurospermum inodorum* have been studied by Tőzsér et al. (2019) and also the potential of *Salix viminalis* in a metal contaminated area by Tőzsér et al. (2018). Keeping these things in mind, the present study was undertaken to identify potential and naturally growing plant species for the restoration of fly ash dykes in a sustainable manner.

2 Materials and Methods

The study site was the fly ash dyke of super thermal power plant (NTPC, Sipat) located at 22°07’ N and 82°16’ 43 E and with an installed capacity of 2980 MW. Six intensive surveys were made in the fly ash dyke during 2013–2015 to identify naturally growing plant species during different seasons. Quantitative assessment was done by laying 30 5×5 m quadrats. In each quadrat, the number of individuals of each species was counted. Relative density, relative frequency and relative cover of all plant species were calculated and IVI (importance value index) of each species was calculated using (Curtis and McIntosh, 1950). Encountered plants were identified with the help of pertinent floras and literature (Duthie, 1960).

Composite samples of fly ash were collected from the rhizospheric regions of the dominant species (*Cynodon dactylon*, *Typha latifolia, Ipomea carnea, Lantana camara*, *Cassia tora*) of the fly ash dykes and pooled to reduce the spatial heterogeneity of fly ash. The samples were air-dried and ground to pass through a 2.0-mm sieve, homogenized and analyzed for physicochemical characteristics. The physicochemical properties of fly ash and soil were carried out following the standard protocols. pH and electrical conductivity (EC) were measured as per the protocol given by Jackson (1967). Water holding capacity (WHC) and bulk density (BD) were determined using the protocol given by Black et al. (1965). % Organic carbon (%OC) was determined using a dichromate oxidation method (Walkley and Black, 1934). % phosphorous (%P) was determined with

Olsen method (Singh et al., 2007). Total element concentration (μg g^{-1}) of fly ash was analyzed after concentrated nitric acid digestion by atomic absorption spectrophotometer AAS-7000 (Shimadzu).

3 Results

In the present study, a sum of 9 plant species belonging to 9 families was reported in 2013 (Table 1), a sum of 18 plant species belonging to 14 families was reported in 2014 (Table 2) and a sum of 29 plant species belonging to 19 families was reported in 2015 (Table 3). The ecological importance of these plant species present in dyke is also given in Table 1, 2 and 3. Maximum of 4 species were from the Fabaceae family followed by Euphorbiaceae and Asteraceae (3 species), Rhamnaceae, Caesalpiniaceae and Convolvulaceae (2 species) and only single species from other families (Fig. 1). Most of the species reported were herbs (62%) followed by trees and shrubs (9 %) and rest species were grasses and tall grasses (Fig. 2). Relative density, relative frequency and relative cover of all the species present in the dyke are shown in Figs 3, 4 and 5 respectively. Relative density reported for *Cynodon dactylon* (25.19) was minimum and minimum for *Butea monospermae* (0.51). Relative cover was maximum for *Ipomea carnea* and minimum for *Solanum xanthocarpum*. Importance value indexes (IVI) of these species are given in Table 4. *Cynodon dactylon* (37.25) was having maximum IVI value followed by *Ipomea carnea* (22.43) and *Cyperus rotundus* (22.18) and least IVI value for *Solanum xanthocarpum* (4.116).

Table 1 Phytodiversity on fly ash dyke after 1 year and their ecological importance.

Sl No	Botanical name	Family	Habit	Ecological importance
1	*Cynodon dactylon*	Poaceae	Grass	++
2	*Cassia tora*	Caesalpiniaceae	Herb	+++
3	*Acacia nilotica*	Mimosaceae	Tree	+++
4	*Ziziphus nummularia*	Rhamnaceae	Shrub	++
5	*Ipomea carnea*	Convolvulacea	Shrub	+++
6	*Cyperus rotundus*	Cyperaceae	Grass	++
7	*Lantana camara*	Verbenaceae	Shrub	+++
8	*Calotropis procera*	Asclepiadaceae	Shrub	+++

Table 2 Phytodiversity on fly ash dyke after 2 years and their ecological importance.

Sl No	Botanical name	Family	Habit	Ecological importance
1	*Cynodon dactylon*	Poaceae	Grass	++
2	*Cassia occidentalis*	Caesalpiniaceae	Herb	+++
3	*Cassia tora*	Caesalpiniaceae	Herb	+++
4	*Desmodium gangeticum*	Fabaceae	Herb	++
5	*Tephrosia purpurea*	Fabaceae	Herb	+++
6	*Butea monospermae*	Fabaceae	Tree	+++
7	*Solanum xanthocarpum*	Solanaceae	Herb	++
8	*Acacia nilotica*	Mimosaceae	Tree	+++
9	*Zizyphus mauritiana*	Rhamnaceae	Tree	+++
10	*Ziziphus nummularia*	Rhamnaceae	Shrub	++
11	*Euphorbia hirta*	Euphorbiaceae	Herb	++
12	*Ipomea carnea*	Convolvulacea	Shrub	+++
13	*Cyperus rotundus*	Cyperaceae	Grass	++
14	*Lantana camara*	Verbenaceae	Shrub	+++
15	*Achyranthes aspera*	Amaranthaceae	Herb	++
16	*Calotropis procera*	Asclepiadaceae	Shrub	+++
17	*Typha latifolia*	Typhaceae	Tall grass	++

Table 3 Phytodiversity on fly ash dyke after 3 years and their ecological importance.

Sl No	Botanical name	Family	Habit	Ecological importance
1	*Cynodon dactylon*	Poaceae	Grass	++
2	*Cassia occidentalis*	Caesalpiniaceae	Herb	+++
3	*Cassia tora*	Caesalpiniaceae	Herb	+++
4	*Desmodium gangeticum*	Fabaceae	Herb	++
5	*Tephrosia purpurea*	Fabaceae	Herb	+++
6	*Butea monospermae*	Fabaceae	Tree	+++
7	*Prosopis juliflora*	Fabaceae	Tree	+++
8	*Solanum xanthocarpum*	Solanaceae	Herb	++
9	*Acacia nilotica*	Mimosaceae	Tree	+++
10	*Centella asiatica*	Apiaceae	Herb	+
11	*Zizyphus mauritiana*	Rhamnaceae	Tree	+++
12	*Ziziphus nummularia*	Rhamnaceae	Shrub	++
13	*Phyllanthus niruri*	Euphorbiaceae	Herb	+
14	*Euphorbia hirta*	Euphorbiaceae	Herb	++
15	*Croton bonplandianum*	Euphorbiaceae	Herb	+++
16	*Ipomea carnea*	Convolvulacea	Shrub	+++
17	*Convolvulus arvensis*	Convolvulaceae	Herb	++
18	*Cyperus rotundus*	Cyperaceae	Grass	++
19	*Lantana camara*	Verbenaceae	Shrub	+++
20	*Achyranthes aspera*	Amaranthaceae	Herb	++
21	*Boerrhavia diffusa*	Nyctaginaceae	Herb	+
22	*Rungia pectinata*	Acanthaceae	Herb	+
23	*Calotropis procera*	Asclepiadaceae	Shrub	+++
24	*Tridax procumbens*	Asteraceae	Herb	++
25	*Ageratum conyziodes*	Asteraceae	Herb	++
26	*Parthenium hysterphorus*	Asteraceae	Herb	++
27	*Leucas aspera*	Lamiaceae	Herb	++
28	*Sida cordifolia*	Malvaceae	Herb	++
29	*Typha latifolia*	Typhaceae	Tall grass	++

'+', add organic matter
'+ +', reduces re-suspension of fly ash by wind
'+ + +', reduces re-suspension of fly ash by wind and add organic matter

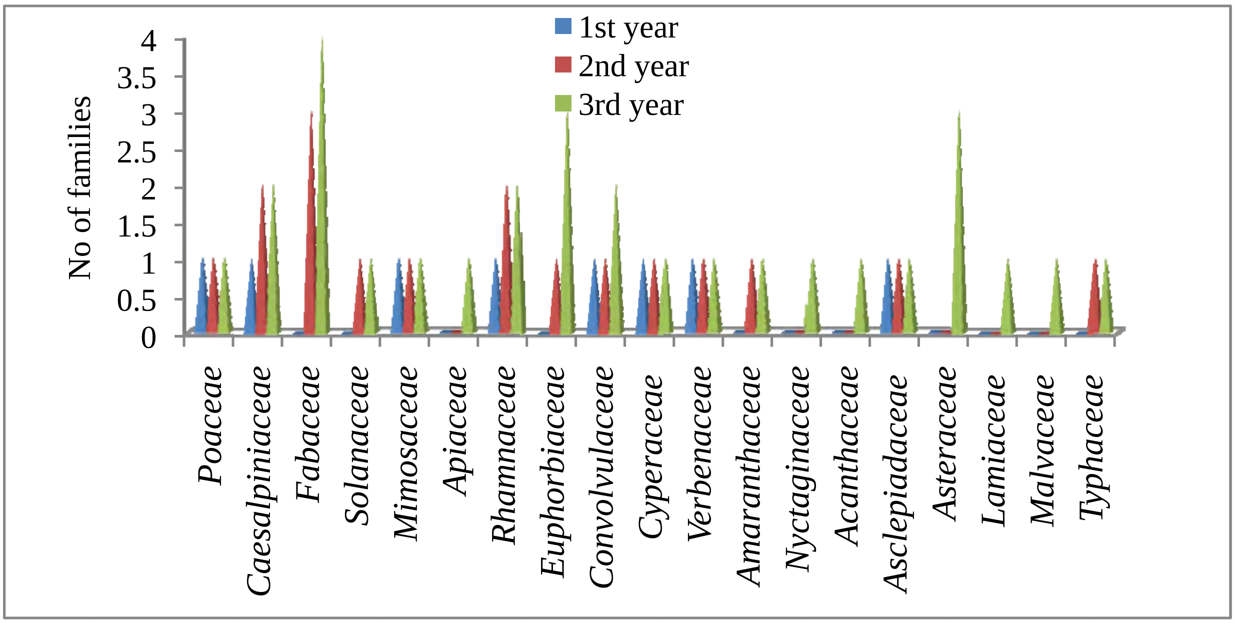

Fig. 1 Graphical representation of number of families that was present in fly ash dyke in different years.

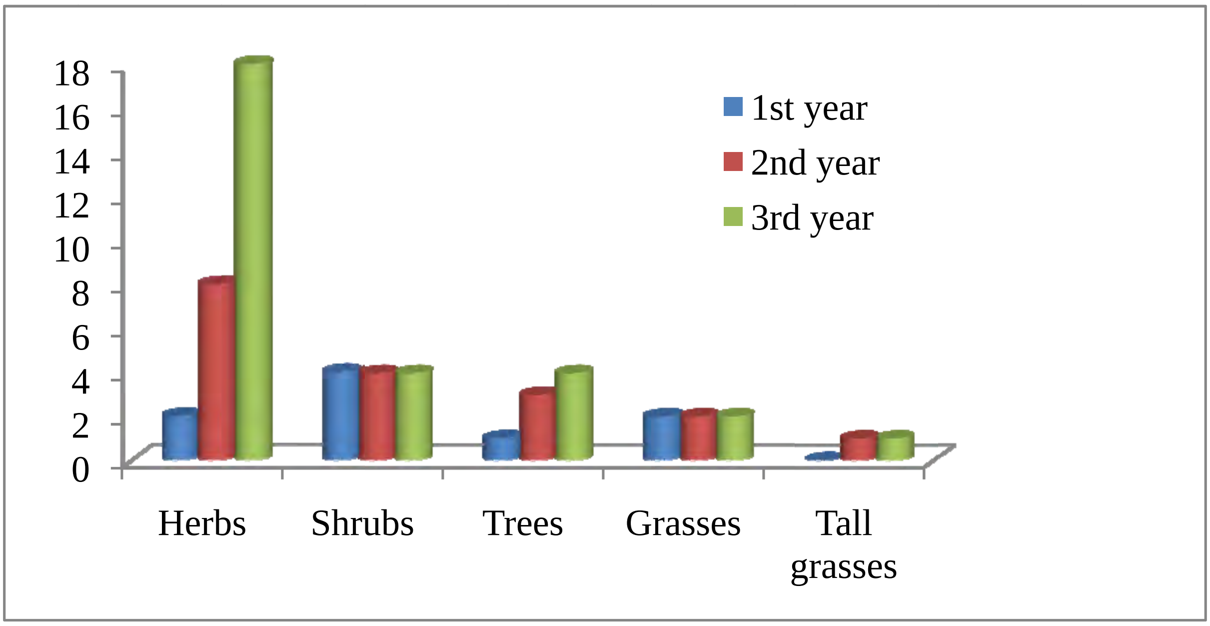

Fig. 2 Graphical representation of number of herbs, shrubs, trees, grasses and tall grass species that were present in fly ash dyke in different years.

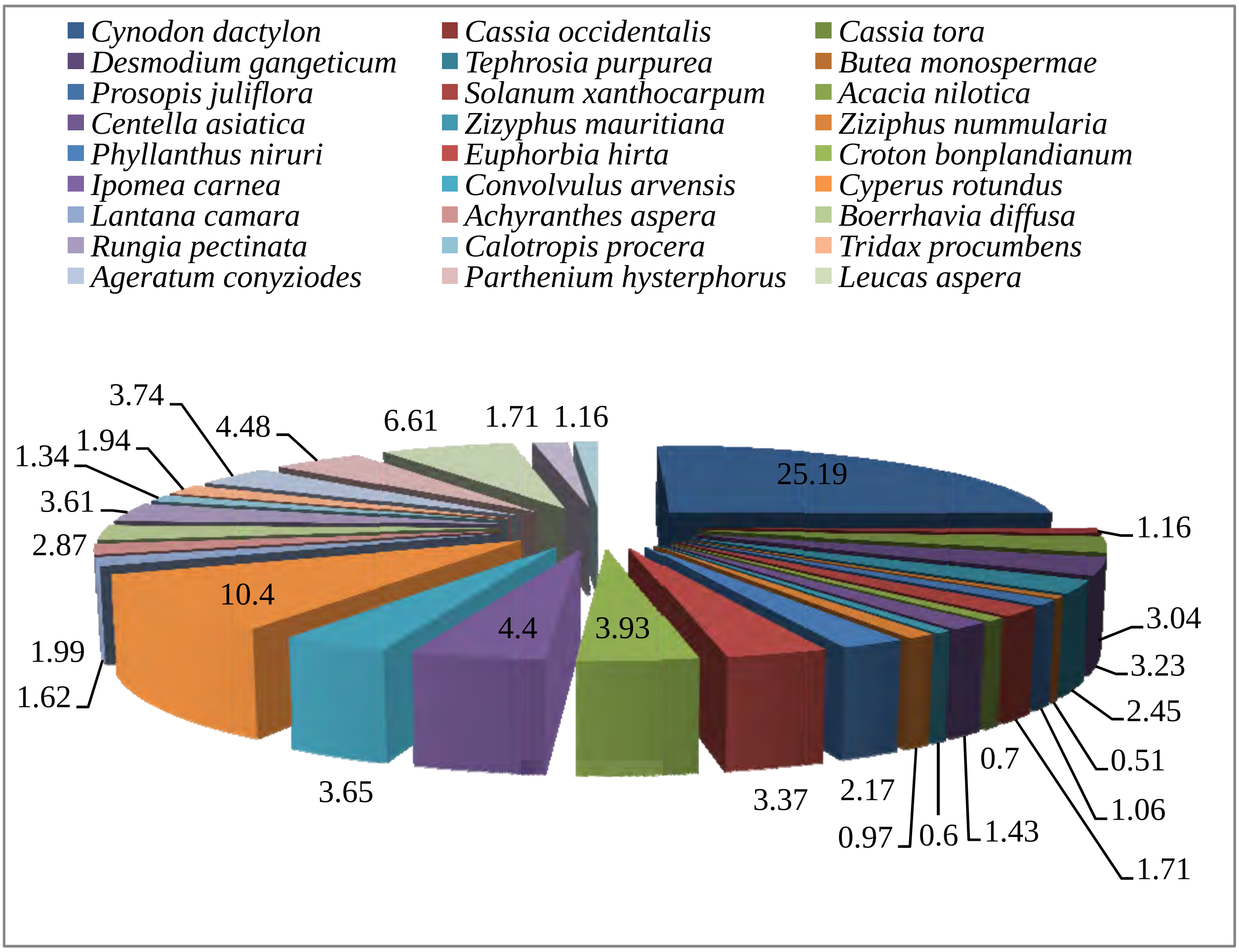

Fig. 3 Relative density of different plant species in fly ash after 3rd year.

Table 4 Importance value index of different plant species in fly ash after 3rd year.

Sl no	Name of plant	IVI
1	*Cynodon dactylon*	37.25
2	*Cassia occidentalis*	9.71
3	*Cassia tora*	11.17
4	*Desmodium gangeticum*	6.45
5	*Tephrosia purpurea*	5.27
6	*Butea monospermae*	6.65
7	*Prosopis juliflora*	8.69
8	*Solanum xanthocarpum*	4.116
9	*Acacia nilotica*	11.32
10	*Centella asiatica*	5.872
11	*Zizyphus mauritiana*	8.7
12	*Ziziphus nummularia*	11.02
13	*Phyllanthus niruri*	8.066
14	*Euphorbia hirta*	8.01
15	*Croton bonplandianum*	11.91
16	*Ipomea carnea*	22.43
17	*Convolvulus arvensis*	11.26
18	*Cyperus rotundus*	22.18
19	*Lantana camara*	8.18
20	*Achyranthes aspera*	8.45
21	*Boerrhavia diffusa*	7.65
22	*Rungia pectinata*	7.13
23	*Calotropis procera*	8.4
24	*Tridax procumbens*	5.39
25	*Ageratum conyziodes*	7.19
26	*Parthenium hysterphorus*	11.84
27	*Leucas aspera*	12
28	*Sida cordifolia*	7.09
29	*Typha latifolia*	7.29

The fly ash contained various heavy metals in varied concentrations (Table 5). Table 5 indicates that after the growth of plants for one year in the dyke, the metal concentration was significantly reduced in the fly ash. The changes in physico–chemical characteristics of fly ash after plant growth are shown in Table 6. It is clear from the table that WHC and porosity of fly ash was increased and bulk density reduced. % organic carbon and % available phosphorus content also increased in fly ash. In other words it can be said that there was improvement in the fly ash physic-chemical properties and it can be mixed with soil for agriculture purposed.

Table 5 Heavy metal concentration (μg g^{-1} of materials).

Metals	Fresh fly ash 1st year	Fly ash after growing season 2nd year
Fe	33.02	13.3
Zn	1.402	0.30
Pb	0	0
Cd	0.082	0.06
Mo	4.49	0.60
Cu	0	0
Cr	0.213	0.05
Co	0.176	0.05
Ni	0.127	0.01
V	3.98	0.55

Table 6 Physico–chemical characteristics of fly ash before and after plant growth.

		Fly ash before plant growth	Fly ash after 2nd year
Physical properties	WHC (%)	40	54
	Porosity (%)	67	71.5
	Sand (%)	37.5	35.5
	Silt (%)	50	48.5
	Clay (%)	12.5	16
	Texture	Silty loam	Silty loam
	BD (g/cm)	0.98	0.92
Chemical properties	pH	7.65	7.2
	EC (mmhos/cm)	0.655	0.505
	OC (%)	0.35	0.51
	P (%)	0.04	0.051

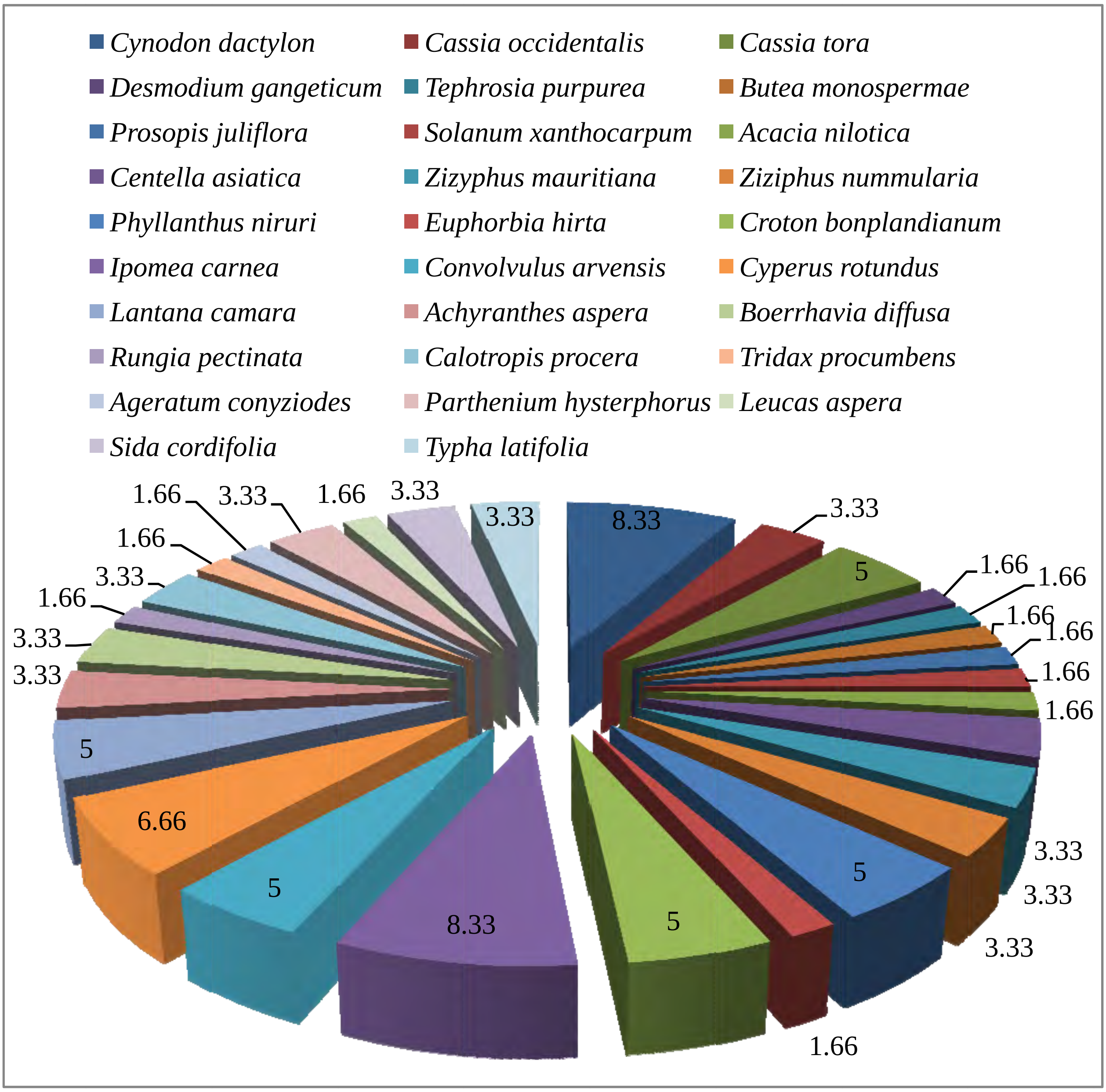

Fig. 4 Relative frequency of different plant species in fly ash after 3rd year.

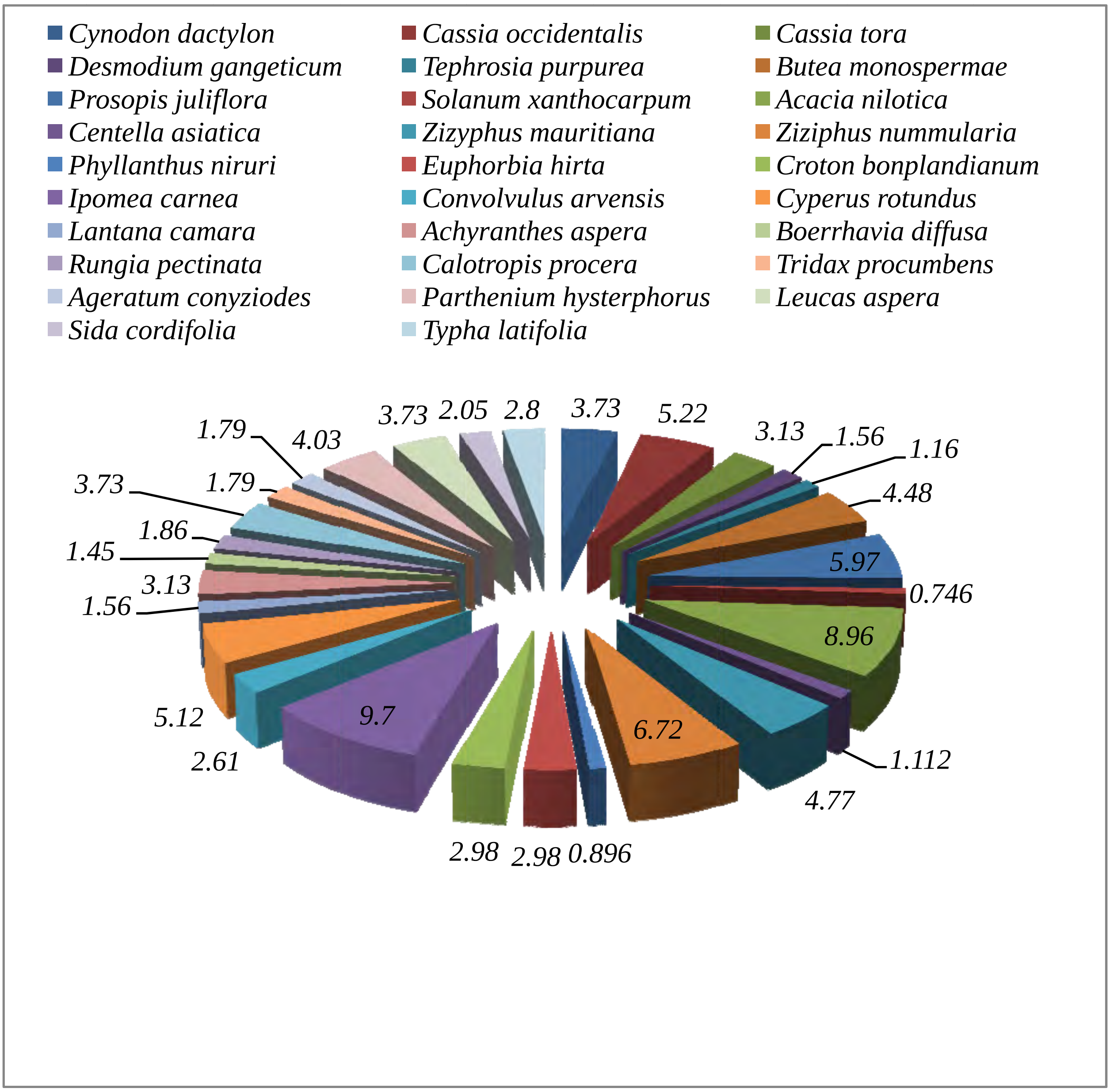

Fig. 5 Relative cover (relative dominance) of different plant species in fly ash after 3rd year.

4 Discussion

The growth of different plant species on fly ash dyke which is a disturbed site is somewhat similar to secondary ecological succession because the area is barren and it is having sufficient nutrients for plant growth. The substratum was having low WHC and porosity and also less availability of organic carbon and available phosphorus. Initial floristic composition model of succession of Egler (1954) can be used for explaining the colonization of fly ash dyke. The site may contain seed or propagules of pioneer as well as late successional species that may have come from nearby naturally growing plant species. Since the site is disturbed, first it was colonized by ruderal species such as *Ipomea carnea*, *Cynodon dactylon*, *Calotropis procera* and later on by stress tolerant species such as *Ziziphus nummularia* (Haynes, 2009).The death and decay of plant/plant parts of ruderal species improved the physic-chemical properties of fly ash such as increased WHC and porosity, reduced bulk density and increased availability of organic carbon and phosphorus. Increased WHC with low BD of coal fly ash makes it a suitable soil amending agent because amended soils have the tendency to reduce BD, increase soil porosity as well as WHC with improvement in soil texture (Sharma and Kalra, 2006; Mahale et al., 2012). Increase in essential plant nutrient availability by fly ash further leads to increase in plant growth and biomass production (Kishore et al., 2009). The growth of plant on dyke considerably reduced the metals concentration in fly ash and improved the environment leading to further growth of more plant species (Chiu et al., 2006).

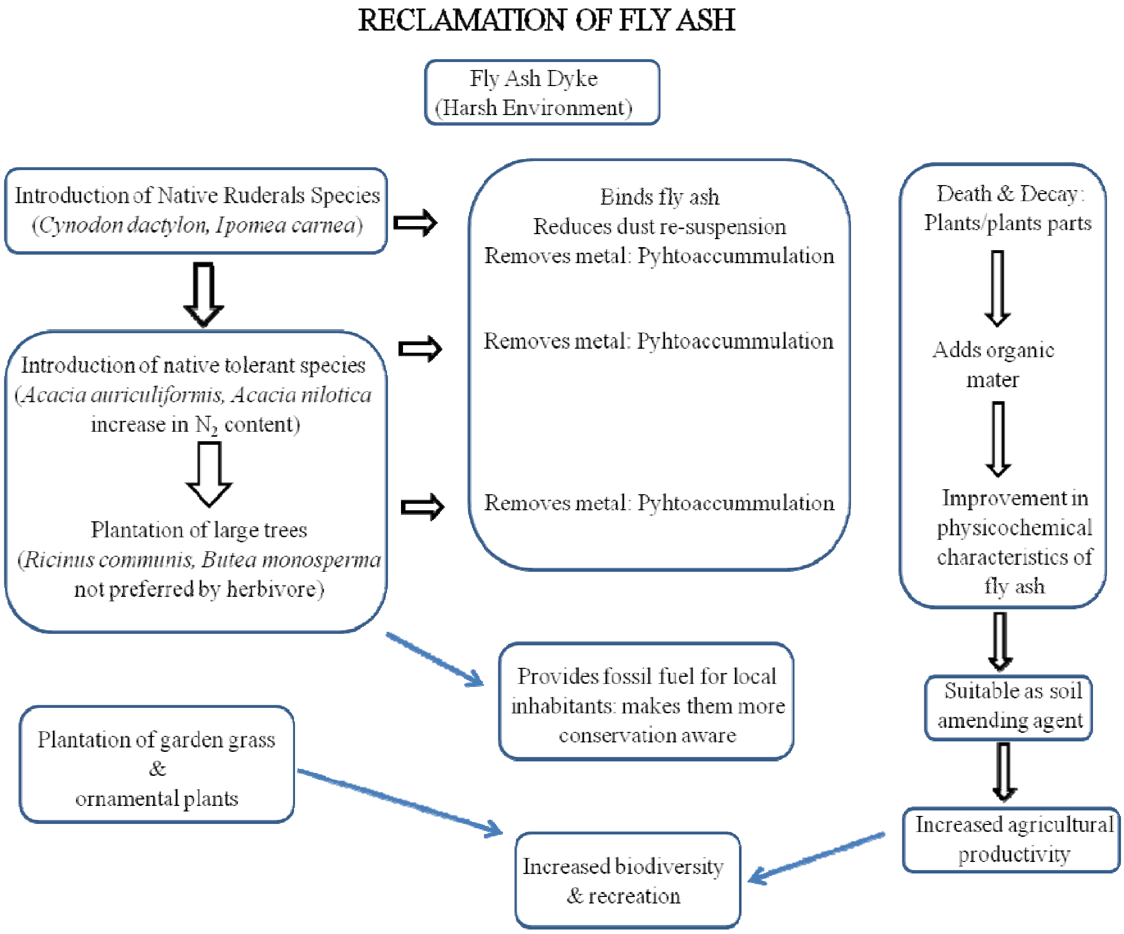

Fig. 6 Possible mechanism for the reclamation of fly ash dyke.

The growth of plant species such as *Desmodium gangeticum*, *Prosopis juliflora*, *Butea monospermae* and *Tephrosia purpurea* of Fabaceae family on dykes helps in nitrogen fixation and therefore increases N_2 content in the fly ash. Presence of mycorrhiza in the roots of different plant species such as *Parthenium hysterophorus* increases the P content of fly ash (Orwa et al., 2009). This may cause growth of competitor species and soon they were able to colonize the dyke as the environment became favorable for them (Connell and Slatyer, 1977). The type of plant species and there number increased during study period leading to higher diversity of plants by the end of third year. The presence of grasses such as *Cynodon dactylon* and *Cyperus rotundus* helps in binding the fly ash particles because of their extensive root system, and prevents their re-suspension in the environment and thus prevent particulate pollution (Sharma et al., 2005).

The present study showed that fly ash generated from coal fired thermal power plants is an important source of heavy metals. These metals can pollute the surrounding environment of the dyke. The growth of native plant species over a period of time on dyke was able to reduce the metal contamination of fly ash. The plant species were also able to modify the physico-chemical characteristics of the fly ash and made it suitable soil amending agent. The possible mechanism by which fly ash dykes can be reclaimed in a sustainable way is shown in Fig. 6. Therefore, it can be said that native plant species can be used for the reclamation of fly ash dyke for agricultural purposes and reduce the dust problem of fly ash.

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