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## The Prospects of Fly Ash Utilization as a Source of Soil Amendment and its Effects on Properties of Soil - A Review

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**Abstract:** Fly ash, a coal combustion residue collected from flue stacks of coal burning power plants, is generally disposed near the thermal power plant. Disposal of fly ash on land using faulty practices causes land degradation and soil erosion. To use fly ash in environmentally sound manner, the most possible and suitable option is to use it as a soil amendment as it improves the physical, chemical and biological characteristics of soil due to its pozzolonic nature. As it is rich in macronutrients and trace elements it can be utilized as a soil ameliorant to recover the soil characteristics & fertility of degraded lands. Its alkaline nature and silt size particles make it a suitable additive for degraded land. It improves texture & water holding capacity of degraded land because of presence of silt sized particles. It increases moisture retention & available water capacity in degraded soils. Besides this, as a soil additive it can be used in wasteland reclamation, reclamation of acidic mine spoil and to enhance carbon sequestration on degraded land. This article explores possibilities of utilization of fly ash as a source of soil amendment in various attributes and its effects on various characteristics of soil.

**Keywords:** Fly ash, soil amendment, prospects, utilization, effects

### I. INTRODUCTION

Combustion of bituminous coal in thermal power plants results into a finely divided residue known as fly ash (Tripathi and Sahu, 1997). This fly ash contains various minerals but most of the fly ash contains non crystalline ferro-alumino-silicate glassy particles (Qafoku et al., 1999). In India, majority of coal based power plants generate fly ash on a large scale every year (Sharma, 1986). India generated 340.11 million tones (MT) of fly ash in 2024-25 of which 332.63 MT was utilized across infrastructure and industrial sectors (National conference on fly ash utilization organized by NTPC, 2025), with 98% used in industries like cement and bricks. Dumping of huge amount of fly ash is a major difficulty for the thermal power plants in India. This fly ash is generally disposed on land near to the thermal power plant premises. It is estimated that around sixty six thousand acres of land generate ash ponds. Such a huge amount of waste if

not utilized properly may result into generation of huge dumps of fly ash near the power plant resulting into soil erosion and other adverse effects on environment (Jambhulkar and Juwarkar, 2009). In India, approximately only 5 percent of fly ash is used while rest of the fly ash residues are unused interacting with the environmental matrices. Therefore, such an enormous quantity of waste needs to be managed in a sustainable manner.

Generally, the pH of fly ash is alkaline having pH; 9-11 (Jambhulkar & Juwarkar, 2009). Since it is alkaline in nature and also contains mineral substances therefore it is utilized to recover the physico-chemical characteristics of soil (Yeledhalli et al, 2007). Since fly ash possesses silt size particles it helps to improve physico-chemical properties of soil. These silt sized particles, increases micro porosity and improve water retention capacity in sandy soils and thus alter the soil texture permanently (Ghodrati et al, 1995). It is also

used instead of top soil in mine spoil dumps, because of occurrence of silt size particles and thus improves properties of soil (Adriano and Waber, 2001). Fly ash is used as an amendment in problem soils to increase pH in acidic soil and to develop soil structure (Carlson and Adriano, 1993). Fly ash can also be used in wasteland reclamation, in problem and nutrient deprived soils and to enhance carbon sequestration potential on degraded lands.

Several attempts have been made to utilize this waste as an amendment to improve soil quality that may be useful for soil conditioning. On the other hands, the presence of toxic metals such as Ni, Cr, Cd and Pb etc. raised doubts to use fly ash for soil amelioration. These toxic metals are generally reported to be present in un-weathered fly ash (fresh fly ash). But as the fly ash starts weathering the toxicity of these toxic metals slowly starts declining and therefore it is the weathered fly ash which is utilized as a soil amendment in most of the field experiments and for reclamation of mining wastelands. Fly ash also contains trace elements like Lanthanum (La), Terbium (Tb) and Cobalt (Co) (Adriano et al., 1980). Besides these it also possesses Boron (B), Calcium (Ca), Molybdenum (Mo), Sulfur (S), Selenium (Se) and Strontium (Sr) (Page et al., 1979). Due to presence of Carbonates of calcium it is used as a liming agent (McCarty et al., 1994). Presence of cation,  $Ca^{2+}$  and other basic cations helps to improve soil texture and stabilizes soil through cation bridging (Palumbo et al, 2004). Since it stabilizes soil hence it can be used as a soil additive for degraded lands and wastelands.

It is used as a soil additive because the incorporation of fly ash to soil improves soil properties due to its pozzolonic nature. However, its scope to use it as a soil additive sometimes becomes limited due to Aluminium toxicity as an Alumino-silicate complex. (Fulekar and Dave, 1992). But presence of severity of Aluminium toxicity varies from ash to ash and it also depend on what type of coal is used. However, it is noticed that in majority of fly ash, the Aluminum toxicity was found to be within toxicity limits therefore use of such fly ash can be considered as a soil additive. Moreover, utilization of weathered fly ash is suggested since there are remote chances of any toxicity; but before its utilization it is necessary to know the characteristics of fly ash and the soil where it is used as an amendment. However, its accessibility and most qualitative nature of fly ash offer an enormous possibility for it being used in different behavior to successful amendments.

Until now, lot of research work is done to utilize it in agriculture sector to improve vegetation and crop growth, but so far, very little research work is done on what type of fly ash is used in agriculture sector as a soil amendment to boost crop & vegetation productivity. And also whether un-weathered or weathered fly ash is safe to utilize it as a soil amendment. The current article summarizes the possibilities and magnitude of its utilization in different areas as an ameliorant and the recommendations thereof. It also summarizes the exploitation of fly ash for reclamation of degraded lands and its impacts on different properties of soil.

## II. MATERIALS AND METHODS

### Properties of fly ash

#### (i) Physical properties of fly ash

When finely ground coal is ignited at a temperature of 500-1400 °C, the resultant residue so formed is called as fly ash. (Mattigod et al., 1990). Fly ash consists of very fine particles. The fine particles of fly ash have on an average diameter of 0.5 -10µm (Jambhulkar & Juwarkar, 2009). It possesses low bulk density, high surface area and light texture (**Table1**). The fine particle of fly ash consists of micron and submicron spherical particles of 0.02-110 mm size (Davison et al., 1974). The submicron particles are trapped into large particles (Fischer et al., 1976). Fly ash has generally Loam to Silty loam texture (**Table1**). The colour of fly ash is generally grey to black. The color of fly ash depends on coal quality and parent coal. It is reported that light grey colored fly ash has lower content of carbon while dark grey colored fly ash has high carbon content. Generally the colour of fly ash is grey to black (**Table1**).

TABLE 1  
Physical Properties of Fly Ash

Physical properties	Concentration
Colour	Grey to black
Texture	Silty loam ( Chang et al,1977)
Porosity	43.02–55.77% ( Juwarkar & Jambhulkar,2008)
Bulk Density	1.02 -1.7 g/cm <sup>3</sup> ( Jala & Goyal,2006)
Maximum water holding capacity	60.40 % (Yeledhalli et al,2007)
Specific gravity	2.0 to 2.5 g/cm <sup>3</sup> ( Natush &Wallace,1974)
Surface area	160 –900 m <sup>2</sup> /kg (ASTMC 204 specification)
Mean particle density	2.7 – 3.4 g/cm <sup>3</sup> ( Natush &Wallace,1974)
Average pore volume	0.005 – 0.043 cc/g (Amonette et al,2003)

#### (ii) Chemical properties of fly ash

Majority of fly ash are alkaline in nature, since it possesses high pH which varies from coal to coal. It is also based on sulphur content in coal (Carlson and Adriano, 1993). Variation in pH is attributed to sulphur content in parent coal. (Jambhulkar & Juwarkar, 2009). Thus, fly ash containing low percentage of sulphur is alkaline (Gupta and Sinha, 2008). Presence of high percentage of sulphur gives acidic fly ash. Since fly ash possesses most of the hydroxides of different elements it bears alkaline fly ash as observed in Indian fly ashes. (Mishra and Shukla, 1986). (**Table 2**)

Electrical conductivity of fly ash is dependent on parent coal and the amount of dissolved salts. Electrical conductivity is more in alkaline fly ash while less in acidic fly ash (Yeledhalli et al, 2007). Generally, the electrical conductivity in un-weathered fly ash was reported to be 4.32 mS/cm (Juwarkar and Jambhulkar, 2008) (Table 2). Un-weathered fly ash contains more dissolved salts and thus high electrical conductivity. (Biliski et al, 1995). Organic carbon in fly ash depends on the origin of the parent coal whether it is bituminous or sub-bituminous. The organic carbon content in fly ash reported by Gupta and Sinha, 2008 was 1.70% while 1.12% organic carbon was reported by Juwarkar and Jambhulkar, 2008 and 1.17% by Tripathi et al, 2004. (Table 2).

TABLE 2  
Chemical Characteristics of Fly Ash

Chemical properties	Concentration
pH	8.70 (Rai et al, 2004)
Electrical conductivity	4.32 mS/cm (Juwarkar & Jambhulkar, 2008)
Organic carbon %	1.12 (Juwarkar & Jambhulkar, 2008)

### (iii) Radioactive elements, heavy metals and trace elements

Generally, in Indian fly ash radioactive elements are not observed (Zielinski and Finkelman, 1997). Although radioactive elements are not observed in fly ash but in few fly ashes derived from coal power plant, Thorium and Uranium were found and emission of Thorium and Uranium were estimated to be ~ 44.351 Terabecquerel (TBq) and ~ 41.089 TBq respectively in the environment (Mishra et al, 2023). Indian coal generally do not have radioactivity and even if it is present it is not harmful. Therefore such fly ash can be used as a soil ameliorant, but before using it as a soil ameliorant presence of radioactive elements should be tested for good results. Central Fuel Research Institute, Dhanbad observed there is no harm in using fly ash for application to soil since no adverse results were reported in soil as well as on plant growth.

Fly ash is enriched with major elements but their concentration is generally found to be low as compared to soil (Table 3). Fly ash contains trace concentrations of many heavy metals, minor and trace elements. These include Ni, V, As, Cd, B, Cr, Mo, Zn, Pb, Hg, Se, U & Th (Table 4).

### Composition of fly ash

Generally, fly ash consists of oxides of Silicon, Iron, Aluminium, and Calcium. Approximately, 0.7 to 4.0 % consists of Sodium, Phosphorus, Potassium and Sulfur while the remaining ash comprises of trace elements. On an average, 85 – 95 % of fly ash contains Silicon, Aluminium, Iron, Calcium, Magnesium, Sodium, Potassium Cadmium, Lead, Cobalt, Copper, Manganese, Molybdenum, Nickel, Zinc

and Boron (Gupta et al, 2002). Fly ash differs in its chemical constituents based on the parent coal from which it is generated. Fly ash is generated from three types of coal viz. bituminous, sub-bituminous, and lignite (Table 5).

TABLE 3  
Major Elements in Fly Ash, Coal and Soil (Page et al, 1979)

Major Elements,%	Fly ash	Coal	Soil
Al	0.2-17.4	1.3	3-29
Si	1.43-27.8	2.5	24-32
Ca	0.12-23.1	0.53	0.8-51
Fe	2-28	1.5	0.07- 0.61
Mg	0.03-7.5	0.13	0.03-3.1
Na	0.02-2.10	0.05	0.04-2.8
K	0.16-3.4	0.17	0.05-3.2
S	0.2-1.4	2.1	0.02-2.1
P	0.03-0.7	0.04	0.006-0.3
N	--	1.2	0.02-0.9
Ba	0.012-1.1	0.014	0.02-0.4
Sr	0.05-0.38	0.011	0.04-0.5

TABLE 4  
Minor and Trace Elements in Fly ash, Coal and Soil (Page et al, 1979)

Minor & Trace Elements, mg/kg	Fly ash	Coal	Soil
As	2.1- 6302	16	0.2-39
B	11- 619	51	3-101
Cd	0.8-131	1.4	0.02-7.1
Co	8-521	7.1	2-39
Cr	11-1001	16	6-3001
Cu	15-2801	18	1-101
Hg	0.03-1.1	0.9	--
Mn	58.2-3001	99	99-4001
Mo	7.1-161	3.1	0.3-5.1
Ni	6.2-4301	16	11-1001
Pb	3.0-5001	15	3-99
Sb	0.7-203	1.2	0.7-11
Se	0.3-133	4.2	0.2-2.1
Th	14-67	1.3	1.8
U	0.7-18	1.7	19-251
V	51-5001	19	--
Zn	11-3501	38	11-301

### Fly Ash Generation & Utilization

It is reported that (Annual Report of Central Electricity Authority 2021,22) that in 2021-22, nearly 270.82 million tones of fly ash was generated in 200 thermal power plants and 95.95% (259.86 million tonnes) was utilized in various sectors. It is projected that in India the fly ash production may increase to 600 million tones/year by 2031-32. (Chandrakant et al, 2024).

As per the notification of MoEF and CC dated 31<sup>st</sup> December 2021, each power plant is responsible for utilizing 100% fly ash generated during the year and if the utilization is below 80%, under such circumstances, a power plant is required to achieve average utilization of 100% in a three year life cycle (MoEF and CC,2021).

TABLE 5  
Types of Coal and their Chemical composition  
(Expressed as percent by weight)  
[ASTM C618-92 Standard specification, 1994]

Component	Bituminous	Sub-bituminous	Lignite
SiO <sub>2</sub>	21-62	39-61	16-44
Al <sub>2</sub> O <sub>3</sub>	6-37	21-31	11-26
Fe <sub>2</sub> O <sub>3</sub>	11-42	5-11	5-16
CaO	0.9-1.0	6-31	16-41
MgO	0.02-0.5	2-7	4-9
SO <sub>3</sub>	0.02-0.4	0-3	0.1-9
Na <sub>2</sub> O	0.06-0.4	0-3	0.1-7
K <sub>2</sub> O	0.03-0.3	0-2	0.1-5

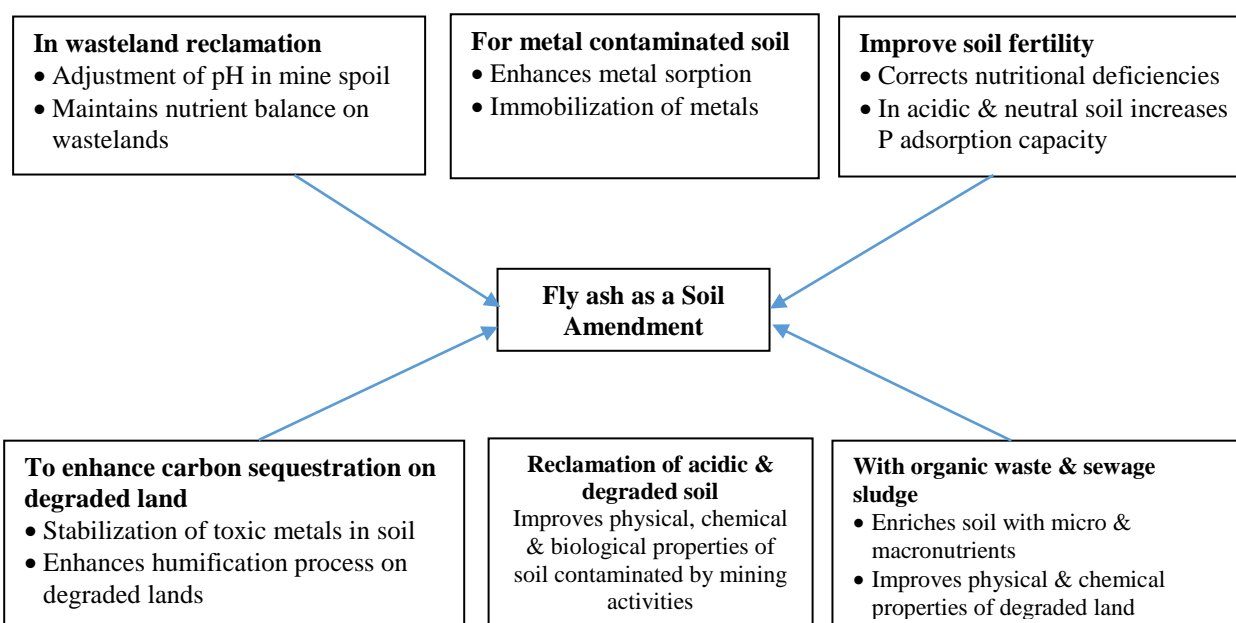


Fig.1. Possibilities of Fly Ash Utilization as a Soil Amendment

**(ii) Carbon sequestration potential on degraded lands**

Degraded lands, which are characterized by acidic pH, devoid of nutrients, low humus content, poor soil structure and

LOI	0-14	0-4	0-6
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**Possibilities of Fly Ash Utilization as a Soil Amendment**

**(i) Wasteland reclamation**

Fly ash is generally disposed as wet slurry and is passed through pipes where it is collected in a slurry form forming ash ponds. These ash ponds occupy majority of land near thermal power plant (Jala and Goyal, 2006). In India, it is observed that 36,000 hectare of land has been occupied by ash ponds (Jamwal, 2003). Many possibilities to use fly ash in bulk have been investigated. But the best option was considered to use it for land application (Adriano and Weber, 2001). During coal mining millions of hectares of land became wasteland. These wastelands form mine spoil overburden dumps and pollute the environment in nearby vicinity of mining areas. In this regard fly ash can be used for stabilization of mine spoil overburden dumps (Capp and Gillmore, 1973). Fly ash is utilized for reclamation of acidic mine spoils and alkaline wastelands (Jala and Goyal, 2006) (Fig.1). Only weathered fly ash can be used to neutralize acidic mine spoils. If un-weathered fly ash is used it increases the soil salinity (Jala and Goyal, 2006). Therefore, use of weathered fly ash is recommended along with some organic amendments having high organic matter content. Moreover, organic amendments such as poultry bio solid, sewage sludge, and farm yard manure/cow dung manure and animal waste can be used in restoration of degraded land (Juwarkar & Jambhulkar, 2008; Punshon et al, 2002). These organic amendments were found to improve soil fertility with no adverse effects on nutrient status of soil.

low level of moisture; offer the possibility for carbon sequestration using fly ash as an amendment material (Palumbo et al, 2004). Fly ash can improve these adverse conditions through, direct or indirect contribution of nutrient elements to soil and stabilization of toxic metals in soil. Fly ash combined with its cenospheric shaped particles and high level of metal oxide content especially oxides of Iron can be used as an amendment to enhance the humification process on degraded lands (Amonette et al, 2003). Nanometer sized pores; high alkalinity is responsible for its beneficial use for carbon sequestration. (Palumbo et al, 2004). Fly ash improves soil texture; soil moisture, improves nutrient status of soil and thus the required amount of nutrients are made available to plants. Nutrient availability to plants leads to more biomass and vegetation production capturing more organic carbon in plant biomass. Thus utilizing fly ash as an amendment the stability of the degraded lands can be restored and carbon sequestration potential can be enhanced. (Palumbo et al, 2004). These stabilized reclaimed dumps in long run forms terrestrial ecosystem which then acts as a sink for stabilization of greenhouse gases to safe levels in the atmosphere.

### **(iii) Reclamation of acidic and degraded soils**

The Space allocation Centre (SAC) of ISRO reported that 97.85 million hectares of land in India were degraded in the year 2018-19 accounting for about 29.77% of the country's total land area. The primary factors contributing to land degradation in India include soil erosion by water and wind, intensive rainfall, loss of vegetation cover and indiscriminate use of fertilizers. Efforts have been put forth for the development of such types of land using organic amendments such as paper mill sludge, municipal sludge, bio-solids and oil sludge from oil industry etc. But due to limited availability their applications on large scale is restricted. Such types of degraded land can be made fertile using fly ash as a soil ameliorant due to its easy availability. Fly ash contains essential plant nutrients therefore it can be used for ameliorating degraded lands and wastelands. Besides this it can also be used for neutralization of acidic soils which in turn improves properties of soil. Mine spoil overburden dumps, acid mine drainage and mine tailings from mining activities pollutes the nearby land ecosystem due to presence of toxic metals in them. In this area fly ash can be utilized. Thus; fly ash improves properties of soil contaminated by mining activities.

### **(iv) Metal contaminated soils**

Fly ash having high pH around 9-11 can be used for recovery of metal contaminated soils. (Kim et al, 2012). The study was conducted for soil contaminated with Lead (Pb) and Copper (Cu). It was found that fly ash could stabilize this contaminated soil. The reduction percentage in leaching of Cu and Pb was found to be 95% and 98% in laboratory batch experiment and by 95% and 96% for field experiment (Kim et al, 2012). The amendment of fly ash reduced the exchangeable metal forms and enhanced metal sorption. Fly Ash helps in metal immobilization too (Jambhulkar & Juwarkar, 2009). Since fly Ash possesses oxides of different elements such as

Al, Si, Fe, Ca, Mg etc it is capable of retaining metals (Pan et al, 2003). Thus fly ash increases metal sorption by raising soil pH, supplying metal sorbents such as silicon oxide and Aluminium oxide (Bertocchi et al, 2006).

### **(v) Soil fertility**

As fly ash is rich in P, K, Ca, Mg, Mn, Zn, carbonates and bicarbonates therefore its application to soil results in increase in Phosphorus adsorption and Phosphorus retention capacity of soil (**Fig.1**). Fly ash corrects plants nutritional deficiencies with respect to P, Mg, Mo, P, S and Zn. Fly Ash and acidic soils possess Phosphorus fixation ability hence mixing of both solved the Phosphorus fixation problem (Saraswat & Chaudhary, 2015). When fly ash was applied to soil planted with oil seed crops improvement in the fertility status of soil was observed (Saraswat & Chaudhary, 2015). Nutrient deficiencies of soil were corrected by direct addition of fly ash through pH corrections (Saraswat & Chaudhary, 2015).

### **(vi) Organic waste & sewage sludge**

Lot of research work has been done on blending of fly ash with various types of organic and inorganic materials such as gypsum, animal manure, poultry waste, sewage sludge, compost, pressmud etc. for land reclamation purpose (Punshon et al, 2002). Blending of fly ash with these materials were reported to enhance nutrient availability in soil, pH buffering capacity, organic carbon addition, microbial properties of soil and overall general health of soil (Punshon et al, 2002). Fly ash gives positive results on soil application after blending with these materials rather than when fly ash is used as such (Punshon et al, 2002).

Organic wastes in conjunction with fly ash were reported to increase the macronutrient content in soil (Garau et al, 1991). However, when alkaline fly ash is used in combination with organic wastes as a soil amendment, the liming effect of fly ash decreases soil pH, due to decomposition of organic wastes (Palumbo et al, 2004). Blending of fly ash with organic material can enrich the soil with macro as well as micronutrients. Rautaray et al, 2003 noticed that fly ash along with organic wastes improved soil properties with respect to pH, organic carbon and available Nitrogen, Phosphorus and Potassium. Mixture of animal waste and fly ash is a rich source of trace elements (Schumann, 1997). Poultry litter along with fly ash was used for degraded land which in turn improved the physical properties of soil, organic matter content & increased the Ca, Mg, P & K content in surface soils (Punshon et al, 2002). Sewage sludge is the best organic amendment in combination with fly ash. Both contain useful nutrients hence their application to soil brings encouraging results (Shaheen et al, 2014). Utilization of both can alleviate land disposal problems otherwise land will get contaminated since they are produced in large quantities.

### **(vii) Fly ash utilization with biochar**

The co-application of biochar with fly ash can produce composite amendments that enhance pH buffering capacity,

nutrient availability and pollutant immobilization (Feng et al, 2025). Since biochar is a carbon rich substance it enhances soil structure and immobilize heavy metals. Biochar can stabilize the toxic elements in industrial waste such as fly ash (Feng et al, 2025). Due to its unique physico-chemical properties such as large specific surface area, high carbon content and well developed pore structure biochar has been widely studied for application in soil amendment, green house gas mitigation and carbon sequestration (Rizwan et al, 2016). The co-application of bio char and fly ash can immobilize heavy metals released from industrial waste, reducing environmental risk. On the other hand, the inorganic nutrients abundant in industrial waste can enhance the nutrient content and improve the potential of biochar. This synergistic application helps to lower soil improvement costs and promotes resource recycling, achieving a win-win outcome for both environmental and economic benefits (Feng et al, 2025). Bio char has been shown to effectively inhibit the volatilization of potentially toxic elements like As, Cd, Pb, Cr and Zn in fly ash through surface oxygen functional groups of biochar adsorb and fix toxic elements via change interaction biochar provides a stable carbon source, increasing the fixed carbon pool and promoting the precipitation of toxic elements (Yousaf et al, 2017). Fly ash as a soil amendment, serves as a catalyst when used in combination with biochar, reducing the activation energy during the pyrolysis process, increasing gas production and improving the water retention properties of biochar simultaneously (Yang et al, 2025).

## **Effect of Fly Ash Amendment on Soil Properties**

### **Effect on Physical Properties of Soil**

#### **(i) Maximum water holding capacity**

Although fly ash do not retain water, but still it improves water holding capacity of the soil (Chang et al, 1977). When fly ash was used as an amendment the water holding capacity of sandy and loamy textured soils increased by 10 % (Chang et al, 1977). Field experiments conducted on fly ash application on lateritic sandy loam soil by Sahoo and Kar in 1997, have reported that application of fly ash at the rate of 12 Mg ha<sup>-1</sup> improved the maximum water holding capacity of the soil considerably. Ghodrati et al, 1995 studied effect of fly ash (0, 5, 10, 20, 30 and 40%) for amending loamy sand and the coarse textured soils with low moisture holding capacities in soil columns and observed that soil water holding capacity increased from 9 to 24% in the soil amended with 25% fly ash.

Presence of silty loam texture in fly ash helps to improve the water retention capacity of soils. Since fly ash has a good surface area and pore space volume it improves the capacity of the soil to hold water. Because fly ash possesses low bulk density and thus high porosity it helps to create more space in soil (Sikka & Kansal, 1994). Amendments of soil with fly ash @ 250-850 T/ha improved the water holding capacities of soil by 25 % (Chang et al, 1977). It was observed that there was increase in available water in ash content for sandy and sandy loam textured soils (Kalra et al, 2000). This change in

available water is related to increase in capillary pores, which ultimately lowers the porosity of soil.

#### **(ii) Bulk density**

Presences of silt sized particles in fly ash have great influence on bulk density of soil (Gupta et al, 2002). Bulk density of soil reflects on soil texture, soil moisture, dissolved salts and solute movement. Generally, fly ash having very low bulk density can be utilized to adjust the high bulk density of soil (Jala & Goyal, 2006). Generally it is observed that application of Fly ash to soil decreases bulk density and in turn helps to improve porosity and moisture in soil (Page et al, 1979).

Shinde et al., 1995; concluded from a pot culture study that 7.5 percent of slightly alkaline fly ash decreased bulk density of the black cotton soil under groundnut cultivation. Field experiments conducted on fly ash application on lateritic sandy loam soil by Sahoo and Kar in 1998, have reported that the bulk density was decreased when fly ash was applied at the rate of 55 Mg ha<sup>-1</sup>. Chang et al, 1977 conducted experiment on fly ash addition on five types of soil and studied its effect on bulk density and observed that silty clay soil showed an increase in bulk density from 0.87 to 1.09. Campbell et al, 1983 observed increase in soil bulk density when fly ash is added @ 18% (v/v) beyond which it is decreased. Sale et al, 1996 noticed increase in soil bulk density when fly ash was added @ 25% (v/v) but it decreases with time lapse, may be due to presence of cenospheres in fly ash.

#### **(iii) Porosity**

Soil porosity can be the fraction of total soil volume that is occupied by voids filled with water (Gupta et al, 2002). For improving porosity in degraded soil fly ash can be used as a soil conditioner (Oswal, et al 1999). A pot culture study conducted by Shinde et al., 1995 reported that 8.6 percent of slightly alkaline fly ash increased porosity of soil. Fly ash addition at the rate of 2.3, 4 and 9 percent (w/w) decreased porosity in sandy loam soils. The pozzolonic nature of fly ash helps to recover porosity of soil (Adriano and Weber, 2001). Besides this the cenospheric particles of fly ash enhances micro porosity of treated soil (Adriano et al, 1980). The dominance of silt size particles in fly ash may support for aeration, penetration and water release in the treated zone (Adriano and Weber, 2001). Thus, fly ash helps in increasing moisture retention and aeration in poor soils.

#### **(iv) Hydraulic conductivity**

As fly ash is enriched with electrolytes, its application to soil improves hydraulic conductivity (Gupta et al, 2002). Soil hydraulic conductivity was improved even at low rates of fly ash application, but decreased rapidly in case the amount of fly ash exceeded 22 percent for calcareous soil and 8 percent for acidic soil (Cervelli, 1989). Field experiments conducted on fly ash application on lateritic sandy loam soil by Sahoo and Kar in 1998, have reported that the hydraulic conductivity increased when fly ash was applied at the rate of 20 and 50 Mg ha<sup>-1</sup>. Chang et al, 1977 reported increase in hydraulic

conductivity helped in reducing soil encrustation in sandy/loamy soils. Fly ash reduced hydraulic conductivity when added to acidic soils @ 13% and 22 % to calcareous soils (Chang et al, 1977).

#### **(v) Texture**

Fly ash possesses silt size particles and also it is rich in Calcium (Sale et al, 1997). When fly ash is used as a soil ameliorant it modifies the soil texture (Sale et al, 1996). And also it was observed that the texture of silty clay and sandy loam could be changed to loam by fly ash addition. The application of fly ash @ 70T/ha altered the texture of sandy soil to loam (Fail & Wochock, 1977). Presences of silt size particles are responsible for altered soil texture. Direct amendment with weathered fly ash can modify soil texture. This may be attributed to presence of cenospheric nature of fly ash which modifies soil texture (Khan & Khan, 1996).

### **Effect on chemical & microbiological properties of soil**

#### **(i) pH**

It has been reported by Andoh in 1986, that even low applications of fly ash increase the pH of the soil noticeably. The pH of soil gets increased due to alkaline fly ash addition is because of release of hydroxyl ions from fly ash. (Wong and Wong, 1990). Page et al 1979, confirmed this view by adding 8 percent alkaline fly ash to calcareous, as well as acidic soil and observed that the pH of the calcareous soil increased from 8.0 to 10.8 and from 5.4 to 9.9 in the acidic soil. A pot culture experiment conducted by Wong and Wong (1990) led him to conclude that application of 12 percent coal fly ash increased the soil pH from 7.3 to 8.6 and 6.7 to 9.7 in sandy and sandy loam soil respectively. Application of fly ash @8% by weight increases pH from 5.5 to 10 of the calcareous soil (Page et al, 1979). Fresh fly ash has been found more effective to raise soil pH than that of weathered fly ash (Phung et al, 1979).

pH in fly ash depends on what type of coal is used. Its sulphur content is also responsible for acidic or alkaline nature of fly ash. Acidic fly ash is used to bring down the pH of highly alkaline soils while alkaline fly ash is used for reclamation of acidic mine spoils. Since alkaline fly ash is rich in oxides of certain elements present in fly ash, their hydrolysis will automatically increase the soil pH (Sharma, 1989). Therefore, such type of fly ash is useful for application to acidic mine spoils. However, use of its liming potential must be undertaken with caution, since it possesses Boron. Long term effects of Boron are harmful for plants growth.

#### **(ii) Electrical conductivity**

Fly ash contains soluble salts and electrolytes therefore its addition to soil increases electrical conductivity of soil (El Mogazi et al, 1988). Khandkar et al. (1996) conducted pot experiment with un-weathered coal fly ash and reported increase in the electrical conductivity. Fulekar and Dave (1991, 1992) conducted a column experiment with fly ash and found increased electrical conductivity.

Fly ash application to soil considerably increases the electrical conductivity due to increased level of soluble salts (Shreshtha & Lal, 2006). Matsi & Keramidis (1999) noticed an increase of soil electrical conductivity from 0.4 to 2.7 dS/m in red soil when fly ash @50g/kg of soil was added. The incorporation of 60 Tonnes per acre of un weathered fly ash increased soil salinity and also increased the soluble salts of B, Ca and Mg. Kalra et al, 2000 noticed a rise in electrical conductivity with fly ash content in soil mixtures of acidic fly ash. Weathered fly ash has less impact on salinity of soil.

#### **(iii) Nutrient properties of soil**

Fly Ash can be considered as a source of nutrients and trace elements (Jala & Goyal, 2006). Mitra et al, 2005 found that the application of fly ash on nutrient deprived soil improved nutrient contents with respect to Organic carbon, Phosphorus, Potassium, Calcium, Magnesium, Fe, Mn, Zinc & Copper. Fly Ash corrects nutrient deficiency on nutrient deprived soils and degraded lands. Fly Ash has ability to support the availability of soil nutrients to plants by adjusting soil properties especially pH. However, care should be taken while utilizing the fly ash. Fresh (Un-weathered) fly ash addition to soil is avoided because it may create phytotoxicity in long run. Weathered fly ash addition should be considered since weathered fly ash contains nutrients in available form, which are readily available to plants and there are few chances of Phytotoxicity. Before addition of fly ash to soil it should be thoroughly checked with respect to Boron, Mercury and Arsenic toxicity. Besides these, Vanadium, Barium and other radioactive elements such as Thorium should also be checked while utilizing fly ash as a source of soil amendment. Presence of these elements and their concentration varies with respect to type of fly ash (weathered/unweathered) used in the study. And the level of phytotoxicity also varies from which coal, fly ash is derived from. Few weathered fly ash does not possess Boron and Mercury toxicity and even if it is present it is in the permissible limits. Fly ash amendment can increase the concentration of trace elements particularly Selenium. Sometimes Selenium is required as a trace element by few plant species.

#### **(iv) Microbiological properties of soil**

Due to fly ash amendment it was reported by Vallini et al, 1999; that there is an increase in the bacterial and Actinomycetes count and increase in soil dehydrogenase activity. Increased counts of soil bacteria were reported, when it was amended with weathered fly ash. Fly ash when used in combination with sewage sludge as an organic amendment, it was observed that there is increase in microbial activity (Pitchel, 1990 and Pitchel and Hayes, 1990). Application of fly ash with small amount of NPK fertilizers increased the counts of total bacteria, Actinomycetes but decreased the counts of fungi, while the activity of dehydrogenase and urease increased (Yeledhalli et al, 2007). Addition of fly ash to sandy soil and silt loam decreased microbial respiration in soil (Arthur et al, 1984). Also total Bacteria, Actinomycetes and Fungal counts decreased (Pitchel and Hayes, 1990). When 6%

fly Ash was applied to soil there was increase in soil dehydrogenase activity. (Shrivastava et al, 2009).

Some negative results with microbiological properties have been observed when fly ash with excess amount of soluble salt was used. As fly ash weathers the effect of soluble salts decreases. pH and electrical conductivity are two important parameters for microbial activity. Therefore, before application of fly ash it should be thoroughly tested for such parameters.

### Techniques for safe disposal of fly ash into environment

Transportation of fly ash in dry state and slurry should be carried out via pneumatic conveyor belt system and pipelines by using electric pumps which is expected to be safe and reliable method as there would not be ash spills due to the thick concentration or fugitive dust emission and thereby minimizing exposure to the workers as well as environment. However, proper maintenance, monitoring and care should be taken to not physically damage the pipelines. Personnel connected with the operation, inspection and maintenance should be provided with adequate training on regular basis for smooth functioning of the entire process and to create awareness. Care should be taken to not let supernatant slurry water to flow into any stream, nallah and natural or artificial water body where aquatic life persist or used by people. (NEERI Report, 2018).

It is advised to adopt High Concentration Slurry Disposal (HCSD) for fly ash disposal which will lead to thicker concentration of slurry by reduced water consumption for slurry formation leading to faster consolidation of ash into thicker mass and would not subjected to run out and would be highly impermeable. Leaching, erosion would be very less and also fugitive dust will be minimized in HCSD system, because of less water consumption there will be no breaching of ash dyke and thus minimizing the heavy metal transfer into the environment (NEERI Report, 2018). HCSD technique is advocated considering its faster consolidation of ash into thicker mass leading to higher impermeability and minimized leaching of metals including minimization of fugitive dust emission.

## III. RESULTS AND DISCUSSION

### Recommendations to use fly ash as a source of soil amendment

- Addition of un weathered fly ash is not advisable as it may substantially increase the soil salinity
- Large quantity of neutral coal fly ash can be used for reclamation of acidic mine spoil
- Before application of fly ash to soil, Aluminum toxicity should be thoroughly checked since fly ash is a combination of ferro-aluminosilicate complex
- The metal toxicity with respect to Arsenic, Mercury & Boron should be thoroughly checked before its application

- Transportation of fly ash in dry state and slurry should be carried out via Pneumatic conveyor belt system & pipelines using an electric pump which is supposed to be safe method as there would be no ash spills.
- As far as possible fly ash should not be disposed on land in order to avoid soil contamination. It should be stored in dome shaped silos
- Fly ash should be given to the mining companies for reclamation and stabilization of mining wastelands
- Maximum utilization of fly ash can be done along with amendments such as sewage sludge, organic waste, poultry litter, animal manure, pressmud and compost etc. for eroded, degraded land & wastelands.
- For maximum benefit weathered (age old) fly ash utilization must be done in regular practice
- Before utilization of fly ash for field trials laboratory experiments should be conducted and fly ash should be analyzed with respect to radionuclides, heavy metal toxicity and other toxic elements if any
- Lower rate of application of fly ash to soil should be made in practice to avoid toxicity and other issues
- Before its utilization as a soil ameliorant both fly ash and soil should be examined properly with respect to existing climatic conditions
- Toxicity guidelines should be followed for soil and fly ash before its utilization as soil amendment.
- It is necessary to examine the soil before fly ash application with respect to metal toxicity, salinity and other pollutants.
- Laboratory experiments should be conducted to decide the proper dose of fly ash to be applied on soil

### Government of India, policies & programmes for fly ash utilization

- ✓ MOEF has issued a notification (14<sup>th</sup> September, 1999) on promotion of fly ash that people staying within a radius of 50 km from coal or lignite based thermal power plant should utilize fly ash for manufacture of clay bricks or tiles or blocks for use in construction activities with mixing at least 25% of fly ash, bottom ash or pond ash with soil on weight to weight basis ( Dhadse et al,2008)
- ✓ Maharashtra government has made it mandatory for any agency involved in constructing buildings within 50-100 kms from coal or lignite based thermal power plant to use fly ash bricks or blocks or tiles, clay fly ash bricks, cement fly ash bricks or blocks. During 2005-06, fly ash (25.16%) produced from nine Maharashtra based thermal power plants (Nashik, Parli, Koradi, Paras, Chandrapur, Khaperkheda, Bhusawal, Dahanu and TATA) are using fly ash in cement industry, brick kiln manufacturing, landfills, ash based products, agriculture and other activities (<http://mpcb.mah.nic.in>)
- ✓ Technology Information Forecasting and Assessment Council (TIFAC) under Department of Science and Technology (DST), Government of India; New Delhi has started Fly Ash Utilization Programme (FAUP) in 1994

with main objectives to make fly ash a useful by-product to reduce environmental pollution and to reduce land required for fly ash disposal (Dhadse et al,2008).

- ✓ Fly ash generated should be utilized 100% in compliance with the provision mentioned in Fly ash notification by MOEF and CC dated 14<sup>th</sup> September 1999 as amended on 25<sup>th</sup> January, 2016. Thermal power plants should collaborate with cement companies and other forms for bulk utilization of fly ash or else store fly ash in Silos or Domes in dry state so that its physico-chemical property is retained and have to be utilized for many other applications (NEERI Report, 2018).

#### IV. CONCLUSION

Fly ash, a solid waste of thermal power plant can be effectively utilized as a soil amendment due to presence of oxides & hydroxides. As it is enriched with macronutrients & trace elements it has a vast potential to improve the properties of degraded land. Sometimes, use of unweathered fly ash may increase the toxicity & soil salinity therefore number of field experiments have to be carried out in different soils under varied agro climatic conditions to establish optimum doses of fly ash for soil amelioration for better results. Lower dose of application of fly as a soil amendment should be adopted in practice for long term benefits. Also, utilization of weathered (age old) fly ash is suggested since it possesses less toxicity with respect to metals. Generally, fly ash should be used in combination with organic amendments such as organic waste, sewage sludge, cow dung manure, compost, poultry litter, pressmud etc. since it increases nutrient availability in soil, improve pH buffering capacity and also improve microbiological properties of soil. Thus fly ash as an amendment improves overall soil health. As, there are many similarities between fly ash and soil hence application of fly ash as a soil additive should not be considered as an apprehensive practice.

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