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Beneficial and Adverse Impacts of Fly Ash Amelioration on Soil Health: A Review

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Abstract:**Disposal of fly ash is the major environmental issue. Generally, it is disposed near the thermal power plant premises. Disposal of fly ash for long period of time imparts various impacts on soil quality and nearby ecosystem. Adverse impacts include soil erosion, while beneficial impact includes improved nutrient status in nutrient deficit soil; as fly ash possess various types of elements such as Se, Sr, Zn, Mo, Ca, Fe, Mg as well as macronutrients such as P and K along with oxides and hydroxides. Therefore, it can be used to improve the soil health of degraded lands & wastelands as a part of its beneficial characteristics. Fly ash improves physico-chemical, biological properties and fertility status of degraded lands. In this regard, an exhaustive review is undertaken on issues of fly ash amelioration on soil health. Both beneficial as well as adverse impacts along with recommendations of fly ash amelioration to soil are discussed in this article.**

Keywords**:adverse impacts, amelioration, beneficial impacts, fly ash, environmental issue and soil health**

I. INTRODUCTION

Fly ash is generated due to burning of coal from thermal power plants. The residue contains unburned carbon. Generally, fly ash contains amorphous ferroalumino-silicate particles (Qafoku et al., 1999). In India, about 442 metric tons per year of fly ash is generated through majority of thermal power plants which is supposed to increase till the end of the year 2035. Therefore, fly ash management is a difficult task for thermal power plant and is a challenging environmental issue.

Majority of land near thermal power plant gets erodeddue to dumping of fly ash. The main reason for erosion of land is presence of heavy metals. These heavy metals may build up in soil and percolate to the ground water (Lal et al, 2012). Fly ash deposition on soil for prolong time can built up with heavy metals such as Arsenic, Mercury and Boron (Lal et al, 2012). Along with this deterioration of microbial and enzymatic activity of soil is another issue (Gupta, et al, 2002).This is the minor drawback of fly ash utilization. To overcome this problem, several research and development activities have been carried out globally for its safe disposal to progress towards environmentally sustainable practices.

Besides its minor drawbacks fly ash posses important beneficial characteristics too which highlights its utilization for improving soil health. Fly ash has medium bulk density, large surface area and verygood texture. Fly ash can be strongly acidic to strongly alkaline depending on sulphur concentration in coal (Jambhulkar&Juwarkar, 2009). Fly ash consists of iron, aluminium and oxides of silicon as major elements. Apart from this, it also contains appreciable quantity of Ca, Mg and K (Adriano et al, 2002). Aluminium is embedded to alumino-silicate structure (Jala and Goyal, 2006). Since, fly ash possesses high amount of trace elements it improves the properties of degraded land and in turn plant growth.

Improvements in pH are reported when acidic pH fly ash was used to adjust pH for alkali soils (Lal et al, 2012). Application of fly ash to soil showed improvements in electrical conductivity (EC) of the soil by improving the concentration of trace elements in it (Adriano et al, 1980). Similarly, there is improvement in hydraulic conductivity of soil (Gupta et al, 2002). If all conditions are persistently monitored for overall benefit, fly ash can bring remarkable changes in the overall properties and nutrient status of soil (Shrivastava et al, 2009). The enriched nutrients present in fly ash can improve nutrient status, in nutrient deficient soil (Martens and Beachm, 1978). Besides this, fly ash can be used in various attributes such as in wasteland reclamation and as an amendment in problem and nutrient deprived soils. Besides this, fly ash is also used to enhance carbon sequestration potential on degraded lands due to presence of nanometer sized pores and high alkalinity. Other beneficial effects consist of improvement in soil texture and moisture retention capacity of soil.

Although, there are few limitations for applying fly ash on soil but still fly ash poses many beneficial properties such as presence of micro, macro and trace elements. Fly ash releases nutrient elements; thereby improving its pH buffering capacity. Due to presence of trace elements it imparts beneficial effects on soil properties, such as improved water holding capacity, increased porosity, improved pH, improved electrical conductivity (EC) and improved dissolved sulphates, carbonates, bicarbonates, chlorides and essential cations (Matsi and Keramidas, 1999).

Until now, lot of research work is done on its utilization in agriculture sector. Very little research work is conducted on its beneficial and adverse effects on soil health. Adverse impacts include presence of few heavy metals, radionuclides and few organic pollutants while positive impacts include improved soil texture, improved pH, improved water holding capacity and improved electrical conductivity (EC) etc. In order to know its long term impacts on soil quality, an exhaustive review is undertaken in this article which thoroughly covers the impacts of its utilization as an amendment on different aspects on soil health. The aim of the review article is to discuss on its environmental issues with respect to its utilization in terms of its positive aspects and limitations in terms of its negative aspects.

GENERATION OF FLY ASH

Fly ash is an inert residue generated due to burning of coal, in coal combustion boilers and is carried off through flue gases. Generally, it is collected from the flue gas in the collection device known as electrostatic precipitator. When coal is burnt in boiler, two types of ashes are produced i.e. fly ash and bottom ash. Out of these 80% is fly ash, which is a lighter portion and is carried off through flue gases. The fly ash is finer in texture than the bottom ash. Remaining 20% ash i.e. bottom ash consists of coarse portion, heavier in weight than fly ash which settles down at the base of the boiler. Combination of both together forms slurry & is disposed through pipelines to ash ponds.

TYPES OF FLY ASH

The quality of coal is considered with respect to its grade and carbon content. Anthracite is hard coal and high in carbon content with carbon content of above 87%, peat is low in carbon content with carbon percentage of 40% and lignite contain nearly 60 - 70% of carbon while sub bituminous coal contain less than 40% carbon. In India, generally; sub-bituminous coal is used. The concentration of ash present in Indian coal is from 35% to 50%. There are three types of coal ashes obtained and they are

Dry fly ash

Dry fly ash is obtained by burning powdered coal. Dry fly ash is generally fine in texture. It is collected using different types of devices such aselectrostatic precipitator and bag house or cyclones.

Bottom ash

Bottom ash is the coarse, incombustible product of unburnt coal from the combustion process of coal.

Pond ash

Unrecycled bottom ash that is discarded in landfills along with fly ash & water forms slurry which is disposed on land. This is known as pond ash.

DISPOSAL OF FLY ASH

It is carried out through wet slurry process or dry disposal process. The mode of disposal in wet slurry process is carried out in slurry form where ash is deposited at the bottom. The mode of disposal of fly ash in dry disposal method is carried out by storing the ash in suitable area; from where it is collected in landfills. The main disadvantage of both the methods is that huge dumps of fly ash are formed on the land, which pollutes environmental matrices. The fly ash then mixes with the soil and subsequently blocks the ordinary drainage channeland pollutes the groundwater. The tiny particles of fly ash get easily suspended in the air. Therefore, while disposing fly ash on land; due care should be taken.

CHARACTERISTICS OF FLY ASH

Physical characteristics

The physical characteristics of fly ash are based upon the coal quality used as a source, procedure of burning coal and whether the fly ash is new or old. Fly ash generally contains 65-90% of silt loam texture with the particle diameter of 0.01-100µm (Nyambura et al, 2011). Bulk density of fly ash ranges from 1.00 to 1.7 gm cm^{-3} (Jala&Goyal 2006) & water holding capacity of fly ash was found to be 40-60% (Jala&Goyal, 2006). Porosity of fly ash varies from 44.01 - 56.78 % (Juwarkar&Jambhulkar, 2008) while the specific gravity of fly ash varies from 2.0 to 2.5 g/cm^3 (Natush& Wallace, 1974). Average pore volume of fly ash ranges from 0.005 to 0.043 cc/g (Amonette et al, 2003). The surface area of fly ash is 170-1000 m^2/kg. It has silty loam texture due to medium porosity and cenospherical particles (Nyambura et al, 2011). The colour of fly ash is typically grey to black. Light colored fly ashes generally contain low carbon.

Chemical characteristics

Chemically, fly ash is a non crystalline, amorphous ferro - alumino silicate particles. Major elementspresent in fly ash are Si, Al, Fe, Ca, Mg, K, Na, S and P and all exist in the oxidized states (Page et al, 1979). Besides this, it is rich in different types of minerals also. The pH of fly ash may vary from strongly acidic to strongly alkaline (4.5-12.0) in reaction depending on sulphur content in coal. Electrical conductivity depends on the presence of dissolved salts in it. Electrical conductivity in fly ash was found to be 4.20 mS/cm, while the organic carbon was found to be 1.12% (Juwarkar&Jambhulkar, 2008). Cation Exchange Capacity was found to be 8.5 (Cmol/kg), (Gupta & Sinha, 2008). The concentration of carbon percentage in sub bituminous fly ash is lower as compared to bituminous fly ashes.

BENEFICIAL IMPACTS OF FLY ASH AMELIORATION ON SOIL

Impact on physical characteristics of soil

Soils with poor physical properties can be improved with respect to texture, bulk density and water holding capacity when it is amended with weathered (age old) fly ash. Fly ash can be utilized to improve the texture of coarse textured soils since it possess siltcontent. Fly ash can change almost all physical properties of amended soil based on the type of the soil and the quality and quantity of fly ash (Okabe et al, 1986). If the soil is sandy and coarse textured, fly ash addition was found effective in improving the soil texture. Besides this, there is increase in porosity and improvement in bulk density because of presence of silt sized particles of fly ash. The silt sized particles, are responsible for increasing micro porosity; thereby improving the soil texture. The soil texture of degraded and coarse textured soil can be improved usingfly ash. Fly ash also improved the water holding capacity and pH in acidic soil. (Chang et al., 1977, Carlson and Adriano, 1993). Lower application rate at the rate of 65 T ha $^{-1}$ was found beneficial to improve the texture of sandy and clayey soil to loamy texture. Adriano and Weber, 2001, found that the bulk density of soil remains unchanged when fly ash was applied and the concentration of bulk density was found to be 2.16 gm/cc. same as natural soil's bulk density. Therefore, it is advised that only weathered (age old) fly ash at lower application rate should be used for problem soils.

Impact onchemical characteristics of soil

Mostly, fly ash carries positive impacts on chemical properties of soil. Sulfur present in fly ash improves sulfur content in soil and ultimately it is helpful for plants (Sale et al., 1996). Carbonates present in fly ash acts as a lime (McCarty et al., 1994). The calcium and other basic cations in fly ash help to improve soil structure. Soil structure is also improved by forming floccules with soil through cation bridging (Palumbo et al, 2004). The organic matter gets adsorbed on soil surfaces thereby making the soil structure more stable (Palumbo et al, 2004). The pH of soil increases from 5.3 to 9.7 when it is applied at the rate of 7% (Page et al, 1979). For raising pH levels of acidic soil unweathered (fresh) fly ash has been found more suitable than that of weathered fly ash (Phung et al, 1979). Highly alkaline fly ash was not found suitable for application to acidic & alkaline soil mixture. Thus,there is a decrease in concentration of trace elements and heavy metals (Phung et al, 1979).

The organic matter present in fly ash promotes pH buffering capacity by binding essential trace elements, metals and nutrients. Microbe's interaction and organic matter releases nutrient elements to the soil. Calcium present in fly ash promotes the interaction of organic matter with soil. So organic amendment (fly ash) helps for overall soil improvement. The mobility of toxic metals also gets stabilized due to addition of organic matter.

Impact onmicrobiological characteristics of soil

Microbial activity is important for majority of biogeochemical processes. It is also important for different types of soil reactions and breakdown of organic matter. Microbial activity releases plant nutrients and convert complex organic compounds to simpler inorganic compounds. Therefore, only weathered fly ash containingvery less concentration oftrace elements should be applied to soil to achieve maximum benefit. Microbial activity was found remarkable at lower application rate of fly ash application to soil. But at higher application rates it showed inhibitory effects(Arthur et al. 1984). Acidic fly ash (pH3.5-5.0) seems more beneficial for microbial activity than alkaline fly ash (Pitchel& Hayes, 1990). If the soil amended with fly ash has high pH levels it creates unfavorable environment for soilmicroorganisms.

Few laboratory studies conducted with respect tomicrobiological activity showed positive and good response to fly ash application. There is an increase in the bacterial and Actinomycetes count and increase in soil dehydrogenase activity as was reported by Vallini et al, 1999. Pati and Sahu 2004, observed increased respiration of fly ash ameliorated soil, which improved activity of soil bacteria. Amendment of fly ash with sewage sludge showed increased microbial activity (Pitchel and Hayes, 1990). Application of fly ash with small quantity of N, P and K fertilizers improved the counts of total bacteria, Actinomycetes but decreased the counts of fungi, while the activity of dehydrogenase and urease enzyme increased (Yeledhalli et al, 2007). Microorganism's activity is observed well with weathered (age old) fly ash application because of accumulation of nutrients required for microorganism's growth (Rippon and Wood, 1975).

Impact on soil fertility status

It is observed that cation exchange capacity (CEC) of soil is improved due to weathered fly ash application. As such there is improvement in the fertility status of soil because of increased quantity of essential nutrients due to amendment with weathered fly ash (Carlson & Adriano, 1993). Fly ash application to acidic soils improved phosphorus adsorption capacity of soil while its application to alkaline soil showed negligible results (Sheshadri et al, 2013). Amendment of fly ash to oil seed crops showed considerable amount of nutrient uptake thereby improving the fertility status of soil (Lee et al, 2006). Experimental investigation of fly ash application showed that the essential nutrients in fly ash helped to improve the productivity of soil (Adriano et al, 1980).When fly ash (weathered) was applied at the rate of 8 % to the soil (w/w) it was reported that the concentrations of few trace elements improved in soil (Lai et al, 1999). Similarly, when 20% weathered fly ash (w/w) was added in soil there was increase in concentration in nitrogen, phosphorus and potassium (Wong & Lai, 1996). Soil pH is an important part in maintaining the fertility of soil. Therefore, pH should be maintained in order to ameliorate degraded soil, particularly with respect to nutrient deprived soil.

Impact on soil enzymatic activity

When fly ash was applied @10% or less than 10% it was observed that there is improvement in microbial biomass, bacterial enumeration & soil dehydrogenase activity. Similarly, when fly ash was applied @10 to 12% it was reported that there was increased microbial activity & soil dehydrogenase activity (Jala, 2005). Even soil phosphatase enzyme activity improved (Jala, 2005).The laboratory incubation study conducted by Shrivastava et al, 2009; reported improvements on soil dehydrogenase activity, at a concentration of 10%. Therefore, it is evident that application of fly ash @10% or less than 10% has remarkable effect on soil microbial activity, because more nutrients are sufficient to microbes to carry out various metabolic activities.

Impact on soil invertebrates

Very little research work is done on effect of fly ash on soil invertebrates. Reported literature suggests that fly ash contain arthropods, protozoan, rotifers, annelids etc. (Shrivastava&Shrivastava, 2014). Amongst annelids, earthworms are present in fly ash. Earthworm helps to improve the productivity of soil in presence of flyash. They improve nitrogen; phosphorus and potassium content in the fly ash and reduce the toxic heavy metals from fly ash. (Usmani& Kumar, 2017). Earthworms are one of the beneficial animals of soil communities; they are ecologically important and maintain the soil fertility. Earthworms help in maintaining soil structure and have great significance. Earthworms serve as a useful indicator of soil health, as they appear as significant part of soil fauna and in turn soil biomass (Edwards, 2004). When Red Earthworms (*Eiseniafetida*) are added to fly ash enriched with heavy metals they are able to tolerate harsh environmental conditions. (Usmani& Kumar, 2017). There are different species of earthworms such as *Eiseniafetida, Eudriluseugeniae, Perionyxexacavatus* and *Perionyxsansibaricus* which are supposedto be bioaccumulators and help in reducing the toxicity of fly ash and increasing nutrient content i.e. nitrogen, phosphorus and potassium (Usmani& Kumar, 2017). Thus, fly ash and different species of earthworms have beneficial association. Species of earthworm (*Eiseniafoetida*) showed positive and encouraging results with respect to phosphate solubilizing bacteria when combination of cow dung and fly ash was inoculated for 50 days (Malik &Thapliyal, 2009),which showed rich availability of the nutrients (Bhattacharya & Chattopadhyay, 2002).Thus, earthworms help in providing the nutrients into available forms, which improves the fertility of soil.

Impact on wastelands

Coal mining activity, generates lot of solid waste in the form of overburden material. These overburden material when dumped in unmined areas, pollutes the environmental matrices. Fly ash can be utilized for large scale application on these overburden dumps for reclamation and stabilization of these dumps (Fail and Wochok, 1977). Acidic fly ash can be utilized for alkaline wastelands (Jala and Goyal, 2006). Only weathered fly ash should be utilized for reclamation purpose. Use of unweathered fly ash should be strictly avoided (Jala and Goyal, 2006). Weathered fly ash along with manure and press mud has beneficial effects for its application on wastelands (Jambhulkar et al, 2018). Weathered fly ash along with poultry bio solid, sewage sludge and farm yard manure (FYM) should be utilized in restoration of eroded lands (Punshon et al, 2002). Using farm yard manure (FYM) as an amendment field experiment was conducted to reclaim Khaperkheda fly ash dump in Maharashtra by Juwarkar&Jambhulkar, 2008.

Impact on degraded lands

Land becomes degraded due to human induced activities. Such types of land have loss of productive capacity. These lands are infertile and poor in soil quality. Since these lands are infertile they have negligible nutrients, low humus content and inadequate moisture retention capacity and acidic pH. Degraded lands offer the greatest potential for carbon sequestration through fly ash utilization. Fly ash due to its metal oxide content especially oxides of Iron (Fe) can be used to accelerate the humification process on degraded lands (Amonette et al, 2003). Nanometer sized pores; high alkalinity is responsible for its beneficial use for carbon sequestration. Beneficial effects for carbon sequestration includes; improved soil structure, improved moisture content in soil, providing nutrients, adding pH buffering capacity and substitute as a metal ion buffer in soil. Thus, the stability of the degraded lands can be restored and carbon sequestration potential can be enhanced. 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

ADVERSE IMPACTS OF FLY ASH AMELIORATION ON SOIL

Impact on soil enzymatic activity

Application of fly ash, more than 10% has got inhibitory effect on soil enzyme activity and there is decline in microbial activity since substrate availability is reduced. It is also observed that because of reduced substrate availability more organic compounds are built up. These organic compounds reduce the soil enzyme activity. Thus, it is evident that higher rate of application of weathered fly ash (more than 10%) has inhibitory effects on soil enzymatic activity.

Impact on soil microbiological characteristics

Application of fly ash to sandy textured soil reduced respiration in microorganisms and also reduced microbial mineralization (Arthur et al, 1984). The main reason for reduction in microbial activity is its high pH and electrical conductivity (EC). There is decrease in carbon di oxide evolution rate when fly ash is applied (Wong and Wong 1986).When fly ash containing excess trace elements was applied to soil, microbial activity was inhibited.

Impacts due to heavy metal and boron toxicity

Heavy metals such as As and Hg are considered as elements of ecological concern (Saraswat& Chaudhary, 2014). Application of fly ash to soil may create metal & boron toxicity in soil in long run. When heavy metals and boron becomes excessive in soil it will create toxicity to plants also. When these elements become more reactive in soil they will affect microbial activity too (Adriano et al, 1978). Therefore, it is suggested that application rate of fly ash at lower concentration should be considered and the properties of fly ash & soil should be matched before its application with due care.

The major metals which impart toxicity are Arsenic, Mercury and Boron

(a)Arsenic

Arsenic is generated from coal pyrite and flue gases from thermal power plants. Generally, it occurs as Arsenic trioxide. This Arsenic trioxide gets deposited in the soil and imparts toxicity. The concentration of Arsenic ranges from 5 to 442 mg/kg and may reach up to 950 mg/kg (Huggins et al, 2007).

(b)Mercury

The major source ofMercury is through emission of flue gases. Usually, the level of Mercury (Hg) in coal is 0.3 ppm. Mercury is emitted in the environment from industrial chimneys. In India, it was found that Mercury in coastal soil is above the prescribed levels of toxicity.

(c)Boron

Boron toxicity is the major, concerning issue for fly ash application to soil. It persists in soil. The concentration of Boron in fly ash was found to be 20 to 62 mg/kg and may reach up to 245 mg/kg. (Haynes, 2009). Boron concentration of greater than 30 mg/kg is supposed as extremely toxic. Boron concentration of 20 mg/kg is supposed as a little toxic and 30 mg/kg as moderately toxic to plants (Haynes, 2009).

Impact on soil salinity

Soil salinity plays an important role with respect to soluble salt content. Weathered (age old) fly ash contains less soluble salts as compared to unweathered (fresh) fly ash. Therefore, unweathered fly ash when applied to soil increases the soluble salt content considerably (Lal, et al, 2012)). Soluble salts concentration can be high in unweathered ash deposits. Un weathered fly ash have electrical conductivity (EC) greater than 13 ds/m. When unweathered fly ash was amended with soil, the concentration of soil salinity increased (Adriano et al, 1978, Phung et al, 1978). Also, it was observed that as the soil salinity increases there is increase in concentration of Ca++ions (Plank et al, 1975). Thus, when weathered fly ash was amended with soil a decrease in soluble salt content was observed. (Adriano et al, 1980). Hence, it is advised that only weathered (age old) fly ash should be used in considering the soluble salt concentration.

Impact due to organic pollutants

Complex Organic molecules such as Polychlorinated Biphenyls (PCBs), Polyaromatic Hydrocarbons (PAHs), Polychlorinated dibenzo furans (PCDFs) and Polychlorinated dibenzo-p-dioxins (PCDDs), and monomethyl and dimethyl sulphate are present in fly ash which may impart toxicity in long run. It is observed that the concentration of organic pollutants in weathered fly ash is very low and within safe limits (Jambhulkar et al, 2018)

Impact due to radioactivity

Fly ash generally contains radioactive elements. Radionuclide's such as U^{238} and Th^{232} are also present in fly ash. Although, radionuclides are present in fly ash but their concentration is low (Zielinski and Finkelman, 1997). Thorium is present in fly ashbut its concentration is less than 10%. Uranium is present in it and its concentration varies from 20 to100 ppm. Besides U and Th, it also contains radioactive elements like ^{222}Ru and ^{220} Ru (Sharma, 1989). On doing radioactivity analyses it was reported that the activity levels of both Uranium and Thorium are within safe limits. Therefore, radioactive elements do not generate any adverse impacts on soil.

RECOMMENDATIONS FOR FLY ASH APPLICATION ON SOIL

- Depending on soil & fly ash characteristics, statistical models should be developed to verify the appropriateness and rate of application of fly ash along with organic amendments
- Categorizing suitable levels for heavy metals & toxic elements in fly ash
- Government should take certain initiatives to encourage fly ash use for reclamation of degraded lands and mining wastelands.
- Weathered (age old) fly ash should be utilized for application to soil to pursue utmost advantage
- To examine possible pollutants in soil before its use

- More care should be taken with respect to presence of toxic heavy metals; radionuclides etc. before its application
- Laboratory and field trials along with some organic amendments should be considered to avoid adverse effects on soil health.
- It is essential to match the fly ash properties with soil properties and atmospheric conditions to give utmost advantage.
- Lower concentration application to soil should be adopted in practice which improves hydraulic movement in soil
- Due to high concentration of trace elements it should be used for improving health of degraded land
- It should be utilized to enhances carbon sequestration potential on degraded land
- It should be utilized for stabilization of toxic metals in soil
- Un weathered (fresh) fly ash cannot be used for soil application as it posses soluble salt concentration

II. Conclusion

Fly ash a coal combustion residue, although has few limitations with respect to presence of heavy metals, few organic pollutants and radionuclide's has a great potential to improve the soil health of degraded lands. Fly ash improves physical characteristics, chemical characteristics, microbiological characteristics of degraded land, since it posses high concentration of trace elements, micro and macro nutrients along with oxides and hydroxides. It improves physical characteristics of degraded land with respect to pH, porosity, texture, bulk density and water holding capacity. Application of fly ash with small concentration of Nitrogen, Phosphorus and Potassium fertilizers improved the counts of Bacteria and Actinomycetes in degraded soil. Fly ash also improves nutrient and fertility status in nutrient deprived soils. Weathered fly ash along with organic amendments can be utilized to restore the productivity of degraded lands. Except few adverse impacts of fly ash on soil health there are lots of beneficial impacts of fly ash application on soil health therefore it should be used for improving soil health. This approach of fly ash utilization will thus resolve the major crisis for coal based thermal power plant.

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