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Fly ash utilization and its potential benefits in agriculture: A review

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ABSTRACT

Fly ash is the residue left behind after combustion of coal in thermal power plants which requires huge land area, water resources and energy for deposition. Fly ash continues to pose several unavoidable environmental, economic and social concerns. Therefore, its proper management is of utmost importance. This review paper attempts to give an elaborate idea on the importance, type, utilization, characterisation and exhaustive utilization of fly ash in agriculture. Fly ash is widely used in construction of bricks, blocks, tiles, cement, concrete, land reclamation, raising ground levels etc. It has immense potential in agriculture due to its natural characteristics and potential to modify soil health and crop performance. Various macronutrients except C and N, and micronutrients in fly ash increase soil fertility and crop productivity. Appropriate use of fly ash in agricultural soil as well as in plants as source of fertilizer and as soil conditioner, as pesticide or as carrier of insecticides has been included in this paper. Being alkaline in nature, fly ash, instead of lime can reduce net CO_2 emission in agriculture and thereby reduce global warming to a certain extent.

1. INTRODUCTION

Fly ash is the residue of combustion of coal of thermal power plants and consists of mineral constituents of coal which are not fully burnt. Around 75-85% of the ash produced from the combustion of the coal is carried out of the furnace with the flue gasses and is extracted by electrostatic or cyclonic precipitator, known as fly ash. The physical, chemical and mineralogical properties of fly ash depend on the nature of parent coal, conditions of combustion, type of emission control devices, storage and handling methods. Therefore, ash produced by burning of anthracite, bituminous, sub-bituminous and lignite coal has different composition. The coal ash by-product has been classified as a Green List waste under the Organization for Economic Cooperation and Development. It is not considered as a waste material. However, in many countries, this industrial by-product has not been properly utilized rather it has been neglected like a waste substance.

Considerable research and development work have been undertaken across the country towards confidence building and developing suitable technologies for disposal and utilization of fly ash in construction industries. Percentage utilization of the total ash generated in different countries amounts to 100% in Denmark, Italy and Netherlands, 85% in Germany, France and Australia, 50% in UK, 45% in China and 38% in India (Basu *et al.*, 2009). Many field experiments and pot culture studies on the potential of fly ash as an amendment in agriculture have been conducted by various agencies, research institutes at different locations all over the world. Here, utilization of fly ash in agriculture is highlighted with the aim of helping opening up the usage of fly ash and reducing the environmental and economic impacts of its disposal.

Fly Ash Classification

Coal type is one of the factors having the greatest effect on the fly ash characteristics. The composition of the fly ash produced from different types of coal is given in Table 1. The coal rank arranged in an ascending order of carbon contents is: Peat < Lignite < sub-bituminous coal < bituminous coal < anthracite. Indian coal is of mostly sub

Table: 1
Range (%) of chemical composition for fly ash produced from different coals

Component	Bituminous	Sub-bituminous	Lignite
SiO_2	20 - 60	40 - 60	15 - 45
Al_2O_3	5 - 35	20 - 30	10 - 25
Fe_2O_3	10 - 40	4 - 10	4 - 15
CaO	1 - 12	5 - 30	15 - 40
MgO	0 - 5	1 - 6	3 - 10
SO_3	0 - 4	0 - 2	0 - 10
Na_2O	0 - 4	0 - 2	0 - 6
K_2O	0 - 3	0 - 4	0 - 4
LOI (Loss of Ignition, %)	0 - 15	0 - 3	0 - 5

Source: Upadhyay and Kamal, 2007

bituminous rank followed by bituminous and lignite (brown coal). The ash content in Indian coal ranges from 35 to 50%.

On the basis of silica, alumina and iron oxide content, fly ash has been classified into two classes, F and C. The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. Class C fly ash is normally produced from the burning of younger lignite and sub-bituminous coals, and usually contains a significant amount of calcium oxide (CaO), also known as lime (Upadhyay and Kamal, 2007). Wang and Wu (2006) grouped fly ashes into two classes, *i.e.* Class F produced from anthracite, bituminous and sub-bituminous coals containing less than 7% CaO, and Class C produced from lignite coal containing more liming material, upto 30%.

Fly Ash Utilization in India

During the last 30 years, extensive research has been carried out to utilize fly ash in various sectors as many have considered fly ash as a by-product rather than waste (Matani, 1998). A large number of technologies have been developed for gainful utilization and safe management of fly ash through research projects funded by Fly Ash Mission / Fly Ash Unit under Ministry of Science and Technology, Government of India, since 1994. Propagation of these technologies would facilitate and accelerate the fly ash utilization in the country. The utilization of fly ash has increased from 6.64 million tonnes (Mt) in 1996-97 (Tiwari *et al.*, 2016) to a level of 102.54 Mt in 2014-15. The highest level of fly ash utilization of about 62.6% was achieved in the year 2009-10 and it was about 58.48% in the year 2011-12, about 61.37% in the year 2012-13, 57.63% in the year 2013-14 and 55.69% in 2014-15. Researchers have been attempting to convert this by product into wealth by means of exploring viable avenues for fly ash management over the past few years. Common approaches of fly ash utilization that are presently followed in India are cement industry, reclamation of low-lying areas, construction of roads / embankments / flyovers and raising of ash dykes, back filling / stowing of mines, building materials like bricks, blocks and tiles etc. distemper ceramics making and agriculture.

Physico-chemical Properties of Fly Ash

Physico-chemical properties of fly ash depend on the nature of the parent coal composition, conditions of combustion in the furnace, particle size, collector setup and age of the ash (Basu *et al.*, 2009). Physico-chemical properties of fly ash together with that for soil (for comparison) are presented in Table 2. Fly ash is generally silty loam having particles of diameter less than 0.01 mm (Chang *et al.*, 1977). Its colour is one of the important physical properties for estimating the lime content qualitatively. Darker colour suggests high organic matter content while lighter colour indicates the presence of high calcium oxide (Cockrell and Leonard, 1970). The specific gravity of coal ashes is around 2.0 but can vary to a large extent from 1.6 to 3.1 (McLaren and Digioia, 1987). More carbon content decreases its specific gravity, whereas presence of iron increases it (Sahu and Gayathri, 2014). Mishra (2008) found that the bulk density and porosity of the ash samples varied from 0.828 to 1.256 gm cm^{-3} and 50.25 to 70.25%, respectively. According to Mishra and Das (2010) the bulk density, porosity and water holding capacity of the fly ash samples range between 1.00 and 1.06 gm cm^{-3}, 51.15-53.27% and 50.70-55.11%, respectively. The specific surface area of fly ash ranges between 1 to 9.44 $m^2 g^{-1}$ (Jena, 1993). Mishra and Das (2010) also observed that the specific surface area of fly ash is in the range of 0.5747-0.5845 $m^2 cm^{-3}$. The spherical particles of fly ash constitute 10 to 85% of the total coal ash residue, usually having a diameter of 0.5 to 100 microns and a highly porous nature (Rani and Jain, 2015).

It composed of a varied combination of amorphous and crystalline phases is usually considered as ferro-aluminosilicate (Lim and Choi, 2014) and has a matrix similar to soil. It also contains about 69% of a fine earthed fraction (clay/silt) that is derived from coal. Fly ash mainly consists of SiO_2 (71%), Al_2O_3 (32%) and Fe_2O_3 (6%) (Salunkhe and Mandal, 2014). The elements present in fly

Table: 2
Physico-chemical properties of TISCO power plant fly ash and local soil

Properties	Fly ash	Soil[a]
Specific gravity	1.89	2.34
Moisture content (%)	0.73	1.70
Bulk density (Mg m^{-3})	0.96	1.53
Porosity (%)	36.25	-
Water holding capacity (%)	74.55	41.55
Lime reactivity (kg cm^{-2})	36.44	--
Organic carbon (%)	0.36	0.44
Cation exchange capacity [cmol(+) kg^{-1}]	2.65	8.23
Available nitrogen (kg ha^{-1})	2.7	21.15
pH (1:2.5)	9.67	5.57
Electrical conductivity (dS m^{-1})	0.22	0.11

a: Red lateritic soil of order Ultisols; Source: Rai et al., 2010 ash in declining order are O, Si, Al, Fe, Ti, K, Ca, P and Mg. Moreover, trace quantities of Mn, Cr, Ni and Cu are identified in some of the fly ash (Mishra and Das, 2010).

X-ray diffraction studies revealed that the major mineral found in coal ashes is quartz with lesser proportions of feldspars, carbonates and chlorites (Upadhyay and Kamal, 2007). It can be classified as an amorphous ferro-alumino silicate mineral. Quartz (SiO_2) and mullite ($Al_6Si_2O_{13}$) predominated in the mineral composition of the "fresh" fly ash derived after bituminous coal combustion which is a common feature for such wastes (Kierczak and Chudy, 2014).

The elemental composition of fly ash worked out by various workers is presented in Table 3. Shaheen *et al.* (2014) stated that the chemical characteristics of fly ash depend largely on geological factors related to the coal deposits and on different operating conditions/practices employed at the power plants. Thus, fly ash from every coal fired plant has its own chemical characteristics. Depending on the content of sulphur in the fly ash, the pH varies from 4.5 to 12.0 and electrical conductivity varies from 0.42-0.45 dS m^{-1} (Basu *et al.*, 2009). Fly ash produced from coals containing high amounts of anthracite (usually contains high amounts of sulphur, S) are acidic in nature while that produced from lignite (usually lower in S and higher in Ca) are alkaline. Generally, the coal from India is low in S but high in ash content (40%) compared to the coal produced in the US which usually is rich in S (2%) but contains only 5-10% ash (Singh *et al.*, 2010). It may be concluded from this result that the fly ash can be used in agriculture field as a valuable fertilizer source.

Influence of Fly Ash on Soil Properties

The effect of fly ash on soil properties has been studied by several workers. Few beneficial effects of fly ash in combination with organic matter on soil have been reported, such as improved soils through higher nutrient concentrations, better texture, higher porosity and mass moisture content, enhanced the biological activity in the soil.

Influence of Fly Ash on Soil Physico-chemical Properties

Fly ash is a useful soil amendment which can improve the physical and chemical properties of nutrient deficient soils which in turn improves the soil fertility and productivity (Patra *et al.,* 2012). Application of high rates of fly ash can change the surface texture of soils, usually by increasing the silt content (Garg *et al.*, 2003). Addition of fly ash at 200 t $acre^{-1}$ improved the physical and chemical properties of soil and shifted the USDA textural class of the refuge from sandy loam to silt loam (Buck *et al.*, 1990). According to Dhindsa *et al.* (2016), the fine textured soils changed from clay loam to sandy loam and sandy to loamy sand on mixing with 40% fly ash and with 50% fly ash, respectively. The deeper color of fly ash increases the specific heat capacity of the soil and increases soil temperature which significantly increase the water uptake efficiency of corn roots (Wang *et al.*, 2018).

The application of fly ash in light soil influences to

Table: 3
Major and trace element composition of fly ash and soil (to compare)

Elements	Fly ash				Soil[a]
	Page *et al.,* 1979	Basu *et al.,* 2009	Lopareva-Pohu *et al.,* 2011	Maiti *et al.,* 2016	
P (%)	0.04-0.8	0.005-0.2	0.024	-	0.005-0.2
K (%)	0.15-3.5	0.15-3.5	0.021	0.37 ± 0.12	0.04-3.0
Ca (%)	0.11-22.2	0.11-22.2	18.4	3.65 ± 0.61	0.7-50
Mg (%)	0.04-7.6	0.04-7.6	0.19	2.04 ± 0.97	0.06-0.6
S (%)	0.1-1.5	0.1-1.5	0.13	-	0.01-2.0
Al (%)	0.1-17.3	0.1-17.3	4.7	-	4-30
Na (%)	0.01-2.03	0.01-2.03	-	0.29 ± 0.09	0.04-3.0
Fe (%)	1-29	36-1333	3.1	-	0.7-55
Mn (mg kg^{-1})	58-3000	58-3000	418	4.16 ± 2.31	100-4000
Zn (mg kg^{-1})	10-3500	10-3500	85	2.35 ± 0.47	10-300
Cu (mg kg^{-1})	14-2800	14-2800	38	1.14 ± 0.20	2-100
B (mg kg^{-1})	10-618	10-618	0.40	-	2-100
As (mg kg^{-1})	2.3-6300	2.3-6300	20.4	-	0.1-40
Cd (mg kg^{-1})	0.7-130	0.7-130	-	0.34± 0.04	0.01-7.0
Co (mg kg^{-1})	7-520	7-520	17	<0.05	1-40
Cr (mg kg^{-1})	10-1000	10-1000	46	-	5-3000
Hg (mg kg^{-1})	0.02-1.0	0.02-1.0	0.40	-	-
Mo (mg kg^{-1})	7-160	7-160	-	-	0.2-5.0
Ni (mg kg^{-1})	6.3-4300	6.3-4300	48	0.82 ± 0.17	10-1000
Pb (mg kg^{-1})	3.1-5000	3.1-5000	39	0.56 ± 0.08	2-100
Se (mg kg^{-1})	0.2-134	0.2-134	-	-	0.1-2.0

a: Red lateritic soil of order Ultisols reduce bulk density and hydraulic conductivity and increase the water holding capacity. Murgan and Vijayarangam (2013) reported that the hydraulic conductivity is reducing when fly ash is amended at greater than 10% to the acidic soils. And it was also observed that silty clay soil showed an increase in bulk density from 0.89 to 1.01 Mg m^{-3} and a remarkable decrease in soils having bulk density varying between 1.25 and 1.60 Mg m^{-3} when the corresponding rates of fly ash amendment increased from 0 to 100%.

Electrical conductivity is an important characteristic of soils with respect to its effect on plant growth. Since fly ash is rich in soluble salts, usually its application increases soil electrical conductivity (Singh *et al.*, 2010). However, in some cases soil electrical conductivity decreased following fly ash application (Gupta and Sinha, 2009). According to Rout *et al.* (2016), no significant effect of fly ash (40 t ha^{-1}) and chemical fertilizer was found on soil pH, EC, bulk density, pore space and organic carbon content. But significant different in particle density might be due to occupation of some pore space by finer fly ash particles which increased the particle weight without increasing volume. Fly ash in agriculture has been used based on its liming potential and supply of mineral nutrients such as Ca, Na, K, P, Mg, B, S, Fe, Cu, Zn, Mn, Zn and Mo which promote plant growth and also improve the condition of nutrient deficiency in soils (Kumpiene *et al.*, 2007). Soil boron can be improved following fly ash application (Tsadilas *et al.*, 2002). Boron is usually present in considerable amounts in fly ash. Nonetheless, the use of fly ash as a soil amendment has the potential to improve soil physical and chemical conditions when applied in appropriate amounts.

Influence of Fly Ash on Biological Properties of Soil

Information regarding the effect of fly ash amendment on soil biological properties is very scanty. In the soil system, soil enzymes play a key biochemical role in organic matter decomposition (Sinsabaugh *et al.*, 1991), stabilizing the soil structure, nutrient cycling (Dick *et al.*, 1994). In general, the enzymatic activities of soil enzymes are used to reflect outcomes resulting from agricultural cultivation, and the existence of different soil properties, and pedological amendments (Ceccanti *et al.,* 1993). Adding fly ash to soil stimulates enzyme activity *viz.,* dehydrogenase, urease and phosphatases, etc. (Pati and Sahu, 2004). Soil microbial biomass and dehydrogenase activity were reported to be highest at an amendment rate of 10% (w/w), because at this rate reasonable level of nutrients were provided to micro-organisms for carrying out various metabolic activities (Saffigna *et al.*, 1989). The urease activity in the control was 17.90 N-NH_4 g^{-1} which increased significantly to 29.90 N-NH_4 g^{-1} due to application of fly ash at the rate of 25 t ha^{-1} (Yeledhalli *et al.*, 2007). Further, there was decline in the urease activity due to higher doses of fly ash application with NPK.

The results of several laboratory experiments revealed that application of un-weathered fly ash particularly to sandy soil greatly inhibited the microbial respiration, enzymatic activity and soil N cycling processes like nitrification and N mineralization (Garau *et al.*, 1991). These adverse effects were partly due to the presence of excessive levels of soluble salts and trace elements in un-weathered fly ash. However, the concentration of soluble salts and other trace elements was found to decrease due to weathering of fly ash during natural leaching, thereby reducing the detrimental effects over time (Basu *et al.*, 2009). The microbe-mediated processes in the soil are disturbed by the application of pollutants such as fly ash leading to the imbalance of ecosystem (Murgan and Vijayarangam, 2013). The application of lignite fly ash reduced the growth of seven soil borne pathogenic micro-organisms as reported by Karpagavalli and Ramabadran (1997), whereas the population of *Rhizobium* spp. and phosphorus solubilizing bacteria were increased under the soil amended with either farmyard manure or fly ash individually or in combination (Sen, 1997). Gaind and Gaur, (2004) reported that *Azotobacter chroococcum*, *Azospirillum brasilense* and *Bacillus circulans* showed their maximum viability when fly ash alone was applied to soil, whereas *Pseudomonas striata* proliferated most in soil: ash (1:1) applications. Bhattacharya and Chattopadhyaya (2004) showed that the application of fly ash along with organic fertilizer in the ratio of 1:1 increases the content of nitrogen fixing bacteria and thus enhances the compounds NH_4^+ and No_3^-.

Influence of Fly Ash on Soil Moisture

Coal fly ash application can affect soil hydraulic conductivity, depending on soil type and quantity of ash applied. At low rates fly ash improves soil hydraulic conductivity (Adriano *et al.*, 1980). Fly ash had been shown to increase the amount of plant available water in sandy soils (Tabone *et al*. 2010). Application of fly ash along with organic fertilizer improves the soil structures and increases the net photosynthetic rate and reduces the transpiration rate at the same time so as to reduce water consumption that maintains moisture content in plants and promote plant growth. This increases soil water conservation performance and crop yield also (Wang *et al*., 2018).

Influence of Fly Ash on Plant Growth and Yield in Agriculture

Fly ash has huge potential in increasing agricultural crop production. It can also be used as insecticide and if used along with bio-waste, it significantly supplements the utility of chemical fertilizers.

Dhindsa *et al.* (2016) reported that the addition of 20% fly ash in clayey soil and 30% in sandy soils improved the germination, tillering, plant height, biological and grain yield of wheat. Mahale *et al.* (2012) studied the fly ash amendment in soil with different concentration using three species *viz.,* wheat (*Triticum aestivum*), moong bean (*Vigna radiata)* and urd bean (*Vigna mungo)* and found that the application of fly ash improves the seed germination rate whereas in the absence of fly ash the seed germination rate was very slow. An experiment was conducted by Tripathi *et al.* (2009) on the effect of fly ash application (100 t ha^{-1}) on macro nutrient uptake by wheat, maize and eggplant crops grown in sequence and it was observed the fly ash application increased the plant uptake of macronutrients (N, P, K, S, Ca and Mg). They further showed that fly ash application enhanced the soil pool of plant available micronutrients (Fe, Mn, Zn, and Ni) while that of some toxic elements (Cu, Pb, Cr, Se, and Mo) was slightly increased, particularly for the second and third crops after the fly ash application. Tsadilas *et al.* (2009) found that application of fly ash to an acidic Alfisol field soil increased tissue concentrations of B, Cu, and Zn in wheat plant, while those of Fe and Mn decreased.

Application of fly ash in soils having inherent structural, nutritional limitations can lead to improvement in crop yields which can thus enhance food security (Ukwattage *et al.*, 2013). Yeledhalli *et al.* (2012) concluded that the bulk application of fly ash at 30-40 t ha^{-1} with recommended dose of NPK fertilizers alone or along with FYM @ 20 t ha^{-1} increased the grain yield of both sunflower and maize significantly. Gautam *et al.* (2012) revealed that the most suitable treatment for improved plant growth and crop yield for oil yielding plant *Brassica juncea* is 40% fly ash with soil as it gives the maximum crop yield. Robab *et al.* (2010) showed an improved growth of *Solanum nigrum* upto concentrations of 30% fly ash but further increase caused deleterious effects on the plant growth, biomass, leaf area, number of leaf per plant and leaf photosynthetic pigments. Das *et al.* (2013) showed a rice yield increase of 23.3 and 32.4% in treatments over control which received fly ash @ 5 and 15 t ha^{-1}.

On the other hand, higher doses of fly ash (15 and 20%) caused significant reductions in the growth and biomass yield of *Beta vulgaris* L. (Singh *et al.*, 2008). Pandey *et al.* (2009) reported that the application of fly ash at 25% rate was found to have positive results in most of the studied growth and yield parameters of *Cajanus cajan*. However, the yield parameters were adversely affected at higher rates (50 and 100%, w/w) of fly ash compared to the control. Rout *et al.* (2016) studied on seed yield of *kharif* sesame grown on an acid soil and revealed that with application of fly ash @ 40 t ha^{-1} along with recommended dose of NPK resulted 23.7% yield increase over the 100% recommended dose. This might be due to the fact that fly ash improves the soil physical environment, nutrient availability and crop yield (Sharma and Kalra, 2006). Thakare *et al.* (2013) reported that 5 to 10% fly ash-soil blending concentrations were found beneficial for the growth and yield of chilli plant and concluded that fly ash acts as an excellent soil modifier, conditioner and a source of essential nutrients for appreciably improving the texture and fertility with significant increase in crop yield. Fly ash can be used safely for ornamental plants, oil seed crops and forestry plantations which are grown for their aesthetic purposes and thus, the accumulation of toxic elements in plant biomass is not of much alarming.

Fly Ash as an Ameliorant for Reclamation of Acid Soil

Indian fly ash is generally alkaline in nature which can be used as a substitute for lime and additionally they can supply vital plant nutrients. Taylor *et al.* (1988) reported that fly ash is a feasible alternative to lime for treating acidic coal soils in the region. Tsadilas *et al.* (2009) concluded that fly ash application increased soil pH from 5.6 to 6.6 and 7.5, respectively for 5.5 and 11 t ha^{-1} fly ash application rates, with significant enhancement in wheat biomass and grain yields compared to the untreated control soil. Due to the presence of high concentrations of Ca and Mg in most fly ashes, it appears to be a suitable soil amendment for liming purpose and to enhance Ca and Mg contents in the soil (Bilski *et al.,* 2011). The presence of almost all essential plant nutrients in fly ash and its ameliorating effects on physical and chemical nature of the soil thus makes fly ash a useful amendment for crop production especially for degraded soils and waste lands (Ukwattage *et al.*, 2013).

Fly Ash and its Influence on Soil Erosion

Coal ash has been reported to be effective in reduction of soil erosion of top soil in a post-mine land if the soil-ash mixture has over 30% of coal ash (Matsumoto *et al.,* 2016). This has been attributed to the presence of fine fractions and microporous structures in coal ash which enhance the water retention capacity of soil, thus leading to the prevention of erosion. On the other hand, Kumar *et al.* (2017) reportedly used fly ash for the stabilization of soil along the banks of a river to prevent soil erosion that is caused by the flood. It has been suggested that 15% fly ash-soil mixture was appropriate for preventing the lateral erosion as the shear strength of mixture is greater than the critical shear strength of the soil. Calcium containing by-products of coal combustion can be used as effective amendments for the reduction of soil erosion which depends upon the solubility of the native minerals (Tishmack *et al.,* 2001).

Fly Ash for Insect-pest Management

Fly ash has been used in different modes as pesticide or as carrier of insecticide (Vijayakumar and Narayansamy, 1995) although limited quantity could be utilized. Narayansamy and Daniel (1989) have demonstrated the importance of lignite fly ash as an insecticide against an array of lepidopterous and coleopterous pests infestating rice, vegetables and certain other field crops. Based on further studied by Thiyagarajan and Narayansamy (2003) packages of fly ash application were developed for pest control in rice, vegetables like brinjal, okra, tomato, cauliflower, bitter gourd etc. and stored grains. Mathur *et al.* (1985) reported that the toxic properties of fly ash were attributable to abrasive effect on insect pest cuticle. According to Narayansamy (1997), sharp points of mandibles of the chewing insects were worn out and were rendered useless for further feeding. Such feature of fly ash is mainly due to its composition such as SiO_2 at 50-62%. The fly ash along with food settled in the middle intestinal region of the insects and obstructed the food pathway and paralysed digestive and other physiological activities. Similarly, Pandey and Verma (1977) found exposure of insects to inert dusts results in loss of body weight mainly through water loss. According to Wolfson *et al.* (1991), ash do not have any specific insecticidal properties but rather function by reducing the rate of development or by repellence and also causes suffocation by clogging spiracles and trachea.

Fly ash can be used as a filler against the serious storage pest of pulses, pulse beetle *Callosobruchus maculates* as a safe and cheap insecticide to manage the stored product insects (Gupta and Bhaduri, 1984). *Piper nigrum* dust formulation (Pn10D) was prepared by Govindan *et al.* (2010) by mixing pulverized seed powder of *Piper nigrum* (10%) and fly ash (90%) and found that Pn10D at 4% caused mortality of *Callosobruchus maculatus* after 72 hr the treatment. Thus fly ash was used as excellent filler for black pepper, *Piper nigrum* dust formulation against *Callosobruchus maculatus*. Mendki *et al.* (2001) reported that 5000 kg pulse could be protected by application of 1 kg fly ash without any adverse effects on the nutritional quality and percent germination of pulses for as long as 16-18 months. Singh (2011) observed minimum days to mortality of released adults, minimum fecundity, minimum holes, lowest number of F1 adult's emergence, maximum inhibition of F1 adults, minimum weight loss of pulse bruchids at all the application rates of fly ash.

Radionuclides in Fly Ash

Majority of fly ash are not considerably rich in radioactive elements or in associated radioactivity. Although several reports regarding the presence of radionuclides in fly ash are available, studies on their impact are lacking. Results of radioactivity analyses show that the activity levels of gamma emitting radionuclides ^{40}K, ^{226}Ra, ^{228}Raand Ac were within the permissible limits, and that mixing of fly ash with soil at 24% (v/v) was of no consequence (Goyal *et al.*, 2002). Papastefanou (2008) reported that the radioactivity concentrations of the fly ashes produced in coal fired power plants ranged from 263 to 950 Bq kg^{-1} for ^{238}U, from 142 to 605 Bq kg^{-1} for ^{226}Ra, from 133 to 428 Bq kg^{-1} for ^{210}Pb, from 27 to 68 Bq kg^{-1} for ^{228}Ra and from 204 to 382 Bq kg^{-1} for ^{40}K. Mandal *et al.* (2006) reported that the average activity concentrations of the radio elements ^{238}U, ^{232}Th and ^{40}K in the ash were found to be 111, 140 and 351 Bq kg^{-1}, respectively at Kolaghat; 97, 107 and 315 Bq kg^{-1}, respectively at Durgapur, and 106, 126 and 321 Bq kg^{-1}, respectively at Bandel in West Bengal. Ash samples have radium equivalent activity (Ra_{eq}) and external hazards index (H_{ex}) values close to 370 Bq kg^{1} and unity, respectively, which have implications in terms of radiation hazards arising due to the use of these ash samples in building and construction. None of the fly ash samples had radium equivalent activities and external hazard index values more than 370 Bq kg^{-1} and unity, respectively.

Effect of Fly Ash on Groundwater

Hydrogeologic and climatic conditions of the disposal site and physical and chemical characteristics of fly ash are the main factors which determine the influence of ash on groundwater. Weathered fly ash contains higher amount of soluble salts and therefore, deposition of this ash causes more ground water contamination. In case of un-weathered ash, there is generally a higher release of soluble salts initially, but it declines rapidly with time (Theis, 1989). Fly ash contains trace and heavy metals which readily percolate down to the earth and conventionally mix with groundwater. Experiments conducted at Central Fuel Research Institute (CFRI), Dhanbad, India showed that there was no negative influence of fly ash application on the quality of ground water and that the trace and toxic metal contents were within the permissible limits (Basu *et al.*, 2009).

Effect of Fly Ash on Global Warming

Agriculture plays a major role in the global fluxes of the greenhouse gases like carbon dioxide, nitrous oxide, and methane. Use of fly ash as soil ameliorant in place of lime could lead to reduction in CO_2 emissions, thus contributing to minimized global warming (Ferreira *et al.*, 2003). The US Environmental Protection Agency (USEPA) estimated that 9Tg of CO_2 was emitted from an approximate 20 Tg of applied agricultural lime (McBride and West, 2005). An experimental study revealed that 1 ton of fly ash could sequester upto 26 kg of CO_2, *i.e.* 38.18 ton of fly ash could sequester per ton of CO_2 (Montes-Hernandez *et al.*, 2009). Karmakar *et al.* (2010) concluded that use of fly ash for substitute of lime for ameliorating soil may also minimise environmental hazards under rice cultivation in acid lateritic soil. So, use of lime as soil ameliorant can reduce net CO_2 emission and thereby lessen global warming. Agricultural lime application contributes to global warming as Intergovernmental Panel on Climate Change (IPCC) assumes that all the carbon in agricultural lime is finally released as CO_2 to the atmosphere. It is expected that use of fly ash instead of lime as soil ameliorant can reduce net CO_2 emission and thereby lessen global warming.

Acceptability of Fly Ash in Agriculture

Fly ash has great potential in agriculture due to its efficacy in modification of soil health and crop performance. However, since there is a possibility of harm to the environment and human health, long term confirmatory research is necessary before including agriculture as a venue for fly ash utilization. Also, before judging the acceptability of fly ash as an ameliorant or input in agriculture widespread awareness regarding its potential benefits and associated constraints is essential. Moreover, regular estimation of the physical and chemical quality of each lot of fly ash produced needs to be done before recommending its use.

2. CONCLUSIONS

Fly ash contains almost all macronutrients (except nitrogen) and micronutrients, but has low organic carbon. It also contains heavy metals like Pb, Hg, As, Cd, Se, Sc, Ni, and V in trace quantity. Due to fine texture of fly ash, it improves the water holding capacity of light textured soils and reduces the compactness of clay soils. These improvements in physical and chemical nature coupled with positive effect on soil microorganisms make the problem soils productive. Application of fly ash increases yields of various crops at specific recommendation rates which differ from crop to crop. The concentration of nutrients was found more in plants grown on fly ash amended soil when compared to control soil crop. Fly ash can be used as liming material on acid soils, acid mine soils or alkali soils for improving the pH of the soils depending on the nature of soil and fly ash. With growing threat of environmental degradation due to excessive use of chemical fertilizers for pest control and nutrient management, fly ash based bio pesticides and bio fertilizers have emerged as safe and effective alternatives. Owing to its evident potential for improvement of soil properties fly ash can be recommended for use in the field of agriculture but its judicious and balanced use is mandatory to avoid any adversity.

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