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Use of Flyash in Agriculture: A Way to Improve Soil Fertility and its Productivity

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Abstract: Fly Ash (FA)-a coal combustion residue of thermal power plants has been regarded as a problematic solid waste all over the world. Disposal of high amount of fly-ash from thermal power plants absorbs huge amount of water, energy and land area by ash ponds. Therefore, fly-ash management would remain a great concern of the century. However, several studies proposed that FA can be used as a soil ameliorate that may improve physical, chemical and biological properties of the degraded soils and is a source of readily available plant micro-and macro-nutrients. Practical value of FA in agriculture as an eco-friendly and economic fertilizer or soil amendments can be established after repeated field experiments for each type of soil to confirm its quality and safety. Fly-ash has great potentiality in agriculture due to its efficacy in modification of soil health and crop performance. The high concentration of elements (K, Na, Zn, Ca, Mg and Fe) in fly-ash increases the yield of many agricultural crops. But the use of fly-ash in agriculture is limited compare to other sector. An exhaustive review of numerous studies of last four decades took place in this study, which systematically covers the importance, scope and apprehension regarding utilization of fly-ash in agriculture. This study also identified some areas, like soil fertility and its response on cereal oil seed and vegetable crops. 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 in agriculture can reduce net CO_2 emission and also reduce global warming.

Key words: Flyash, soil fertility, productivity, waste management, carbon sequestration, soil properties, soil amendment

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INTRODUCTION

Fly ash is produced as a result of coal combustion in thermal power station and discharged in ash ponds. Combustion of bituminous and sub-bituminous coal and lignite for generation of electricity in thermal power plants produces solid wastes such as fly ash, bottom ash, boiler slag and Flue Gas Desulphurization (FGD) materials, which are commonly known as coal combustion by-products (CCPs) (Vom Berg, 1998). The material is produced in the flue gas scrubbers by reacting slurried limestone or lime with the gaseous SO_2 to produce $CaSO_3$. Now-a-days fly ash (FA) disposal into the environment is one of the major

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Table 1: Flyash production and its utilization by worldwide

Country	Flyash production (million tons per year)	Fly ash utilization
India	112.0	38
China	100.0	45
USA	75.0	65
Germany	40.0	85
UK	15.0	50
Australia	10.0	8
Canada	6.00	75
France	3.00	85
Denmark	2.00	100
Italy	2.00	100
Netherland	2.00	100

Source: http://www.tifac.org.in [accessed 26.07.08]

concerns throughout the world mainly in developing countries. Flyash production depends on the quality of the coal, which contains a relatively high proportion of ash that leads to 10-30% Flyash formation (Singh and Siddiqui, 2003). In India 75% of electricity is generated by coal based thermal power plants, according to the data revealed in Table 1, provided by Government. of India 112 million tones of this kind of waste is produced in India during 2005-06 of which 4 mt is released into the atmosphere (Jamwal, 2003). Percentage ash utilization of the total ash generated in different countries amounts to more than 85% in West Germany, 100% in Denmark, 85% in France, 50% in UK, 45% in China and 38% in India. Kalra *et al.* (1997) have reported that FA production in India will exceed 140 million tons by 2020. Nearly 50-60% of the fly ash is being stored at plant dump sites and other sites intended for this purpose. The disposal of such a huge amount of FA is one of the major problems of developing countries and is usually disposed in basins or landfills near the power plants. Fly ash is some times used in buildings, construction of roads, embankment and cement industries. Its alkaline character and a high concentration of mineral substances have resulted in attempts at using it as fertilizer or amendment to enhance the physico-chemical properties of soil. The FA contains a high concentration of toxic heavy metals such as Cu, Zn, Cd, Pb, Ni, Cr etc. (Rautaray *et al.*, 2003; Lee *et al.*, 2006; Tiwari *et al.*, 2008) along with low nitrogen and phosphorus content and pH ranged from 4.5 to 12.0 depending on the S-content of parental coal. Fly ash is disposed of either by dry or wet methods. In dry disposal, the fly ash is dumped in landfills and fly ash basins. In the wet method, the fly ash is washed out with water into artificial lagoons and is called pond ash. Both methods ultimately lead to dumping the fly ash on open land, which degrades the soil and endangers human health and the environment. Fly ash particles are small enough to escape emission control devices and easily get suspended in the air. Repeated exposure to fly ash can cause irritation in eyes, skin, nose, throat and respiratory tract and result in arsenic poisoning (Carlson and Adriano, 1993; Finkelman *et al.*, 2000). Therefore, disposal and utilization of fly ash needs careful assessment to prevent conversion of arable land into landfills and accumulation of toxic metals in soil (Petruzzelli, 1989) and use it as an ameliorant for problem soils. Restoration and utilization of fly ash dumps for biomass production will be an adjunct to these efforts. The current article reviews various attributes of fly ash for its application in agriculture and deriving agronomic benefits.

PHYSICO-CHEMICAL AND MINERALOGICAL PROPERTIES OF FLYASH

Physical Properties of Fly Ash

The mineralogical, physical and chemical properties of fly ash (Adriano *et al.*, 1980; Carlson and Adriano, 1993) depend on the nature of parent coal, conditions of combustion,

Table 2: Physical properties of fly ash

Parameters	Values
Color	Gray to black
Shape	Spherical
Bulk density (g cm^{-3})	1-1.8
Specific gravity (g cm^{-3})	1.90-2.55
Plasticity	Non plastic
Moisture content (%)	18-38
Cohesion (kg m^{-2})	Negligible
Clay (%)	1-10
Silt (%)	8-85
Sand (%)	7-90
Gravel (%)	0-10

Table 3: Chemical characteristics of Flyash C and F

	Weight (%)	
Oxides	Flyash F	Flyash C
SiO_2	52.5±9.6	36.9±4.7
Al_2O_3	22.8±5.4	17.6±2.7
Fe_2O_3	7.5±4.3	6.2±1.1
CaO	4.9±2.9	25.2±2.8
MgO	1.3±0.7	5.1±1.0
Na_2O	1.0±1.0	1.7±1.2
K_2O	1.3±0.8	0.6±0.6

type of emission control devices and storage and handling methods. Therefore, ash produced by burning of anthracite, bituminous and lignite coal has different compositions. In general, flyash particles are spherical and have a size distribution with medium around 4 μm while the bottom ash has a medium around 70 4 μm and settle close to plant site (Sadasivan *et al.*,1993). Fly ash generated from various thermal power plants in India comprise ranges of silt 8-85, clay 0-10, sand 7-90 and gravel 0-10% (Table 2). Bulk density of fly ash varies from 1 to 1.8 g cm^{-3}. Water Holding Capacity (WHC) of flyash is generally 49-66% on weight basis, while the moisture retention ranges from 6.1% at 15 bar to 13.4% at 1/3 bar. The specific gravity of fly ash ranges from 2.1 to 2.6 g cm^{-3}. Mean particle density for non-magnetic and magnetic particles is 2.7 and 3.4 g cm^{-3}, respectively (Natusch and Wallace, 1974). Flyash has unusually high surface area and light texture due to the presence of large, porous and carbonaceous particles.

Chemical Properties of Fly Ash

Chemically, 90-99% of fly ash is comprised of Si, Al, Fe, Ca, Mg, Na and K with Si and Al forming the major matrix (Adriano *et al.*, 1980). There are mainly two types of ash: Class F (low lime) and Class C (high lime) based on silica, alumina and iron oxide content of fly ash. Al in fly ash is mostly bound in insoluble aluminosilicate structures, which considerably limits its biological toxicity (Page *et al.*, 1979). It is substantially rich in trace elements like lanthanum, terbium, mercury, cobalt and chromium (Adriano *et al.*, 1980). Many trace elements including As, B, Ca, Mo, S, Se and Sr (Page *et al.*, 1979) in the ash are concentrated in the smaller ash particles (Adriano *et al.*, 1980). Table 3 revealed that the content of oxide in flyash varies from class C and class F. The Fe-oxide contents of spheres influences their color which ranges from water-white to yellow orange to deep red or brown to opaque. Ca was found to be the dominant cation in ESP ash and fly ash collected from dump sites, followed by Mg, Na and K (Matti *et al.*, 1990). The pH of fly ash varies from 4.5 to 12.0 depending largely on the sulphur content of the parent coal (Plank and Martens, 1974) and the type of coal used for combustion affects the sulphur content of fly ash (Page *et al.*, 1979).

Table 4: Macro and micronutrients content in flyash

Elements	Fly ash (ppm)
Aluminum	11500-144000
Boron	10-3000
Calcium	5400-177000
Chlorine	13-25000
Cobalt	6-1500
Copper	30-3020
Manganese	31-4400
Phosphorus	600-2500
Potassium	1534-34000
Sulphur	0.11-.25
Iron	7800-289000
Sodium	1180-20300
Nickel	11.8-8000

The concentration of various elements in flyash decreased with increasing particle size (Adriano *et al*., 1978). Eastern US coals that include anthracite are generally high in S and produce acidic ash, While western US coals, which includes lignites, tend to be lower in S and higher in Ca and produce alkaline ash (Furr *et al*., 1977; Page *et al*., 1979). Chemical constituents of fly ash had a relatively low content of major and trace elements (Table 4).

Mineralogical Properties of Flyash

Minerals such as quartz, mullite, hematite, magnetite, calcite and borax were also identified in fly ash and oxidation of C and N during combustion drastically reduces their quantity in ash (Hodgson and Holliday, 1966). The coal produced in India is low in S but high in ash content (40%) whereas the coal produced in US is rich in S (2%) and contains only 5-10% ash.

IMPACT OF FLYASH ON SOIL FERTILITY

Soil properties as influenced by fly-ash application have been studied by several workers (Inam, 2007) for utilizing this industrial waste as an agronomic amendment.

Effect of Flyash on Physical Properties of Soil

Fly-ash application to sandy soil could permanently alter soil texture, increase microporosity and improve the water-holding capacity (Ghodrati *et al*., 1995; Page *et al*., 1979). Fly-ash addition at 70 t ha^{-1} has been reported to alter the texture of sandy and clayey soil to loamy (Capp, 1978). Addition of fly-ash at 200 t acre^{-1} improved the physical properties of soil and shifted the USDA textural class of the refuge from sandy loam to silt loam (Buck *et al*., 1990). The particle size range of fly-ash is similar to silt and changes the bulk density of soil. Chang *et al*. (1977) observed that among five soil types, Reyes silty clay showed an increase in bulk density from 0.89 to 1.01 g cc^{-1} and a marked decrease in soils having bulk density varying between 1.25 and 1.60 g cc^{-1} when the corresponding rates of flyash amendment increased from 0 to 100%. Application of fly-ash at 0, 5, 10 and 15% by weight in clay soil significantly reduced the bulk density and improved the soil structure, which in turn improves porosity, workability, root penetration and moisture-retention capacity of the soil (Kene *et al*., 1991). Prabakar *et al*. (2004) concluded that addition of fly-ash up to 46% reduced the dry density of the soil in the order of 15-20% due to the low specific gravity and unit weight of soil. A gradual increase in fly-ash concentration in the normal field soil (0, 10, 20 up to 100% v/v) was reported to increase the porosity and water-holding capacity (Khan and Khan, 1996). This improvement in water-holding capacity is beneficial for the growth of plants especially under rainfed agriculture. Amendment with fly-ash up to 40% also increased soil porosity from 43 to 53% and water-holding capacity from 39 to 55% (Singh *et al*., 1997). Fly-ash had been shown to increase the amount of plant available water in sandy soils (Taylor and Schumann, 1988). The Ca in fly-ash readily replaces Na at clay exchange sites and thereby enhances flocculation of soil clay particles, keeps the soils friable, enhances water penetration and allows roots to penetrate compact soil layers (Jala and Goyal, 2006). Water-holding capacities of fly-ashes from different thermal power plants in Eastern India were compared and the effect of size fractionation on the water-holding capacity was determined in an investigation by Sarkar and Rano (2007).

Effect of Flyash on Chemical Characteristics of Soil

Lime in flyash (FA) readily reacts with acidic components in soil and releases nutrients such as S, B and Mo in the form and amount beneficial to crop plants. FA improves the nutrient status of soil (Rautaray *et al*., 2003). The FA has been used for correction of sulphur and boron deficiency in acid soils (Chang *et al*., 1977). Application of fly ash for increasing the pH of acidic soils (Phung *et al*., 1979). Most of the fly-ash produced in India is alkaline in nature; hence, its application to agricultural soils could increase the soil pH and thereby neutralize acidic soils (Phung *et al*., 1978). The hydroxide and carbonate salts give fly-ash one of its principal beneficial chemical characteristics, the ability to neutralize acidity in soils (Cetin and Pehlivan, 2007). Fly-ash has been shown to act as a liming material to neutralize soil acidity and provide plant-available nutrients (Taylor and Schumann, 1988). Researches have shown that the use of fly-ash as liming agent in acid soils may improve soil properties and increase crop yield (Matsi and Keramidas, 1999). The electrical conductivity of soil increases with fly ash application and so does the metal content. Decolorization of effluents by fly ash has been reported earlier by a number of workers (Robinson *et al*., 2001) and a mixture of fly ash and coal in the ratio of 1:1 can be substituted for activated carbon owing to increase in surface area available for absorption (Gupta *et al*., 1990). Metals like Fe, Zn, Cu, Mn, Ni and Cd have been shown to be available at higher concentrations in DTPA extracts of FA (Gupta *et al*., 2007). The increased accumulation of essential ions such as Zn, Mn and Cu by the paddy shoot/grain might be due to increased activity of ionic transporters (Hall and Williams, 2003), in turn due to higher essential ion availability in the FA. Sarangi *et al*. (2001) observed that gradual increases in soil pH, conductivity, available phosphorus, organic carbon and organic matter with increased application rate of fly ash (Table 5). Flyash is considered to be a rich source of Si and application of FA in Si-deficient soils has been demonstrated to improve the Si content of rice plants as well as their growth (Lee *et al*., 2006).

Table 5: Effect of flyash on soil properties

		Tons ha^{-1} fly ash in field soil					
Parameters	Days after amendment	0	10	12.5	15.0	17.5	20.0
pH	35	7.40	7.50	7.50	7.50	7.70	7.80
	110	7.50	7.50	7.60	7.60	7.60	7.60
EC (mmho cm^{-1})	35	0.11	0.12	0.13	0.13	0.13	0.15
	110	0.18	0.18	0.19	0.23	0.24	0.24
Available P (mg 100 g^{-1})	35	2.20	2.40	2.50	2.60	2.80	2.90
	110	1.90	1.90	2.0	2.50	2.80	2.80
OC (%)	35	0.37	0.38	0.38	0.43	0.44	0.46
	110	0.30	0.34	0.34	0.34	0.37	0.39
OM (%)	35	0.63	0.66	0.66	0.74	0.76	0.79
	110	0.51	0.58	0.58	0.58	0.64	0.67
N (%)	35	0.09	0.08	0.08	0.06	0.06	0.06
	110	0.06	0.06	0.05	0.04	0.05	0.05

Effect of Flyash on Biological Properties of Soil

There is a dearth of studies regarding the effects of FA amendment on soil biological properties. Numerous short-term laboratory incubation studies found that the addition of unweathered FA to sandy soils severely inhibited microbial respiration, numbers, size, enzyme activity and soil nitrogen cycling processes such as nitrification and N mineralization (Cerevelli *et al*., 1986; Wong and Wong, 1986; Pichtel, 1990; Garau *et al*., 1991). Information regarding the effect of fly-ash amendment on soil biological properties is very scanty (Schutter and Fuhramann, 2001). These adverse effects were partly due to the presence of excessive levels of soluble salts and trace elements in unweathered 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 (Sims *et al*., 1995). Moreover, the use of extremely alkaline (pH 11-12) fly-ash could also be the reason for those adverse effects. The application of lignite fly-ash reduced the growth of seven soil borne pathogenic microorganisms, whereas the population of *Rhizobium* sp. and P-solubilizing bacteria were increased under the soil amended with either farmyard manure or fly-ash individually or in combination. Amendment of Class F, bituminous flyash to soil at a rate of 505 Mg ha^{-1} did not cause any negative effect on soil microbial communities and improved the populations of fungi, including arbuscular mycorrhizal fungi and gram-negative bacteria as revealed from analysis of community fatty acids (Schutter and Fuhrmann, 2001). Machulla *et al*. (2004) suggested that the microbial communities that developed in 17-20-year-old lignite ash deposits in Germany contained specific ash-tolerant populations that different significantly from those in surrounding soils. Kumar *et al*. (2008) isolated metal tolerant plant growth promoting bacteria (NBRI K28 *Enterobacter* sp.) from FA contaminated soils and found that the strain NBRI K28 and its siderophore overproducing mutant NBRI K28 SD1 are capable of stimulating plant biomass and enhance phytoextraction of metals (Ni, Zn and Cr) from FA by metal accumulating plant i.e., *Brassica juncea* (Indian mustard). Concurrent production of siderophores, Indole Acetic Acid (IAA) and phosphate solubilization revealed its plant growth promotion potential. Finally, in most of the cases mutant of NBRI K28, exerted more pronounced effect on metal accumulation and growth performance of *B. juncea* plants than wild type. Actinomycetes and fungi declined with 5% FA and all populations declined at the 10 and 20% rate. With 20% FA bacteria, actinomycetes and fungi decreased by 57, 80 and 86%, respectively (Pichtel, 1990). Garampalli *et al*. (2005) revealed on the basis of pot-culture experiment that using sterile, phosphorus-deficient soil to study the effect of FA at three different concentrations viz., 10, 20 and 30 g FA kg^{-1} soil on the infectivity and effectiveness of vesicular arbuscular mycorrhiza (VAM) Glomus aggregatum in pigeonpea (*Cajanus cajan* L.) cv. Maruti. All the concentrations of FA amendment in soil were found to significantly affect the intensity of VAM colonization inside the plant roots and at higher concentration (30 g FA kg^{-1} soil); the formation of VAM fungal structure was suppressed completely. The dry weight of the pigeonpea plants under the influence of FA amendment in VAM fungus infested soils was found to be considerably less (though not significant enough) when compared to the plants grown without FA that otherwise resulted in significant increase in growth over the plants without *G. aggregatum* inoculation. However, FA amendment without VAM inoculation was also found to enhance the growth of plants as compared to control plants (without FA and VAM inoculums). Hrynkiewiez *et al*. (2009) evaluated the use of inoculation with a mycorrhiza-associated bacterial strain (*Sphingomonas* sp. 23L) to promote mycorrhiza formation and plant growth of three willow clones (*Salix* sp.) on fly ash from an overburdened dump in a pot experiment. They conclude that inoculation with mycorrihza promoting bacterial strains might be a suitable approach to support mycorrhiza formation

Table 6: Effect of Flyash on soil enzymes activity

Parameters	Days after amendment	Tons ha^{-1} fly ash in field soil					
		0	10	12.5	15.0	17.5	20.0
Protease activity	35	30.900	34.50	37.20	49.90	42.60	43.70
(µg tyrosine g/soil/h)	110	26.200	36.40	39.3	39.10	38.90	36.00
Amylase activity	35	53.900	58.20	62.60	78.30	35.30	40.30
(µg glucose g/soil/h)	110	44.200	48.30	50.60	63.00	20.80	23.50
Invertase activity	35	553.400	363.60	382.00	495.80	511.80	635.80
(µg glucose g/soil/h)	110	65.000	75.00	89.10	128.70	80.60	62.90
Dehyrogenase activity	35	6.640	9.12	9.30	12.70	8.00	10.85
(µg formazan g/soil/h)	110	0.340	0.31	0.32	0.36	0.33	0.31
Soil respiration (g CO_2/m/h)	110	0.006	0.05	0.11	0.14	0.14	0.12

with autochthonous site-adopted ectomycorrhizal fungi in FA and thereby to improve re-vegetation of FA landfills with willows. Ray and Adholeya (2008) presented a correlation between organic acid exudation and metal uptake by ectomycorrhizal fungi grown on pond ash *in vitro* and this finding supports the widespread role of low molecular weight organic acid as a function of tolerance, when exposed to metals *in vitro*. The enzymatic activity of soil is also an important factor for measuring soil biological properties after FA amendment in soil. The high pH and electrical conductivity of FA have been suggested to be important elements limitingmicrobial activity (Elliott *et al.*,1982). Sarangi *et al.* (2001) reported that invertase, amylase, dehydrogenase and protease activity increased with increasing application of flyash up to 15 t ha y^{-1}, but decreased with higher levels of flyash application (Table 6). Pati and Sahu (2004) taken 7 concentrations of FA amended soil (0, 2.5, 5, 10, 15, 25 and 50%; w/w) for the toxicity test of earthworms (*Drawida willsi*) and studied the CO_2 evolution and enzyme activities (dehydrogenase, protease and amylase) in the presence and absence of *D. willsi.* They found little or no inhibition of soil respiration and enzyme activities up to 2.5% FA amendment. With further addition of FA, all the above activities were significantly decreased. On the other hand, significant stimulation of soil respiration and microbial activities were observed up to 5% FA amendment when the soils contained earthworms. This may be due to increased microbial activity induced by substrates that are produced by the earthworms. Lal *et al.* (1996) reported that FA added to soil at 16% (w/w) increases enzyme activities (urease and cellulase). However, acid phosphatase activity was depressed and with FA application. So, mix application of FYM and FA proved to be beneficial in augmenting proliferation and activity of microorganisms in acid soils. Fly ash composted with wheat straw and 2% rock phosphate (w/w) for 90 days enhanced chemical and microbiological properties of the compost and fly ash up to 40-60% and did not exert any detrimental effect on either C:N ratio or microbial population (Gaind and Gaur, 2004). The available phosphorus estimation of soil receiving fly ash at varying rates of 0-80 t ha^{-1} showed higher availability of this element compared to control (no fly ash). Both 40 and 60 t ha^{-1} of fly ash resulted in the same status of soil available P. The improved availability may partly have been contributed by fly ash which itself contained some available P and partly to some native phosphate solubilizers. However, the treatments receiving *P. striata* inoculation showed further enhancement in P availability due to their ability to solubilize insoluble phosphorus. The inoculation effect was most pronounced in F40 treatment with available P being 34.7 ppm. Both F40 and F60 treatments were statistically at par with each other but superior to the control.

EFFECT OF FLYASH ON SOIL CARBON SEQUESTRATION POTENTIAL

A significant enhancement of C-sequestration by terrestrial ecosystems is needed to help offset the growth in atmospheric CO_2 inputs during the transition from fossil fuels to renewable and alternative-energy sources over the next 50-100 years. While trees and the ocean are important sinks for C, soils can make a large one-time contribution to this effort if ways can be found to return them to pre-agricultural levels of C. Our part of the challenge is to explore ways of enhancing net sequestration of C by soils while minimizing release of other GHGs. Agricultural lime contributes a prime role in the global fluxes of the greenhouse gases such as carbon dioxide, nitrous oxide and methane. According to the Intergovernmental Panel on Climate Change (IPCC), agricultural lime application contributes to global warming through emission of CO_2 to the atmosphere, the US EPA estimated that 9 Tg (teragram = 1012 g = 106 metric ton) CO_2 was emitted from an approximate 20 Tg of applied agricultural lime in 2001 (McBride and West, 2005). Some researchers have been worked on utilization of FA in place of agricultural lime for minimizing global warming (West and McBride, 2005). An experimental study revealed that 1 tonne of FA could sequester up to 26 kg of CO_2, i.e., 38.18 ton of FA per tonnes of CO_2sequestered. This study confirmed the possibility to use this alkaline residue for CO_2 mitigation (Montes-Hernandez *et al.*, 2009). So, use of FA instead of lime as soil ameliorant can reduce net CO_2 emission and thereby, lessen global warming. In other sector, using FA to replace cement can decrease cement in concrete mixture and results in decreasing CO_2 from the production of cement. This CO_2 is thought to be a major contributor to the greenhouse effect and the global warming of the planet (Ferreira *et al.*, 2003; Tietenberg, 2003). According to one estimate, use of 1 tonne of FA in concrete will avoid 2 tones of CO_2 emitted from cement production and reduces green-house effect and global warming (Krishnamoorthy, 2000; Naik and Tyson, 2000). So, there are some advantages of using FA in concrete and cement production as well as in agricultural sector: (1) use of a zero-cost raw material, (2) conservation of natural resources mainly land (topsoil), water, coal and lime as well as one other resource as chemical fertilizer, (3) elimination of waste and (4) minimization of global warming.

FLY-ASH IMPROVE CROP GROWTH AND THEIR YIELD

Agricultural utilization of fly ash has been proposed because of its considerable content of K, Ca, Mg, S and P (Kalra *et al.*, 1997; Singh *et al.*, 1997). Fly ash addition generally increases plant growth and nutrient uptake (Aitken *et al.*, 1984). Weinstein *et al.* (1989) reported that fly ash increased crop yield of alfalfa (Medicago sativa), barley (*Hordeum vulgare*), Bermuda grass (*Cynodon dactylon*) and white clover (*Trifolium repens*). Addition of unweathered western US fly ash up to 8% (w/w) to either calcareous or acidic soils resulted in higher yield of several agronomic crops (Page *et al.*, 1979) mainly due to increased availability of S to plants. Furr *et al.* (1977) demonstrated that alfalfa, sorghum (*Sorghum bicolor*), field corn (*Zea mays*), millet (*Echinochloa crusgalli*), carrots (*Daucas carota*), onion (*Allium cepa*), beans (*Phaseolus vulgaris*), cabbage (*Brassica oleracea*), potatoes (*Solanum tuberosum*) and tomatoes (*Lycopersicon esculentum*) could be grown on a slightly acidic soil (pH 6.0) treated with 125 mt ha^{-1} of unweathered fly ash. These plants exhibited higher contents of As, B, Mg and Se. Also winter wheat (*Triticum aestivum*) grown on a deep bed of fly ash produced grains containing higher Se (Stoewsand *et al.*, 1978). Greenhouse experiments conducted by Sikka and Kansal (1994) showed that application of 2-4% fly ash significantly increased N, S, Ca, Na and Fe content of rice (*oryza sativa*) plants. The foliar application of fly ash also enhances growth and metabolic rates, as well as increasing the photosynthetic pigments of crops like maize and soybean (Mishra and Shukla, 1986). They did not find any residual effect of fly ash application on the following wheat crop

Table 7: Saving of chemical fertilizers and nutrient use efficiency under different mode of fertilization sources in rice-peanut cropping system

	Saving of chemical fertilizer (%)			Nutrient use efficiency (kg grain kg^{-1} nutrient)		
Fertilization sources	N	P	K	N	P	K
*CF	-	-	-	34.4	34.40	45.90
Organic +CF	37.5	22.0	32.0	37.2	37.20	59.80
Organic+**FA+CF	45.8	33.5	69.6	45.4	105.5	72.90

*CF: Chemical fertilizers, **FA: Flyash

except for a slight increase in Fe content of the soil. The post harvest soil samples from rice and wheat also did not show any change in the nutrient content and pH. The iron content of the soil however, increased to 18 from 12%. Khan and Khan (1996) reported that application at 40% fly ash can increase the yield of tomato by 81% and market value (mean fruit weight). Increased selenium accumulation in plant tissues with increased fly ash application warrants close monitoring and use of appropriate quantity of weathered fly ash depending upon the end use of the produced biomass (Straughan *et al*., 1978). Application of 5-20% fly ash on w/w basis in the plough layer (0-15 cm) increased both grain and straw yield of pearlmillet (*Pennisetum* sp.) followed by wheat (Grewal *et al*., 2001). Lau and Wong (2001) reported that weathered coal fly ash at 5% resulted in higher seed germination rate and root length of lettuce (*Lactuca sativa*). The amino acid content in soybean (*Glycine max*) was found to show an increase when grown in fly ash amended soils in pot cultures (Goyal *et al*., 2002). High yield of aromatic grasses particularly palmarosa (*Cymbopogon martini*) and citronella (*Cymbopogon nardus*), in presence of different fly ash-soil combinations, was attributed to increased availability of major plant nutrients (Neelima *et al*., 1995). Fly ash applied at 25% showed higher yield of brinjal (*Solanum melongena*), tomato and cabbage. Oil seed crops such as sunflower (*Helianthus* sp.) and groundnut (*Arachis hypogaea*) also responded favorably to fly ash amendment. Medicinal plants such as cornmint (*Mentha arvensis*) and vetiver (*Vetiver zizanoides*) were successfully planted in fly ash used in conjunction with 20% farmyard manure (FYM) and mycorrhiza (Sharma *et al*., 2001). The level of 40% fly ash was found to have nematicidal effect and was suggested for the management of root knot disease in tomato caused by *Meloidogyne* sp. and providing nutrients (Khan *et al*., 1997). Tomato cultivars grown on fly ash amended soils had higher tolerance to wilt fungus *Fusarium oxysporum* (Khan and Singh, 2001).

REDUCES THE COST OF CULTIVATION

Saving of chemical fertilizers use of fly-ash along with chemical fertilizers and organic materials in an integrated way can save chemical fertilizer as well as increase the fertilizer use efficiency (FUE). According to Mittra *et al.* (2003), integrated use of fly-ash, organic and inorganic fertilizers saved N, P and K fertilizers to the range of 45.8, 33.5 and 69.6%, respectively and gave higher FUE than chemical fertilizers alone or combined use of organic and chemical fertilizers in a rice-groundnut cropping system (Table 7).

CONCLUSIONS

FA can be used as a potential nutrient supplement for degraded soils thereby solving the solid waste disposal problem to some extent. However, the bioaccumulation of toxic heavy metals and their critical levels for human health in plant parts and soil should be investigated. An ultimate goal would be to utilize FA in degraded/marginal soils to such an extent as to achieve enhanced fertility without affecting the soil quality and minimizing the accumulation of toxic metals in plants below critical levels for human health. There are several potential beneficial and few harmful effects of FA application in soil.

Beneficial Effects

(1) Improves soil texture; (2) reduces bulk density of soil; (3) improves water holding capacity; (4) optimizes pH value; (5) increases soil buffering capacity; (6) improves soil aeration, percolation and water retention in the treated zone (due to dominance of silt-size particles in FA; (7) reduces crust formation; (8) provides micro-nutrients like Fe, Zn, Cu, Mo, B etc.; (9) provides macro-nutrients like K, P, Ca, etc.; (10) reduces the consumption of soil ameliorants (fertilizers, lime); (11) FA can also be used as insecticidal purposes and (12) decreases the metal mobility and availability in soil.

Harmful Effects

(1) Reduction in bioavailability of some nutrients due to high pH (generally from 8 to 12); (2) high salinity and (3) high content of phytotoxic elements, especially boron.

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