Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2017; 6(6): 873-880
Received: 06-09-2017
Accepted: 07-10-2017

Gayatri Sahu
Dept.of Agril. Chemistry & Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur. Nadia, West Bengal, India

Animesh Ghosh Bag
Dept.of Agril. Chemistry & Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur. Nadia, West Bengal, India

Nitin Chatterjee
Dept.of Agril. Chemistry & Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur. Nadia, West Bengal, India

Aritra Kumar Mukherjee
Dept.of Agril. Chemistry & Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur. Nadia, West Bengal, India

Correspondence
Gayatri Sahu
Dept.of Agril. Chemistry & Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur. Nadia, West Bengal, India

Potential use of flyash in agriculture: A way to improve soil health

Gayatri Sahu, Animesh Ghosh Bag, Nitin Chatterjee and Aritra Kumar Mukherjee

Abstract
FA (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. 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.

Keywords: FA, soil health, waste management

Introduction

Fly ash is produced as a result of coal combustion in thermal power station and discharged in ash ponds. Every year thermal power plants in India produce more than 100 million tonnes of FA, which is expected to reach 175 millions in the near future [41]. Disposal of this huge quantity of FA is posing a great problem due to its limited utilization in the manufacturing of bricks, cements, ceiling and other civil construction activities. This would further bring changes in land-use patterns and contribute to land, water and atmospheric degradation, if proper management options for handling ash are not undertaken [45]. The countries like Germany, Denmark, France, U.K., USA, and the Netherlands utilize FA (up to 70 %) as a building material and for other construction purpose, but in India its utilization is less than 15 % [102]. FA contains essential macro-nutrients like P, K, Ca, Mg and S and micro-nutrients including Fe, Mn, Zn, Cu, Co, B and Mo. The pH of FA can vary from 4.5 to 12.0 depending largely on the sulphur content of the parent coal and the type of coal used for combustion affects the sulphur content of FA. Use of FA in agriculture provides a feasible alternative for its safe disposal to improve the soil environment and enhance the crop productivity.

The commercialization of FA as a fertilizer in agricultural sector for crop production is uncommon in the most countries, because FAes may contain non-essential elements (e.g. As, B, Cd, Se) that adversely affect crop and soil and poor in both nitrogen (N is absent because it is oxidized into gaseous constituents during the combustion) and P (excessive Fe and Al convert soluble P to insoluble P compounds, which are not readily available to plants [3]. Factors that restrict the ash disposal in soils are the content of potentially toxic elements (as B, Se, Ni, Mo and Cd), high salinity and reduced solubility of the some nutrients from the high pH of some FAs. Several studies focused mainly on the general characteristics of ashes that are essential for the soil treatments and their benefits to the growth and yield of crops. There is a need to evaluate the impact of FA on the soil system such as soil fertility, soil health, soil microbes, soil enzymatic activity and crop productivity etc. Our aim in this review paper is to briefly explain the properties of FA which is related to incorporation of soil, the effect of FA on the soil system and discuss potential uses of FA for amelioration of structural, nutritional and other problems in degraded soils for the productivity.

Impact of FA on soil fertility

Effect of FA on Physical Properties of Soil

FA application to sandy soil could permanently alter soil texture, increase micro porosity and improve the water holding capacity [31, 68] FA addition at70 t ha^{-1} has been reported to alter the texture of sandy and clayey soil to loamy [14]. 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 [13]. The particle size range of FA is similar to silt and changes the bulk density of soil. Application of FA 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. A gradual increase in FA concentration in the normal field soil (0, 10, 20 up to 100% v/v) was reported to increase the porosity and water-holding capacity [49]. This improvement in water-holding capacity is beneficial for the growth of plants especially under rainfed agriculture. Amendment with FA up to 40% also increased soil porosity from 43 to 53% and water-holding capacity from 39 to 55% [100]. FA had been shown to increase the amount of plant available water in sandy soils [103]. 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 [39].

Effect of FA on Chemical Characteristics of Soil

Lime in FA (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 [82]. The FA has been used for correction of sulphur and boron deficiency in acid soils [19]. Application of FA for increasing the pH of acidic soils [73]. 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 [72]. The hydroxide and carbonate salts give fly-ash one of its principal beneficial chemical characteristics, the ability to neutralize acidity in soils [18]. FA has been shown to act as a liming material to neutralize soil acidity and provide plant available nutrients [103]. Researchers have shown that the use of fly-ash as liming agent in acid soils may improve soil properties and increase crop yield. The electrical conductivity of soil increases with FA application and so does the metal content. Decolorization of effluents by FA has been reported earlier by a number of workers [86] and a mixture of FA and coal in the ratio of 1: 1 can be substituted for activated carbon owing to increase in surface area available for absorption [34]. Metals like Fe, Zn, Cu, Mn, Ni and Cd have been shown to be available at higher concentrations in DTPA extracts of FA. 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 [35] in turn due to higher essential ion availability in the FA. [87] observed that gradual increases in soil pH, conductivity, available phosphorus, organic carbon and organic matter with increased application rate of FA. FA 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 [55].

Effect of FA on Biological Characteristics of Soil

Information regarding the effect of fly ash amendment on soil biological properties is very scanty [88]. The results of several laboratory experiments revealed that application of unweathered fly ash particularly to sandy soil greatly inhibited the microbial respiration, enzymatic activity and soil N cycling processes like nitrification and N mineralization [17, 110, 75, 30]. 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 leach- ing, thereby reducing the detrimental effects over time [95]. 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 as reported by Karpagavalli and Ramabadran [46], whereas the population of Rhizobium sp. and P-solubilizing bacteria were increased. The soil fly-ash environment was the most suitable for the proliferation of these bacteria, thereby contributing towards enhanced availability of soil phosphorus [26]. Gaind and Gaur [27] found that the application of fly-ash at 40 t ha 1 in conjunction with *Pseudomonas striata* inoculation improved the bean yield, nutrient uptake by grain and highest population of the bacteria in the inoculated series, though both 40 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 [88].

[29] 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 g, 20 g and 30 g FA kg^{-1} soil on the infectivity and effectiveness of vesiculararbuscular 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 *C. cajan* 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).

[36] 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 spp.*) on FA 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 with autochthonous site-adopted ectomycorrhizal fungi in FA and thereby to improve revegetation of FA landfills with willows. [80] 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 limiting microbial activity [22]. It has been found that a significant increase in the rate of CO_2 evolution and the activity of soil enzymes (protease and dehydrogenase) in FA amended soil from a pot culture experiment. Increase in enzyme activity and CO_2 evolution in soil have been reported as favourable for soil microbial activity. The enzymatic activity was measured in 6 treatments after one month of planting and before harvesting the rice crop. Invertase, amylase, dehydrogenase and protease activity increased with increasing application of FA up to 10 t ha^{-1}, but decreased with higher levels of FA application [84, 74] reported that soil phosphatase, sulfatase, dehydrogenase and invertase were inhibited as FA treatment levels increased. Catalase activity was not significantly affected by FA concentration. [70] 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. Co-application of FA and earthworms at lower doses can thus be considered to stimulate soil biological activity and thereby improve nutrient cycling in acidic soil. Addition of the sludge to the FA–soil mixtures generally enhanced enzyme activity. [52] reported that FA added to soil @ 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.

FA as a source of plant nutrients

Chemically, fly ash contains elements like Ca, Fe, Mg, and K, essential to plant growth, but also other elements such as B, Se, and Mo, and metals that can be toxic to the plants [37, 38, 50, 55, 44]. Lime in fly ash readily reacts with acidic components in soil leading to release of nutrients such as S, B and Mo in the form and amount favourable to crop plants [39]. FA contains negligible amount of soluble salt and organic carbon and adequate quantity of K, CaO, MgO, Zn and Mo. However, it is potentially toxic to plants due to high B content (345 mg kg^{-1}) [103]. After application of fly ash, the downward move of nutrients through soil column and the availability of nutrients for plant growth became limited to a depth of 80 cm from the soil surface [60]. According to [47] a gradual increase in fly ash concentration in the normal field soil from 0, 10, and 20 up to 100% v/v increased the pH, thereby improving the availability of sulfate, carbonate, bicarbonate, chloride, P, K, Ca, Mg, Mn, Cu, Zn and B. They also found that addition of fly ash to acidic and alkaline soil decreased the amounts of Fe, Mn, Ni, Co and Pb released from acid soil. However, the release of these metals from alkaline soil remained unchanged. The changes in the selected properties and heavy metal contents of three soil types in India were studied by [102]. The mixtures of soil with different proportion of fly ash and sludge, either alone or in combination, at a maximum application rate of 52 t ha^{-1} were incubated for 90 day at near field capacity moisture level. Sewage sludge, due to its acidic and saline nature, high organic matter and heavy metal contents, had more impact on soil properties than the fly ash. Electrostatic precipitator (ESP) ash collected directly from thermal power station in Bathinda, India, was more fine textured, lower in pH and richer in nutrients than the ash of dumping sites [94]. The ashes had both higher saturation moisture percentage and lower bulk density as compared to the normal cultivated soils. The dominant cation on the exchange complex was found to be Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+} in addition to high S content. In a study with methi (*Trigonella foenum–graecum*), Inam [37] applied different basal doses of fly-ash at 0, 5, 10 and 15 t ha^{-1} along with two doses of nitrogen (40 and 20 kg ha^{-1}). Uniform basal dose of 30 kg P and 40 kg K ha^{-1} was also applied. In general, fly ash at 10 t ha^{-1} with 20 kg N ha^{-1} proved better, while higher dose of fly ash proved deleterious. FA is not recognized as an optimal source of phosphorus as it was found inferior to monocalcium phosphate [58]. However, it hastened Ca^{2+} and Mg^{2+} uptake by legumes [67].

Use of fly ash in composting

In sewage sludge composting, lime is used to raise the pH and thereby to kill pathogens and to reduce the avail- ability of heavy metals enriched in sludge [21]. Since alkaline coal fly ash contain a large amount of CaO, it can serve the purpose of lime [42], as it reduced the availability of heavy metals by physical adsorption and precipitation at high pH [107]. Moreover, it is also cheaper than lime. Co-composting of fly ash at 20% level with wheat straw and 2% rock phosphate (w/w) for 90 day recorded lowest C:N of 16.4:1 and highest available and total phosphorus [27]. Mixing alkaline fly-ash with highly carbonaceous acidic material to make compost for soil treatment had also been suggested [3]. The low nitrogen content of fly-ash is an important constraint for its agricultural application. In a study, [10] investigated the possibility of improving the N status in mixtures of fly ash and organic matter by implementing vermicomposting technology. Different combinations of fly ash and cow dung viz., fly ash alone, cow dung alone and fly ash + cow dung at 1:1, 1:3 and 3:1 ratios were incubated with and without epigeic earthworms (*Eisenia foetida*) for 50 day. Results revealed that different bio-available forms of N, such as easily mineralizable NH_4 and NO_3, considerably increased in the series treated with earthworms. It could be largely attributed to augmented microbiological activity in the vermicomposted samples and also to considerable rise in the concentration of N-fixing bacteria in this series. Among the three combinations, the highest avail- ability of N was recorded in 1:1 mixture of vermicomposted fly ash and cow dung. For proper fly ash/sludge ratios, the fly ash could also act as an outstanding neutralizer in the acidic waste. Leaching of heavy metals from the aggregate samples was below the environmental limits within a pH range between 3 and 9 [75, 76].

FA for improving crop growth and yield

Several reports are available related to the use of fly ash as a soil amendment for the benefit of a large number of field crops. The safe and sustainable use of sewage sludge/fly ash combination on agricultural soils is suggested to be a highly promising endeavor from environmental point of view [86]. FA, having both the soil amending and nutrient enriching properties, is helpful in improving crop growth and yield in low fertility acid lateritic soils [8, 25] 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*) grew on a slightly acidic soil (pH 6.0) treated with 125 MT ha^{-1} of unweathered fly ash and that these crops showed higher contents of As, B, Mg and Se. Application of weathered coal fly ash at 5% resulted in higher seed germination rate and root length of lettuce (*Lactuca sativa*) [53]. The crop response to fly ash application may vary widely from beneficial to toxic depending on the concentration of various elements present in it [33, 44]. Application of fly ash extract in the lower concentration range of 0.5–1.0% (w/w) had no significant effect on germination and seedling growth of corn and soybean, whereas higher concentration of fly ash extract had deleterious effect on germination, viability, number of roots, shoot and root length, fresh weight and dry matter of seedling of both the crops [92]. Use of swine manure with fly ash balanced the ratio between monovalent and bivalent cations ($Na^+ + K^+/Ca^{2+} + Mg^{2+}$), which are detrimental to the soil and thereby increased the availability of Ca and Mg [32]. Application of fly ash at 10 and 20 t ha^{-1} improved rice yield from 1.02 to 3.83 t ha^{-1} in 1979 and 4.65 t ha^{-1} in 1980. Similarly, wheat yield was improved from 0.57 t ha^{-1} (control) to 2.53 t ha^{-1} in 1979 and 2.85 t ha^{-1} during 1980s [101]. Amendment of fly-ash up to 40% improved the growth and yield of rice crop, whereas the gradual decline in plant growth and yield parameters was found from 60% to 100% fly ash amended soil. This adverse effect was attributed to salinity caused by higher levels of sulfate, chloride, carbonate and bicarbonate in fly ash amended soil [96]. Possessing alkalinity and containing some essential mineral elements, coal fly ash could be an alternative to lime amendment and a nutrientsource of container substrates for ornamental plant growth [20]. Medicinal plants such as cornmint (*Mentha arvensis*) and vetiver (*Vetiver zizanoides*) were successfully planted in fly ash mixed with 20% farmyard manure and mycorrhiza [2, 91]. Amendment of different fly ash–soil combinations resulted in high yield of aromatic grasses, particularly palmarosa (*Cymbopogon martini*) and citronella (*Cymbopogon nardus*), which was due to increased availability of major plant nutrients [6, 66]. Lee *et al*. [56] applied fly ash at 0, 40, 80, and 120 Mg ha^{-1} in paddy soil to determine boron (B) uptake by rice and characteristics of accumulation in the soil. Results indicated that in all fly ash treatments, B content in rice leaves and available B in soil at all growing stages were higher than those of control but all were below toxicity levels. Boron occluded in amorphous iron and aluminium oxides was 20–39% of total B and was not influenced by fly ash application. Most of the B accumulated by fly ash application was residual B which is of plant unavailable form and comprised >60% of the total B in soil. Therefore, it could reasonably be stated that fly ash could be a good soil amendment for rice production without B toxicity.

Improvement of degraded lands by FA

Sometimes soil loses fertility and quality due to environmental causes and unmanaged exploitation by human. For increasing soil productivity, waste FA could be used as exploitable resource for the management of degraded soils, because FA possesses several similarities like soil and contains essential micro-nutrients (Fe, Mn, Zn, Cu, Co, B and Mo) and macro-nutrients (P, K, Ca, Mg and S). FA also can be used in the reclamation of wastelands (sodic soil, acidic soil and mine spoil) as FA possesses many of the functional properties of lime and gypsum [89, 51]. [69] also suggested the use of FA in the reclamation of wastelands. Field experiments have indicated that the chemical constituents of FA can improve agronomic properties of soil [19, 107, 94]. The most promising agronomic use for these materials may be to substitute for lime or fertilizers as soil amendments [87]. Innovative usage options that can utilize greater percentage of FA are being explored and large-scale application on land has been advocated as a promising utilization option [5]. As a result of strip mining of coal, millions of hectares of land worldwide became wasteland. Mine spoil is often characterized as having low fertility, low organic matter content, low water-holding capacity, and low soil biological activity, yet it is used as a substitute for topsoil in surface-mine re-vegetation when topsoil is lacking [81]. Since wasteland re-vegetation objectives may not be met if a suitable soil environment is not provided, amendments such as FA, sewage sludge and arbuscular mycorrhizal fungi can be added to mine spoil to help create a functional soil [78]. Addition of alkaline FA to wasteland or mine spoils increases the soil pH, decreases soil bulk density, alters soil texture, increases water-holding capacity, reduces compaction and enhances soil fertility [14, 41, 23, 61]. The amount of FA needed to reclaim such areas depends upon the pH of FA, state of weathered and pH of the land to be reclaimed. Huge volume of neutral FA can be profitably used [1] by coapplication of a lime-stabilized biosolid for the reclamation of acid mine spoil. [77] reported that application of FA and poultry biosolid helped in restoration of eroded land with no adverse effect on the soil nutrient status and environment. [85] observed in a field experiment that wasteland (agriculturally unproductive) soil amended with 25% (w/w) FA resulted in a 40% increase in plant growth. FA neutralizing ability also depends on its source and extent to which it is weathered. Addition of unweathered FA is not advisable as it may substantially increase the soil salinity. Lagooning, leaching and stockpiling appreciably solve this problem, minimizing boron toxicity and other ill effects of unweathered FA [68, 72]. FA could be used as an alternative to lime for reclaiming the acidic mine spoils [16, 98].

Using FA for reducing global warming

Agricultural lime contributes a prime role in the global fluxes of the greenhouse gases such as carbon dioxide, nitrous oxide and methane. Many researches revealed that additional opportunities have arisen for lessening the global warming potential by altering the agronomic practices [82]. 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 tonnes) CO_2 was emitted from an approximate 20 Tg of applied agricultural lime in 2001 [104]. Some researchers have been worked on utilization of FA in place of agricultural lime for minimizing global warming [9, 59]. An experimental study revealed that 1 tonne of FA could sequester up to 26 kg of CO_2, i.e., 38.18 tonnes of FA per tonnes of CO_2 sequestered. This study confirmed the possibility to use this alkaline residue for CO_2 mitigation [62]. 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 [24, 100]. According to one estimate,use of 1 tonne of FA in concrete will avoid 2 tonnes of CO_2 emitted from cement production and reduces green-house effect and global warming [50, 65]. 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.

Current aspects of FA incorporation in soil

For effective FA incorporation in soil, a good understanding of how soil biota, especially earthworm, responds to amendment of agricultural soil with FA is needed. Survival rate and function of earthworms are recognized as valuable indices of soil health and fertility in agriculture. In ecological terms, structural features of burrows are known tosignificantly influence hydrology, gas diffusion and nutrient distribution [12, 11]. For instance, long and complex branching burrows were found to be more efficient in conducting water into the soil, compared with less complex burrows [7]. There is a scarcity of studies regarding the effects of FA amended soil on the earthworm. [64] reported that in soil, that are heavily polluted with heavy metals, such as Cu, Cd, Pb and Zn, the burrows showed greater branching and concentration near the soil surface than in non-polluted soils. However, the effects on the burrow characteristics of relatively low amounts of heavy metals, such as those applied to soil through the FA addition [63], have not been reported. Currently, [107] determined basic structural features of burrows created by earthworms of native megascolecid and exotic Aporrectodea trapezoides in intact soil cores (150 mm ID by 0.3 m deep) that were treated with coal FA at 0, 5 or 25 Mg ha^{-1} mixed into the top 50 mm of the cores. The cores were inoculated at a rate equivalent to 850 worms m_2 and after 6 weeks they found that FA reduced the total volume of the burrow system (Vs) by up to 39% for the native species and 29% for the exotic species, these reductions averaged 33% with addition of ash at 5 Mg ha^{-1} and 39% at 25 Mg ha^{-1}. While the native earthworms responded to treatment by burrowing deeper into the soil core and away from the ash-tainted surface soil, the exotic species reduced the depth of burrowing and remained close to the surface. FA addition did not have significant effect on tortuosity of the burrows for either earthworm species. *A. trapezoides* created predominantly vertical burrows, while the native megascolecid worms produced more horizontally oriented burrows in addition to vertical ones. These modifications of earthworm behaviour by FA addition to soil, along with previous experience with plant growth, suggest that an ash application rate of 5 Mg ha_1 is close to optimum for routine agronomic applications. Additionally [57] revealed that up to 50% of FA amendment does not apparently harm the earthworm *L. mauritii* in respect of their survival and growth. A significant increase in tissue metallothionein level was recorded in *L. mauritii* without tissue metal accumulation indicating that metallothionein is involved in scavenging of free radicals and reactive oxygen species metabolites. It is concluded that this biochemical response observed in *L. mauritii* exposed to FA amended soil could be used as a valuable tool for eco-toxicological field monitoring.

Recommendations and perspectives

FA can be directly used as a soil conditioner in different degraded soils, mainly for the purpose of forestry and floriculture. However, the recommendation for a large FA application to agricultural soils in a region cannot be made, unless extensive trials are made to find out a proper combination of FA with each type of soil to establish its quality and safety. Additionally, food-chain transfer studies for all potentially toxic elements present in FA are needed to evaluate the effect of heavy metal on the human health. Concurrently, in future, attention should be given on some important aspects related to FA incorporation to soil like long-term studies of impact of FA on soil quality, soil fertility, soil health and continuous monitoring on the properties of soil and FA. Utilization of FA with organic waste (i.e. poultry, sewage sludge etc.) mixtures without natural soil for successive phytocolonisation of economically important plants and ecological rehabilitation in mining areas, to solve the shortage of soil resource, would be a tendency in the future for the improvement of such areas with economic importance.

Conclusion

Utilization of FA in agriculture may provide a feasible alternative for its safe disposal without serious deleterious effects. However, FA varied widely in its physical and chemical composition, therefore, the mode of use in agriculture is different and depends on the characteristics of soil or soil type. FA application in soil modified the physical and chemical properties of soil along with the growth and yield of crops. At prevailing rates of FA application in farmers fields in villages around NCPP, growth and yield of both the crops increased, but the results were non-significant and hence need to be verified in a well-designed long-term experiment. Relative contributions of soil and canopy environment factors responsible for changes in growth and yield of crops by FA in soil have to be evaluated. 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. Further there is need to investigate the fate of trace/heavy metals in soil-water-plant system with FA applications.

References

1. Abbott DE, Essington ME, Mullen MD, Ammons JT. Fly ash and limestabilized biosolid mixtures in mine spoil reclamation simulated weathering. J. Environ. Qual. 2001; 30:608-616.
2. Adholeya A, Sharma MP, Bhatia NP, *et al*. Mycorrhiza biofertilzer: a tool for reclamation of wasteland and bioremediation. In: National symposium on microbial technologies for environmental management and resource recovery. New Delhi, India: TERI, 1997.
3. Adriano DC, Page AL, Elseewi AA, *et al*. Utilization of flyash and other coal residues in terrestrial ecosystems: a review. J Environ Qual. 1980; 9:333-344.
4. Adriano DC, Page AL, Elseewi AA, Chang AC, Strughan I. Utilization and disposal of fly ash and other coal residue in terrestrial ecosystems, review. J. Environ. Quality. 1980; 9:333-334.
5. Adriano DC, Weber JT. Influence of fly ash on soil physical properties and turf grass establishment. J. Environ. Qual. 2001; 30:596-601.
6. Asokan P, Saxena M, Bose SKZ, *et al*. In: Proceedings of the workshop on Flyash Management in the State of Orissa. Bhubhaneshwar, India: RRL, 1995, 64-75.
7. Bastardie F, Cannavacciuolo M, Capowiez Y, de Dreuzy JR, Bellido A, Cluzeau D. A new simulation for modeling the topology of earthworm burrow systems and their effects on macropore flow in experimental soils. Biol. Fertil. Soils. 2002; 36:161-169.
8. Basu M, Bhadoria PBS, Mahapatra SC. Role of soil amendements in improving groundnut productivity of

acid lateritic soils. Int J Agric Res. 2007; 2(1):87-91.
9. Bernoux M, Volkoff B, Carvalho MS. CO_2 emissions from liming of agricultural soils in Brazil. Global Biogeochem. Cycles. 2003; 17(2):18-21.
10. Bhattacharya SS, Chattapadhyaya GN. Transformation of nitrogen during vercomposting of flyash. Waste Manage Res. 2004; 22(6):488-491.
11. Bouche MB, Al-Addan F. Earthworms, water infiltration and soil stability: some new assessments. Soil Biol. Biochem. 1997; 29:441-452.
12. Bouma J. Influence of soil macroporosity on environmental quality. Adv. Agron. 1991; 46:1-37.
13. Buck JK, Hanston RJ, Beimborn WA. Direct seedling of anthracite refuge using coal flyash as a major soil amendment Proceedings of the Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, 1990, 213-219.
14. Capp JP. Power Plant Flyash Utilization for Land Reclamation in the Eastern United States. In: Reclamation of Drastically Disturbed Lands, Schaller, 1978, 339-353.
15. Capp JP. Power plant fly ash utilization for land reclamation in the eastern United States. In: Schaller, F.W., Sutton, P. (Eds.), Reclamation of Drastically Disturbed Lands. ASA, Madison, WI, 1978, 339-353.
16. Carlson CL, Adriano DC. Environmental impacts of coal combustion residues. J. Environ. Qual. 1993; 22:227-247.
17. Cerevelli S, Petruzzelli G, Perna A, Menicagli R. Soil nitrogen and flyash utilization: a laboratory investigation. Agrochemica, 1986; 30:27-33.
18. Cetin S, Pehlivan E. The use of flyash as a low cost, environmentally friendly alternative to activated carbon for the removal of heavy metals from aqueous solutions. Colloids Surfaces A: Physicochem. Eng. Aspects. 2007; 298:83-87.
19. Chang AC, Lund LJ, Page AL, Warneke JE. Physical properties of fly ash amended soils. J. Environ. Qual. 1997; 6:267-270.
20. Chem J, Li Y. Coal flyash as an amendment to container substrate for Spathiphyllum production. Bioresour Technol. 2006; 97:20-26.
21. Christensen GL. Lime stabilization of wastewater sludge. In: Gutschick KA, editor. Lime for environmental use in ASTM STP 931. Philadelphia: Am Soc for Testing and Materials, 1987, 78-94.
22. Elliott LF, Tittemore D, Papendick RL, Cochran VL, Bezidicek DF. The effect of Mount St. Helen's ash on soil microbial respiration and numbers. J. Environ. Qual. 1982; 11:164-166.
23. Fail Jr JL. Growth response of two grasses and a legume on coal fly ash amended strip mine spoils. Plant Soil. 1987; 101:149-150.
24. Ferreira C, Ribeiro A, Ottosen L. Possible applications for municipal solid waste fly ash. J. Hazard. Mater. 2003; 96:201-216.
25. Furr AK, Parkinson TF, Gutenmann WH, *et al*. Elemental content of vegetables, grains and forages field grown on flyash amended soils. J Agric Food Chem. 1978; 26:357-359.
26. Gaind S, Gaur AC. Impact of flyash and phosphate solubilising bacteria on soybean productivity. Bioresour Technol. 2002; 85:313-315.
27. Gaind S, Gaur AC. Quality assessment of compost prepared from flyash and crop residue. Bioresour Technol. 2003; 87:125-127.
28. Gaind S, Gaur AC. Thermo-tolerant phosphate solubilising micro- organisms and their interaction with mung bean. Plant Soil. 1991, 141-149.
29. Garampalli RH, Deene S, Narayana Reddy C. Infectivity and efficacy of *Glomus aggregatum* and growth response of *Cajanus cajan* (L.) Millsp. in fly ash amended sterile soil. J. Environ. Biol. 2005; 26:705-708.
30. Garau MA, Dalmau JL, Felipo MT. Nitrogen mineralization in soil amended with sewage sludge and flyash. Biol Fertil Soils. 1991; 12:199-201.
31. Ghodrati M, Sims JT, Vasilas BS. Evaluation of flyash as a soil amendment for the Atlantic coastal plain. I. Soil hydraulic properties and elemental leaching. J. Water Soil Air Pollut. 1995; 81:349-361.
32. Giardini L. Aspetti agronomici della gestione dei reflui zootecnici. Rivista di Ingegnaria Agraria. 1991; 12:679-689.
33. Grewal KS, Yadav PS, Mehta SC, *et al*. Direct and residual effect of flyash application to soil on crop yield and soil properties. Crop Res 2001; 21:60-65.
34. Gupta GS, Prasad G, Singh VH. Removal of chrome dye from aqueous solutions by mixed adsorbents: flyash and coal. Water Res. 1990; 24:45-50.
35. Hall JL, Williams LE. Transition metal transporters in plants. J. Exp. Bot. 2003; 54:2601-2613.
36. Hrynkiewiez K, Baum C, Niedojadlo J, Dahm H. Promotion of mycorrhiza formation and growth of willows by the bacterial strain *Sphingomonas* sp. 23L on fly ash. Biol. Fert. Soils. 2009; 45:385-394.
37. Inam A. Response of methi to nitrogen and flyash supplemented as a source of nutrients. Pollut Res. 2007; 26(1):43-47.
38. Inam A. Use of flyash in turnip (Brassica rapa L.) cultivation. Pollut Res. 2007; 26(1):39-42.
39. Jala S, Goyal D. Flyash as a soil ameliorant for improving crop production – a review. Bioresour Technol. 2006; 97:1136-1147.
40. Jamwal N. Looks the ways to utilize fly ash. Down to earth. 2003; 12(3):1-5.
41. Jastrow JD, Zimmerman CA, Dvorak AJ, Hinchman RR. Plant growth and trace element uptake on acidic coal refuse amended with lime or fly-ash. J. Environ. Qual. 1981; 10:154-160.
42. Jiang RF, Yang CG, Su DC, *et al*. Coal flyash and lime stabilized biosolids as an ameliorant for boron deficient acidic soils. Environ Technol. 1999; 20:645-659.
43. Kachroo D, Dixit AK, Bali AS. Influence of crop residue, flyash and varying starter dosages on growth, yield and soil characteristics in rice (Oryza sativa)–wheat (Triticum aestivum) cropping system under irrigated conditions of Jammu region. Indian J Agric Sci. 2006; 76(1):3-6.
44. Kalra N, Harit RC, Sharma SK, *et al*. Soil properties of texturally variant soils. Bioresour Technol. 2000; 75:91-93.
45. Kalra N, Joshi HC, Chaudhary R, Choudhary A, Pathak H, Jain MC, *et al*. Impact of fly ash on environment and Agriculture. The Botanica. 1996b; 46:177-181.
46. Karpagavalli S, Ramabadran R. Effect of lignite fly ash on the growth and dry matter production (DMP) of soil borne pathogens. In: Souv and abstracts: National Sem on Bio-Utilization of Flyash. Berhampur, Orissa, India: Khallikote Autonomous College, 1997, 11.
47. Khan RK, Khan MW. The effect of flyash on plant growth and yield of tomato. Environ Pollut. 1996; 92(2):105-111.

48. Khan RK, Khan MW. The effect of fly ash on plant growth and yield of tomato. Environ. Pollut. 1996; 92:105-111.
49. Korcak RF. Utilization of coal combustion by-products in agricul- ture and horticulture. In: Karlen DL, Wright RJ, Kemper WO, editors, Agriculture utilization of urban and industrial by-products. ASA Special Publication No. 58. ASA, CSSA, SSSA. Mad. WI, 1995, 107-130.
50. Krishnamoorthy R. Ash utilisation in India—prospect and problems. Barrier and utilisation option for large volume application of fly ash in India. In: Hajela, V. (Ed.), Proceedings of theWorkshop on USAID/India Greenhouse Gas Pollution Prevention Project, 2000, 63-67.
51. Kumar D, Singh B. The use of coal fly ash in sodic soil reclamation. Land Degrad. Develop. 2003; 14:285-299.
52. Lal JK, Mishra B, Sarkar AK. Effect of fly ash on soil microbial andenzymatic activity. J. Ind. Soc. Soil Sci. 1996; 44:77-80.
53. Lau SSS, Wong JWC. Toxicity evaluation of weathered coal flyash amended manure compost. Water Air Soil Pollut. 2001; 128:243-254.
54. Lee H, Ha HS, Lee CH, *et al*. Flyash effect on improving soil properties and rice productivity in Korean paddy soils. Bioresour Technol. 2006; 97:1490-1497.
55. Lee H, Ha HS, Lee CS, Lee YB, Kim PJ. Fly ash effect on improving soil properties and rice productivity in Korean paddy soil. Bioresour. Technol. 2006; 97:1490-1497.
56. Lee SB, Lee YB, Lee CH, *et al*. Characteristics of boron accumulation by flyash application in paddy soil. Bioresour Technol. 2008; 99(13):28-32.
57. Maity S, Bhattacharya S, Chaudhury S. Metallothionein response in earthworms Lampito mauritii (Kinberg) exposed to fly ash. Chemosphere, 2009.
58. Martens DC. Availability of plant nutrients in flyash. Compos Sci. 1971; 12:15-19.
59. McBride AC, West TO. Estimating net CO_2 emissions from agricultural lime applied to soils in the US. In: Proceedings of the Fall meeting. American Geophysical Union (Abstract #B41B-0191), 2005.
60. Menon MP, Sajwan KS, Ghuman GS, *et al*. Flyash amended compost as a manure for agricultural crops. J Environ Sci Health A Environ Sci Eng. 1993; 28(9):2167-2182.
61. Mittra BN, Karmakar S, Swain DK, Ghosh BC. Fly ash a potential source of soil amendment and a component of integrated plant nutrient supply system. Fuel. 2005; 84:1447-1451.
62. Montes-Hernandez G, Pe´ rez-Lo´ pez R, Renard F, Nieto JM, Charlet L. Mineral sequestration of CO2 by aqueous carbonation of coal combustion flyash. J. Hazard. Mater. 2009; 16:1347-1354.
63. Muir MA, Yunusa IAM, Burchett MD, Lawrie R, Chan KY, Manoharan V. Short-term responses of contrasting species of earthworms in an agricultural soil amended with coal fly-ash. Soil Biol. Biochem. 2007; 39:987-992.
64. Nahmani J, Capowiez Y, Lavelle P. Effects of metal pollution on soil macroinvertebrate burrow systems. Biol. Fertil. Soils. 2005; 42:31-39.
65. Naik TR, Tyson SS. Environmental benefits from the use of coal combustion products (CCP). In: Verma, C.V.J., Rao, S.V., Kumar, V., Krishnamoorthy, R. (Eds.), Proceedings of the Second International Conference on Fly Ash Disposal, Utilisation, 2000, 40-43.
66. Neelima MR, Khandual S, Tripathy A, *et al*. In: Proceedings of workshop on Flyash Management in the State of Orissa. Bhubhaneshwar, India: RRL, 1995, 76-89.
67. Page AL, Elseewi AA, Straughan IR. Physical and chemical properties of flyash from coal-fired power plants with special reference to environmental impacts. Residue Rev. 1979; 71:83-120.
68. Page AL, Elseewi AA, Straugham I. Physical and chemical properties of flyash from coal fired plants with reference to environmental impacts. Residue Rev. 1979; 71:83-120.
69. Pandey VC, Abhilash PC, Singh N. The Indian perspective of utilizing fly ash in phytoremediation, phytomanagement and biomass production. J. Environ. Manage. 2009b; 90:2943-2958.
70. Pati SS, Sahu SK4. CO_2 evolution and enzyme activities (dehydrogenase, protease and amylase) of fly ash amended soil in the presence and absence of earthworms *(Drawida willsi* Michaelsen) under laboratory conditions. Geoderma. 2004; 118:289-301.
71. Phung HT, Lam HV. The practice of leaching boron and salts from fly ash amended soils. Water, Air Soil Pollut. 1979; 12:247-254.
72. Phung HT, Lund LJ, Page AL. Potential use of Fly Ash as a Liming Material. In: Environmental Chemistry and Cycling Processes, Adriano, D.C. and I.L. Brisbin (Eds.). U.S. Department of Commerce, Springfield, VA, 1978, 504-515.
73. Phung HT, Lund LJ, Page AL. In: Adriano, D.C., Brisbin, I.L. (Eds.), Potential Use of Fly-ash as a Liming Material in Environmental Chemistry and Cycling Processes. CONF-760429. U.S. Department of Energy, 1978, 504.
74. Pitchel JR, Hayes JM. Influence of flyash on soil microbial activity and populations. J Environ Qual. 1990; 19:593-597.
75. Polat M, Lederman E, Pelly I, *et al*. Chemical neutralization of acidic wastes using flyash in Israel. J Chem Technol Biotechnol. 2002; 77(3):377-381.
76. Polat M, Guler E, Lederman E, *et al*. Neutralization of an extremely acidic sludge and stabilization of heavy metals in flyash aggregates. Waste Manage. 2007; 27(4):482-489.
77. Punshon T, Adriano DC, Weber JT. Restoration of drastically eroded land using coal fly ash and poultry biosolid. Sci. Total Environ. 2002; 296:209-225.
78. Ram LC, Srivastava NK, Tripathi RC, Jha SK, Sinha AK, Singh G, *et al*. Management of mine spoil for crop productivity with lignite flyash and biological amendments. J. Environ. Manage. 2006; 79:173-187.
79. Rautaray SK, Ghosh BC, Mittra BN. Effect of fly ash, organic wastes and chemical fertilizers on yield, nutrient uptake, heavy metal content and residual fertility in a rice-mustard cropping sequence under acid lateritic soils. Bioresour. Technol. 2003; 90:275-283.
80. Ray P, Adholeya A. Correlation between organic acid exudation and metal uptake by ectomycorrhizal fungi grown on pond ash *in vitro*. Bio Metals. 2008; 22:275-281.
81. Reddell P, Milnes AR. Mycorrhizas and other specialized nutrient-acquisition strategies: their occurrence in woodland plants from Kakadu and their role in rehabilitation of waste rock dumps at a local uranium mine. Aust. J. Bot. 1992; 40:223-242.
82. Robertson GP, Paul EA, Harwood RR. Greenhouse gases

in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. Science, 2000, 1922-1925.
83. Robinson T, Marchant GR, Nigam P. Remediation of dyes in textile effluent: A critical review on current treatment technologies with a proposed alternative. Bioresour. Technol. 2001; 77:247-255.
84. Sarangi PK, Mahakur D, Mishra PC. Soil biochemical activity and growth response of rice *Oryza saliva* in fly ash amended soil. Bioresour. Technol. 2001; 76:199-205.
85. Saxena M, Asokan P. Fertility improvement by fly-ash application inwasteland. In: Fly-ash Disposal and Utilization, CBIP, International Conference I, 1998, 90-104.
86. Schoeman JL, van Deventer PW. Soils and the environment: the past 25 years. S Afr J Plant Soil. 2004; 21(5):369-387.
87. Schumann AW, Sumner ME. Plant nutrient availability from mixtures of fly ashes and biosolids. J. Environ. Qual. 1999; 28:1651-1657.
88. Schutter ME, Fuhrmann JJ. Soil microbial community responses to flyash amendment as revealed by analyses of whole soils and bacterial isolates. Soil Biol Biochem. 2001; 33:47-58.
89. Shainberg I, Sumner ME, Miller WP, Farina MPW, Pavan MA, Fey MV. Use of gypsum on soils: a review. Adv. Soil Sci.1989; 9:100-111.
90. Sharma MP, Tanu U, Reddy G, *et al*. Herbage yield of Mentha arvensis DC. Holms as influenced by AM fungi inoculation and farmyard manure application grown in flyash over burdens amended with organic matter. In: Interanational ash utilization symposium, KY, USA, 2001.
91. Shukla KN, Mishra LC. Effect of flyash extract on growth and development of corn and soybean seedlings. Water Air Soil Pollut. 1986; 27:155-167.
92. Sikka R, Kansal BD. Characterization of thermal powerplant flyash for agronomic purposes and to identify pollution hazards. Bioresour Technol. 1994; 50:269-273.
93. Sikka R, Kansal BD. Effect of fly-ash application on yield and nutrient composition of rice, wheat and available nutrient status of soils. Bioresour. Technol. 1995; 51:199-203.
94. Sims JT, Vasilas BL, Ghodrati M. Development and evaluation of management strategies for the use of coal flyash as a soil amendments. In: Proceedings of the 11th international symposium of the Am Coal Ash Assoc., Orlando, Florida, 1995, 1-18.
95. Singh LP, Siddiqui ZA. Effects of flyash and Helminthosporium oryzae on growth and yield of three cultivars of rice. Bioresour Technol. 2003; 86:73-78.
96. Sinha KS, Basu K. Mounting fly ash problems in growing coal based power stations few pragmatic approaches towards a solution, in Proc Int Conf fly ash Disposal and Utilization, edited by C.V.J. Verma *et al*. (Central Board of Irrigation and Power, New Delhi). 1998; 1:15-27.
97. Srivastava A, Chhonkar PK. Amelioration of coal mine spoils through fly ash application as liming material. J. Sci. Ind. Res. 1995; 59:309-313. Stehouwer, R.C., Sutton, P., Fowler, R.K., Dick WA. Minespoil amendment with dry flue gas desulfurization by-products. Element solubility and mobility. J. Environ. Qual. 2000; 24:165-174.
98. Taylor EM, Schumann GE. Flyash and lime amendment of acidic coal soil to aid revegetation. J. Environ. Qual. 1998; 17:120-124.
99. Tietenberg T. Environmental and Natural Resource Economics, sixth ed. Addison Wesley, USA, 2003, 404-412.
100. Tiwari KN, Sharma DN, Sharma VK, *et al*. Evaluation of flyash and pyrite for sodic soil rehabilitation in UP, India. Arid Soil Res Rehabil. 1982; 6(2):117-126.
101. Veeresh H, Tripathy S, Chaudhuri D, *et al*. Competitive adsorption behaviour of selected heavy metals in three soil types of India amended with flyash and sewage sludge. Environ Geol. 2003; 44:363-370.
102. Warambhe PE, Kene DR, Thakre KK, *et al*. Evaluation of physiochemical properties of flyash of thermal power station, Koradi (Nagpur) for its likely use in agriculture. J Soils Crops. 1993; 3(1):75-77.
103. West TO, McBride AC. The contribution of agricultural lime to carbon dioxide emissions in the United States: dissolution, transport, and net emissions. Agric. Ecosys. Environ. 2005; 108(2):145-154.
104. Wong JWC. The production of artificial soil mix from coal flyash and sewage sludge. Environ Technol. 1995; 16:741-751.
105. Wong MH, Wong JWC. Effects of flyash on soil microbial activity. Environ Pollut Ser A. 1986; 40:127-144.
106. Wong MH, Wong JWC. Germination and seedling growth of vegetable crops in fly ash amended soils. Agric. Ecosys. Environ. 1989; 26:23-35.
107. Yunusa IAM, Braun M, Lawrie R. Amendment of soil with coal fly ash modified the burrowing habits of two earthworm species. Appl. Soil Ecol. 2009; 42:63-68.