Biological Responses of Agricultural Soils to Fly-Ash Amendment

Rajeev Pratap Singh, Bhavisha Sharma, Abhijit Sarkar, Chandan Sengupta, Pooja Singh, and Mahamad Hakimi Ibrahim

Contents

R.P. Singh (✉) • B. Sharma
Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
e-mail: rajeevprataps@gmail.com

A. Sarkar
Department of Botany, University of Kalyani, Kalyani, West Bengal, India

Research Laboratory for Biotechnology and Biochemistry (RLABB), P.O. Box 13265, Kathmandu, Nepal

C. Sengupta
Department of Botany, University of Kalyani, Kalyani, West Bengal, India

P. Singh
Division of Bio-Resource, Paper and Coatings Technology, School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, Malaysia

M.H. Ibrahim
Environmental Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, Malaysia

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1 Introduction

Increased urbanization and industrialization worldwide has resulted in increased releases of solid waste, and enhanced environmental pollution around the globe. There are several categories of solid waste and these include sewage sludge, and municipal solid wastes (Singh et al. 2011). Fly Ash (FA), a coal combustion residue (CCR), is a major type of solid waste. The global dependence on coal as a major source of energy production, especially to produce electricity, has made FA a prime solid waste problem and a growing environmental pollutant. Proven global coal reserves have been estimated at 847 billion tons for the year 2007 (Sarkar et al. 2012). The USA has the largest share of global coal reserves (25.4%), followed by Russia (15.9%), China (11.6%) and India (8.6%) (Sarkar et al. 2012). Since India became independent in 1947, there has been a rapid increase in power generation, largely dominated by coal-based thermal generation constituting about 79% of total production. Energy production has increased from a capacity of 1,362 MW in 1947 to 120,000 MW in 2005. The Indian government plans to increase installed capacity to 300,000 MW by 2017 (Kumar et al. 2005; Vaidya 2009). India, like the United States, Russia and China, possesses abundant coal reserves, and coal-fueled generation of electricity is the common national policy (Singh et al. 2012; Sarkar et al. 2012).

During the combustion of coal several residues are produced. These include FA, bottom ash, flue gas desulphurization waste, fluidized bed boiler waste and coal gasification ash. FA is a residue of coal combustion (CCRs) that enters the flue gas stream. The nature of the FA produced largely depends on the quality and ash content of the coal that is burned. Indian coal is generally of lower grade than imported coals, and thereby has higher ash content (40%; CEA 2011).

The annual production of FA has increased from about 1.0 million metric tons (MT) in 1947 to about 112 MT during 2005. According to estimates from the FA Utilization Programme (FAUP), FA production is likely to reach 225 MT annually by 2017 (Kumar et al. 2005) (Fig. 1). Disposal of such an enormous amount of FA is a massive problem, particularly if it must be deposited in areas that surround thermal power stations. The major portion of FA produced in India is disposed of in ash ponds and in landfills; a minor proportion (<15%) is used to manufacture bricks, ceramics and cements (Pandey et al. 2009). The utilization of FA (3% of the 40 MT produced in 1994), has increased to ~38% of total production (viz., 112 MT) during 2004–05; this proportion is far below the global utilization rate (Dhadse et al. 2008; Singh et al. 2010) (Fig. 1). In India, 49% of FA is utilized in the cement industry, whereas only about 1% is used in the agricultural sector (Singh et al. 2010).

In agriculture, FA is primarily utilized as a soil amendment to buffer the soil pH (Phung et al. 1978). Such amendment improves soil texture (Fail and Wochok 1977; Chang et al. 1977) and soil nutrient status (Rautaray et al. 2003). However, the majority of the FA that is produced remains in ash storage ponds, and these deposits pose risks of several adverse effects to the environment.

In the present review, our aim is to address how FA can be utilized in global agriculture, and to provide the consequences of this use on soil health. Our major focus is

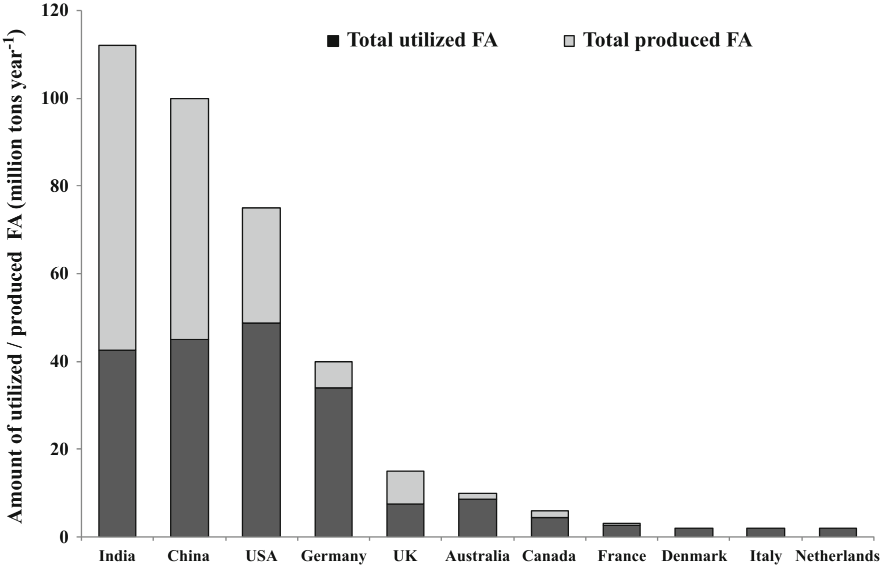

Fig. 1 The amount of FA produced and utilized in different countries. Source: Dhadse et al (2008)

to understand what the biological responses (i.e., physico-chemical, microbial, biochemical, etc.) are to FA-amended agricultural soils, and what effect FA amendment has on agricultural productivity. It is our intent to make this review useful for students and established researchers who work in the areas of soil nutritional dynamics and solid waste amendment. This review should also benefit some policy makers, who face the task of designing better and more sustainable approaches for managing solid waste pollution.

2 Physico-Chemical Properties of Fly Ash (FA)

The physico-chemical properties of FA primarily depend on the nature of the parent coal composition from which it comes, and secondly on the conditions under which the coal is combusted (Karapanagioti and Atalay 2001; Pandey and Singh 2010). Coal is a complex polymeric solid lacking any repeating monomeric units. FA is formed from the mineral matter in coal, and comprises a fine powder consisting of the non-combustible matter in coal, along with a small quantity of carbon that remains from incomplete combustion. FA is the finest of coal ash particles.

Physically, FA is comprised of very fine glass-like particles that are 0.01–100 mm in size (Davison et al. 1974; Jala and Goyal 2006). These FA particles have specific gravities of 2.1–2.6 g m^{-3} (Bern 1976), low to medium bulk density, a large surface area and very light texture. The specific chemical composition of FA depends on the quality of and conditions under which the parent coal was combusted (Jala and

Goyal 2006; Basu et al. 2009; Gupta et al. 2012). Some particles of FA are empty spheres (cenospheres), while others (plerospheres) are filled with small amorphous particles (Hodgson and Holliday 1966). FA constitutes a varied combination of amorphous and crystalline phases (usually considered as ferroaluminosilicate) (Lim and Choi 2014) and has a matrix similar to soil. It also contains about 69% of a fine-earthed fraction (i.e., clay silt) that derives from coal. Hodgson and Townsend (1973) reported that samples of fly-ash-particle fractions contained from 45 to 70% silt and 1 to 4% clay. The bulk density of different fly ashes varies from 1 to 1.8 g cm^3, whereas the pH ranges from 4.5 to 12.0, and depends on the S content of the parent coal (Plank and Martens 1974).

Alkalinity is an important FA characteristic, and results from the presence of Ca, Na, Mg and OH, along with certain other trace metals. Kunavanakrit (1993) reported that FA contained a high amount of Ca and Mg, both of which have high pH (11) and a high cation exchange capacity (CEC). The sub-bituminous and lignite coal ashes produce alkaline solutions when mixed with water. The degree of alkalinity depends on the Ca content, since this element is in the highly reactive CaO form, and is a major constituent of the fly-ash- forming $Ca(OH)_2$ (Hodgson et al. 1982). The characteristics of FA are greatly influenced by the particle size of its components. Particle size also affects the physical properties of fly-ash-amended soil.

Parameters that describe the chemical characteristics of coal include molecular weight, carbon aromaticity, normal aromatic and aliphatic structure and functional groups present. Coal quality is ranked by using several criteria: anthroxylon content, oxygen content, calorific value, ultimate analysis, fixed carbon content, etc. (Hodgson et al. 1982; Speight 2005). By and large, Indian coals have a high mineral matter %, low S content, high moisture, high ash content (Oliveira et al. 2014) and low calorific value (3,500–4,000 kcal kg^{-1}) (Gupta et al. 2012). The ash content of Indian coal varies between 15 and 30% and the S content is usually <1% (Srivastava 2003; Bhatt 2006). FA consists of approximately 95–99% of Si, Al, Fe and Ca oxides and about 0.5–3.5% of Na, P, K and S and the residual is trace elements.

Ahmaruzzaman (2010) described FA as mainly being composed of Si, Al, and Fe, with a major proportion of Ca, K, Na, Ti, along with other trace elements. Coal FA consists of SiO_2 (49–67%), Al_2O_3 (16–29%), Fe_2O_3 (4–10%), CaO (1–4%), MgO (0.2–2%), and SO_3 (0.1–2%) (Anon 2006; Singh et al. 2010). All metals present in soil are also found in fly ash. In Table 1, we compare the physico-chemical characteristics of FA and soil. The concentration of various elements that occur in FA varies with particle size (Khan and Khan 1996). A listing of elements present in FA includes the following: Si, Ca, Mg, Na, K, Cd, Pb, Cu, Co, Fe, Mn, Mo, Ni, Zn, B, F and Al (Tripathi et al. 2004; Gupta and Sinha 2008), and therefore, all important metals essential for plant growth and metabolism are present except organic C and N. The reason FA lacks any or much N is because it is volatilized from the coal (Singh and Yunus 2000). In contrast, FA has a high concentration of phosphorous (P) (400–8,000 mg P kg^{-1}). Unfortunately, this P is not readily available to plants, which may be due to its active interaction with Al, Fe and Ca present in alkaline FA (Gupta et al. 2012).

Table 1 A comparison of the physico-chemical properties of FA, an agricultural soil, and an FA-amended agricultural soil

Properties	Fly Ash (Tripathi et al. 2004)	Fly Ash (Gupta and Sinha 2008)	Soil (Tripathi et al. 2004)	FA amended soil (20% wt/wt) (Singh (2009) (PhD thesis, unpublished data))
pH	8.80	8.12	8.05	7.86
E. C. (mS cm^{-1})	7.61	3.54	0.23	3.477
Organic carbon (%)	1.17	1.7	43.40	0.537
Total nitrogen (%)	0.02	–	2.50	0.117
Total phosphorus (%)	0.14	–	1.06	–
Metals (mg kg^{-1})				
K	9,005.00	28,706.00	–	472.96
Na	5,200.00	41,321.00	–	396.74
Fe	4,150.00	20,054.00	2,850.00	1518.26
Zn	82.00	94.70	22.60	–
Cd	42.30	31.23	< 0.002	–
Pb	40.10	26.81	< 0.005	–
B	29.00	–	1.36	–
Ni	204.00	23.44	23.80	–

Several workers have reported the presence of radionuclides in fly ash; however, little information exists as to their impact (Gowiak and Pacynas 1980; Mittra et al. 2005; Papastefanou 2008). Mittra et al. (2005) analyzed the radioactivity (Bq kg^{-1}) of FA and recorded high radioactivity levels of ^{226}Ra, ^{228}Ac and ^{40}K in soil treated with FA at 40 t ha^{-1}. Moreover, Tadmore (1986) reported the radionuclides of uranium (U) and thorium (Th) series as components of fly ash.

FA is generally rich in toxic heavy metals (e.g., manganese, nickel, lead, etc.) and hazardous organic pollutants (e.g., polycyclic aromatic hydrocarbons, polychlorinated biphenyls, methyl sulphates, chlorinated dioxins and benzofurans (Wheatley and Sadhra 2004). Therefore, using FA in agriculture can result in higher accumulation of such toxic chemicals in food products, which, in turn, could pose human health issues.

3 Biological Responses of Agricultural Soil to FA Amendment

3.1 Physico-Chemical Responses of Soil to FA Amendment

The effect of amending soils with FA has been extensively investigated (Plank and Martens 1974; Elseewi and Page 1984; Jala and Goyal 2006). Kesh et al. (2003) reported FA as a repository of nutrients that assists in reclaiming alkaline and saline soils and improving soil properties. Amending soils with FA affects all soil physical

Table 2 The physico-chemical and biological responses of soil that has been amended with FA

Soil properties	Effect	References
Physical		
pH	Decrease	Pathan et al. (2003), Sinha and Gupta (2005), Gupta and Sinha (2006)
	Increase	Wong and Wong (1990), Jala and Goyal (2006)
Aggregate stability	Increase	Jala and Goyal (2006), Basu et al. (2009), Singh et al. (2010)
Bulk density	Decrease	Page et al. (1979), Singh et al. (2012a), Basu et al. (2009), Gupta et al. (2012)
Water holding capacity	Increase	Campbell et al. (1983), Page et al. (1979), Chang et al. (1977), Jala and Goyal (2006), Basu et al. (2009), Pandey and Singh (2010)
Porosity	Decrease	Page et al. (1979), Pandey and Singh (2010), Gupta et al. (2012)
Chemical		
Toxic elements (Cd, Pb, Ni etc.)	Increase	Gupta and Sinha (2006), Singh et al. (2010), Pandey and Singh (2010)
Fe, Cu, Zn, Mn	Increase	Tripathi et al. (2004), Gupta and Sinha (2006, 2008)
Electrical conductance	Increase	Adriano et al. (1980), Eary et al. (1990)
	Decrease	Gupta and Sinha (2006), Pandey and Singh (2010), Gupta et al. (2012)
Cation exchange capacity (CEC)	Decrease	Sinha and Gupta (2005), Gupta and Sinha. (2006), Jala and Goyal (2006)
Organic carbon / organic matter	Decrease	Gupta and Sinha (2006), Singh et al. (2010), Gupta et al. (2012)
Biological		
Microbial activity	Decrease	Adriano et al. (1978), Wong and Wong (1986), Saffigna et al. (1989)
	Increase	Schutter and Fuhrmann (2001)
Leachablity		
Pesticides	Decrease	Konstantinou and Albanis (2000); Singh et al. (2012b, 2013a, b)
Heavy meals	Increase	Natusch and Wallace (1974)

and chemical characteristics such as texture, bulk density, pH, water-holding capacity, electrical conductance (EC) (Chang et al. 1977; Pathan et al. 2003; Singh et al. 2012a) and particle size distribution (Sharma 1989) (Table 2). A gradual increase in the rate of fly-ash amendment (0% 10% 25%, up to 100% v/v) in normal field soils increased water-holding capacity, EC, and pH (Gupta and Sinha 2006, 2009).

Chemical properties of soil are also affected by adding fly ashes, since they are rich in heavy metal content (Singh et al. 2010, 2012a; Gupta and Sinha 2006, 2009) (Table 2). Campbell et al. (1983) reported that adding FA to soil @ 10% (wt/wt) increased the water holding capacity of soil by 7.2 and 413.2 times for fine and coarse sands, respectively. The water holding capacity of sandy soils is improved from the fine textured nature of fly ash; FA amendment is also known to reduce compaction of clay soils (Sharma and Kalra 2006).

FA amendment also increases the amounts of soluble major and minor inorganic constituents of soil, resulting in a higher EC value (Adriano et al. 1980; Eary et al. 1990; Jala and Goyal 2006; Basu et al 2009; Pandey and Singh 2010) (Table 2). The fly ashes from India are primarily alkaline in nature; hence, applying them increases soil pH from the rapid release of Ca, Na, Al and OH^- (Wong and Wong 1990; Sinha and Gupta 2005) (Table 2).

In addition to containing heavy-metals, FA also retains trace elements that may contaminate soil (Basu et al. 2009; Singh et al. 2010). The majority of trace metals are released at a pH value of approximately 9 (Ahmaruzzaman 2010). Addition of a minute amount of FA to soils can significantly boost solution pH. As pH increases, there is a decrease in trace metal desorption from FA (Theis and Wirth 1977). Fly ash, because of its hydroxide and carbonate salt content, has the ability to neutralize soil acidity (Pathan et al. 2003). However, using excessive amounts of FA to neutralize soil acidity can result in excessive soil alkalinity, particularly with unweathered fly ashes (Sharma et al. 1989). In fact, some acidic fly ashes are deliberately used for reclaiming alkaline soils (Table 2).

Pandey et al. (2009) studied the influence of amending garden soils with fly ash, in which *Cajanus cajan* L. was planted. The amendment altered accumulation and translocation of hazardous metals into edible plant parts. *Cajanus cajan* L. Plants were grown in containers, in which the concentrations of FA had been altered (0% 25%, 50% and 100% wt/wt). Amendment with FA at ratios from 25 to 100% in this garden soil increased the pH, the particle density, porosity and water holding capacity in comparison to controls from 3.47% to 26.39%, 3.98% to 26.14%, 37.50% to 147.92% and 163.16% to 318.42%, respectively. This amendment also decreased bulk density from 8.94 to 48.89% in the amended soil as compared to non-amended soil (Pandey et al. 2009).

Singh et al. (2012a) reported a decrease in NH_4^+, NO_3^-, total N, organic carbon (OC), organic matter (OM), available P, and CEC after rice was transplanted to a soil that had been amended with FA (0–20%). Reduced NH_4^+ and NO_3^- content from different levels of FA amendment was also reported by Singh and Agrawal (2010). Lee et al. (2006) reported increased soil pH and increased availability of Si, P, among other mineralogical components, in a Korean paddy field soil that was amended with fly ash; they concluded that FA can be utilized for improving the nutritional balance in a paddy field soil (Lee et al. 2006).

Generally, the bulk density of soil declined with the addition of fly ash, which in turn reduced porosity and increased water holding capacity (Page et al. 1979; Pandey and Singh 2010). Several workers have reported that FA amendment significantly increases the water holding capacity of the amended soil. Although FA itself does not retain water efficiently, amending sandy and loamy soils with it increased water holding capacity by 8% (Chang et al. 1977). Singh and Agrawal (2010) reported a significant improvement in levels of soil nutrients (e.g., Na, K, Ca, Mg, and Fe) when increasing rates of FA were used to amend soils at Varanasi, India. The high boron (B) level in FA restricts its utilization in crop production (Aitken and Bell 1985). However, if the FA is properly weathered the problem with B can be overcome. FA has a liming effect on soils that increases calcium and hydroxide ion mobility, which in turn enriches bacterial growth (Surridge et al. 2009). However, high levels of toxic heavy metals that can be transferred to soils from adding FA (Page et al. 1979) can hamper normal microbial metabolic processes (Pandey and Singh 2010).

3.2 FA Management and the Soil Biochemical Cycle

Biological indicators are biological species that can be used to monitor environmental or ecosystem health. Biological indicators are often employed to represent some aspect of the living soil and its environment. Such indicators generally respond more rapidly to changes in the soil environment than do physical or chemical indicators (Anderson and Gray 1990; Pascual et al. 2000; Singh et al. 2011). Additionally, biological indicators are sensitive tools for detecting changes in soil conditions that may occur (Singh et al. 2011). Microbes are vital constituents of the soil environment that contribute to the degradation of organic matter and make nutrients more available to other soil organisms. The responses of microbes to the addition of FA have been explored in several studies that we will describe below, although there is a paucity of data for direct effects on the microbes themselves.

In the soil system, soil enzymes play a key biochemical role in organic matter decomposition (Burns 1983; Chròst 1991; Sinsabaugh et al. 1991). Enzymes are critical for catalyzing several reactions that are essential for life processes of soil micro-organisms; these include stabilizing the soil structure, nutrient cycling, decomposition of organic wastes and organic matter formation (Dick et al. 1994). These soil enzymes are continuously being synthesized, accumulated, inactivated and/or decomposed, and therefore play an important function in agriculture, mainly via assisting nutrient cycling (Tabatabai 1994; Dick 1997).

Each and every soil hosts a group of enzymes that perform metabolic processes (McLaren 1975), the presence and titers of which depend on the soil's physicochemical, microbiological and biochemical properties. Because soil enzymes have such a critical role, they respond so quickly to changes in soil management practices and are easy to measure, knowing more about their function potentially helps in assessing the prevailing biological status and function of soils (Dick 1997; Bandick and Dick 1999). Soil enzymes often significantly affect soil biology, environmental management strategies, and growth and nutrient uptake of plants that inhabit ecosystems.

Soil fungi comprise at least 75–95% of soil microbial biomass, and along with bacteria contribute ~90% of the total energy flux to the organic matter decomposition in soil (Paul and Clark 1996). Soil enzyme activity is especially important for fertility. Soil enzymes are routinely measured to provide a biological index of soil fertility. This index serves as an indicator for several biological processes in soil. 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 (Skujins 1978; Ceccanti et al. 1993).

Adding FA to soil stimulates enzyme activity (viz., dehydrogenase, urease and phosphatases, etc.; Pati and Sahu 2004). As mentioned, amending soils with FA adds many elements (e.g., C, K, Ca, Mg, Cu, Zn and Mn), and these elements may alter the chemical and physico-chemical properties of the soils to which they are added (Yeledhalli et al. 2007).

The amount of microbial biomass present is commonly used to characterize the microbiological status of soils (Nannipieri et al. 1990), and to evaluate the effect of soil management practices (Perrott et al. 1992). Soil microbial biomass is a sound indicator of soil health, because such biomass regulates nutrient cycling and acts as a highly labile source of nutrients that are available to plants (Jenkinson and Ladd 1981). Rippon and Wood (1975) attributed increased microbial populations in a soil to the addition of FA . However, higher FA amendment levels sometimes resulted in deposition of excessive amounts of certain toxic elements (e.g., As and B) in soil, and such deposition negatively affected the normal soil microbial dynamics and activity (Lim and Choi 2014). FA amendment of soil may benefit fungi and gram-negative bacteria more than other components of the soil microbial community (Schutter and Fuhrmann 2001).

Soil microbial biomass and dehydrogenase activity were reported to be highest at a FA amendment rate of 10% (wt/wt), because at this rate reasonable levels of nutrients were provided to microorganisms for carrying out various metabolic activities (Wong and Wong 1986; Saffigna et al. 1989). Microbial activity declined when FA was added at levels of more than 10% (Wong and Wong 1986; Saffigna et al. 1989). This decline may have resulted from reduced substrate availability that was associated with accumulation of persistent lignite-derived organic carbon compounds (Rumpel et al. 1998). Gaind and Gaur (2004) reported that *Azotobacter chroococcum*, *Azospirillum brasilense* and *Bacillus circulans* showed their maximum viability when FA alone was applied to soil, whereas *Pseudomonas striata* proliferated most in soil-FA (1:1) applications. Generally, the effects of FA applications on soil aggregation, together with the effects of growing plants on soil microbial diversity may favor plant growth and soil revival. Wong and Wong (1987) found that the application of FA increased microbial respiration in a sandy soil and decreased it in a sandy loam soil. Arthur et al. (1984) concluded that lower rates of FA applied to soil had a modest impact on microbial activity, but higher rates inhibited microorganisms. Schutter and Fuhrmann (2001) reported that amending degraded subsoil with FA caused an increased density of the microbial community.

3.3 FA Management and Soil Microbial Dynamics

As for other major solid wastes, utilization of FA in agriculture has gained popularity worldwide in the past few decades (Singh and Agrawal 2008; Singh et al. 2012). More recently, researchers have studied the effects of FA on soil health, especially the effects on soil–microbial interactions and dynamics (Sarkar et al. 2012). Modern day '-omics' approaches represent state-of-the-art technologies that offer prospects for a major breakthrough in soil – microbial dynamics. The '-omics' have provided modern day researchers with better tools to identify and evaluate microbial diversity in soil, water and air under diverse environmental conditions (Schneider and Riedel 2010). Integrated genomics and proteomics approaches promise to be swift and effective systems for analyzing and deducing gene function in living organisms at genome (*genomics*), transcript (*transcriptomics*), and protein (*proteomics*) levels (Sarkar et al. 2012; Agrawal et al. 2013). These three approaches are commonly referred as the multi-parallel '-omics' approaches in modern biology (Sarkar et al. 2010; Zargar et al. 2011). Recently, researchers have started to work with 'genome' and 'proteome' samples that are directly isolated from environment (Sarkar and Agrawal 2012). These sample entities are termed the 'metagenome' and the 'metaproteome', respectively. The *in-vivo* and *in-vitro* '-omics' approaches have significantly contributed to the evaluation of soil – microbial dynamics in many ecosystems. By using a metagenomics approach Sanapareddy et al. 2009) generated 378,601 sequences by pyrosequencing (by using 454-FLX technology) of DNA samples collected from an activated sludge basin of a wastewater treatment plant in Charlotte, North Carolina, USA. These authors identified a significant number of microbial communities in the sludge basin that might be useful for improving soil health. Wang et al. 2011) employed a metaproteomics approach through in-depth two-dimensional gel electrophoresis (2DGE), coupled with matrix-assisted laser desorption/ionization time-of-flight mass spectrometer (MALDI-TOF/TOF-MS), and identified nearly 122 proteins, constituting a metaproteome of a plant-microbe complex that existed in a crop rhizospheric soil. Other researchers have also utilized '-omics', particularly metagenomics and metaproteomics approaches. Such techniques allow improved discernment of microbial dynamism in soil samples under diverse environmental conditions, and the contributions of microbes to soil health (Schneider and Riedel 2010).

3.4 Other Responses of Soil Health to Fly-Ash Amendment

FA affects aspects of soil health not described above (Ahmaruzzaman 2010) (Table 2). In particular, it is known that FA hinders the normal leaching pattern of metals in soil. The pH, and chemical composition of a soil, as well as the FA used to amend a soil are all important variables that can influence the leaching behaviour of heavy metals (Becker et al. 2013) (Table 2). Amending agricultural soils with FA is known to restrict the normal soil leaching pattern of pesticides, and to boost pesticide retention (Singh et al. 2012b, 2013a, b). Application of FA to soils at the 20–30% level has been reported to detoxify 2, 4-D, alachlor and metolachlor in soil (Albanis et al. 1992, 1998). Konstantinou and Albanis (2000) reported that amending soil with FA up to 25% can immobilize atrazine, propazine, prometryne, molinate, propachlor and propanil herbicides. Singh et al. (2013a, b) reported that FA amendment in soil did not show an adverse effect on weed control efficacy of the herbicides metribuzin and metsulfuron-methyl. Hence, it is conceivable that FA could be used to amend soils in ways to help manage herbicide runoff and leaching losses.

4 Conclusions

Our main conclusions from reviewing the cogent literature on fly ash amendment of agricultural soils and from preparing this review are as follows:

1. Fly ash is a waste product from coal combustion process, and is a potential resource for amending agricultural soils to provide several essential plants nutrients. However, organic C and N are not among these nutrients.
2. When amending agricultural soils with FA, the appropriate methods and amounts used will depend on soil type, nature of the cultivated crop, prevailing climatic conditions and the characteristics of the FA used.
3. FA has a very high affinity for organic pesticides. Therefore, using it as a soil amendment can boost pesticide retention in agricultural soils.
4. Although applying FA in normal agricultural practice may benefit plant nutrition, it has a downside of potentially enhancing contamination by heavy metals in ways that affect ground water, well (drinking) water, and food chain organisms.
5. Harmful effects may result from applying FA to amend agricultural soils. Harm may come from enhanced levels of natural radioactivity (from FA) and from increased levels of toxic heavy metals that could contaminate food or feed. Therefore, care must be taken when FA is to be used as an agricultural soil amendment.
6. FA amendment in agriculture is undoubtedly in its infancy, and requires further study, particularly on dose-response relationships, before it can quality for large scale application in global agriculture.

5 Summary

The volume of solid waste produced in the world is increasing annually, and disposing of such wastes is a growing problem. Fly ash (FA) is a form of solid waste that is derived from the combustion of coal. Research has shown that fly ash may be disposed of by using it to amend agricultural soils. This review addresses the feasibility of amending agricultural field soils with fly ash for the purpose of improving soil health and enhancing the production of agricultural crops. The current annual production of major coal combustion residues (CCRs) is estimated to be ~600 million t worldwide, of which about 500 million t (70–80%) is FA (Ahmaruzzaman 2010). More than 112 million t of FA is generated annually in India alone, and projections show that the production (including both FA and bottom ash) may exceed 170 million t per annum by 2015 (Pandey et al. 2009; Pandey and Singh 2010). Managing this industrial by-product is a big challenge, because more is produced each year, and disposal poses a growing environmental problem.

Studies on FA clearly shows that its application as an amendment to agricultural soils can significantly improve soil quality, and produce higher soil fertility. What FA application method is best and what level of application is appropriate for any one

soil depends on the following factors: type of soil treated, crop grown, the prevailing agro climatic condition and the character of the FA used. Although utilizing FA in agricultural soils may help address solid waste disposal problems and may enhance agricultural production, its use has potential adverse effects also. In particular, using it in agriculture may enhance amounts of radionuclides and heavy metals that reach soils, and may therefore increase organism exposures in some instances.

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