Agricultural use of fly ash: Expected benefits and consequences

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Abstract

Coal is one of the largest sources of energy production in the world accounting in 2006 for about 25% of the world's primary energy supply, that amounts to almost with a worldwide consumption of 3,090 million tons of oil equivalent. Fly ash (FA), is a residue of coal combustion consisted of amorphous ferro-alumino silicate minerals with a matrix very similar to soil. Its elemental composition including both nutrient and toxic elements varies according to types and sources of coal used. It is estimated that the annual amount of the FA produced globally is about 750 million tons that requires a proper management including its disposal which is becoming a very serious problem for the countries using coal as a primary source of energy. Thus, appropriate measures for FA management including safe disposal and utilization are necessary for sustainable management of this waste.

So far two alternative options of FA disposal are in use, i.e. its utilization in construction materials and application to the land as soil amendment. In the first case, FA is used in the production of cement clinker or is blended with cement. In the second case FA is applied to the land, utilizing its properties as soil amendment and source of nutrient supplementation.

The appropriatness of FA as soil improvement is related to its mineralogical, physical and chemical properties of FA which depend on the nature and properties of the coal and the conditions under which it was produced. Fly ash is comprised of very fine particles, with an average diameter <10 µm, which are aggregated into spherical particles of 0.01–100 µm sizes which are hollow spheres (cenospheres) filled with smaller amorphous particles or crystals (pelospheres). These components create interesting properties in the FA such as very large specific surface area ranging from 2,500 to 4,000 cm^2 g^{-1}, and consequently high sorption capacity which makes FA suitable as sorbent for flue gas cleaning from sulphur components, NOx, gaseous organics and for removal from wastewater of several toxic metal ions, and inorganic anions. The bulk density of FA is low to medium ranging from 1 to 1.8 g cm^{-3} and its moisture retention capacity ranges from 6.1% at 15 bars to 13.4% at 1/3 bar. Its organic carbon content i.e. the un-burnt coal estimated as loss on ignition, ranges from 0.5 to 12% giving the black or grey appearance of FA. In addition FA contains high amounts of Fe_2O_3 giving a dark colour. The chemical characteristics of FA depend on geological factors related to the coal deposits and on the operating conditions at the power plants.The main components of FA are silica, alumina and iron oxides with varying amounts of carbon, calcium, magnesium, and sulphur. Fly ashes are distinguished into two classes, i.e. Class F produced from anthracite, bituminous and sub-bituminous coals containing less than 7% CaO, and Class C produced from lignite coal containing more liming material, up to 30%. The pH of FA ranges between 4.5 and 13.25, depending on the sulphur and CaO contents of the parent coal. Fly ashes produced from coals containing high amounts of anthracite (usually contains high amounts of sulphur, S) are acidic while FA including that from lignite (usually lower in S and higher in Ca) are alkaline. The S content of FA usually varies from 0.1 to 1.5% while that of soils ranges from 0.01 to 2%

and the electrical conductivity (EC) of FA in water extracts varies widely. Fly ashes usually contain considerable amounts of plant nutrients such as P, K, Mg, and Ca usually higher than that contained in soils and mostly in forms that are plant available. Trace elements which are essential in plant growth i.e. Fe, Cu, , Zn, Mn, Mo, and B are contianed in FA in quantities similar or higher than in soils, but their availability to plnats vary widely, depending mostly on soil pH. Howevre at the same time FAs besides the elements that are essential for plant growth, contain also significant quantities of potentially toxic elements some of which are of main concern such as Cd, Pb, Ni, Se, and Hg that may enter the food chain through the plants. However, the enrichment of soils with PTEs is considered negligible because of the small amounts applied and their low solubility. Elements that may become restrictive to agronomic use of FA are mostly Mo, Se, and B (as they can be present in large amounts compared to soil levels and their requirements for plant growth. The coal FAs contain also organic constituents of environmental concern which are either macromolecular, insoluble consisting of condensed aromatic and hydroaromatic units, and compounds of low to medium molecular mass, mostly soluble in organic solvents, containing variable levels of aliphatic hydrocarbons, polycyclic aromatic and hydroaromatic hydrocarbons, hydroxylated polycyclic aromatic compounds and heterocyclic compounds. During coal combustion, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) are produced some of which are known mutagens and carcinogens. Furthermore they do not degrade easily, tending to persist in the environment cycling among air, water and soil.

The FA addition to soils can significantly change several physical and chemical properties. Physical properties affected are texture, bulk density, water holding capacity and particle size distribution, depending upon the amount of FA applied and physical properties of the FA and soil. Chemical properties that may be affected by the FA are mainly soil pH in both directions i.e. decrease or increase, depending on the FA characteristics and the degree of weathering (ageing), and sulphur content, electrical conductivity also in both directions, soil boron (B) that may be increased and all the metallic nutrients making the FAs a useful source of micronutrient supplementation. Fly ash contains also appreciable amounts of many potentially toxic trace elements (PTEs) and may cause contamination of soils and groundwater when FA is disposed of on land. Fly ash soil application generally increases the total content of PTEs, but usually the bioavailability and leaching potential of FA-borne metals may not increase significantly or may decrease with time especially in the cases of alkaline FA due to pH increase. Contrary to the physical and chemical properties there is scarcity of information concerning the effects of FA on soil microbial properties. Fly ash can affect soil microbial activity indirectly through its influence on pH, salinization, boron and toxicity of other TEs, and by its influence on soil physical conditions. Laboratory studies showed that FA inhibites microbial respiration and enzyme activity, and N mineralization due to CO_2 evolution, toxic elements excess supply to soils, and soil pH change.

Several studies revealed that FA through its influence on soil physical, chemical and biological properties and processes significantly affect plants growth and productivity. Among the plants of which yield increased due to FA application alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), Bermuda grass (*Cynodon dactylon*) and white clover (*Trifolium repens*), sunflower (*Helianthus sp*.), groundnut (*Arachis hypogaea*) aromatic grasses, i.e. (*Cymbopogon martini*) and citronella (*Cymbopogon nardus*), in FA amended soil was attributed to increased availability of major plant nutrients (Asokan et al., 1995). In general the positive effect of FA was due to the soil pH amelioration and to the increase of FA-borne nutrients in the soil. Application rates of FA reported that positively affect crop yield were 90 ton ha^{-1} in soybean, 8% (w/w) to either calcareous or acidic soils in several agronomic crops, 2-4%, w/w in rice and in Chinese cabbage, 5% in rye grass, and 5.5 to 11 ton ha^{-1} in wheat (*Triticum vulgare*). Other crops positively affected by FA application were *Sesbania cannabina*, *Cajanus cajan*, maize, eggplant, mung bean (*Vignaradiata L.*), and ornamental plants and oil seed crops such as *Mentha piperita*. However, in excessive application rates of FA crop yield may decrease as it was reported for *B. vulgaris* at rates 20% (w/w). The reasons for crop yield increase were the enrichment of soil with essential nutrients like S in calcareous soils, Ca and Mg in acidic soils and the prevention of toxic effects of Al, Mn and other metallic ions by neutralizing soil acidity. In conclusion application of FA in agronomic doses improves soil properties and fertility and enchances plant growth and crop yield but at high FA application rates may cause adverse effects. However, due the high variability in the nature and composition of FA (pH, major and micronutrients) and that of soil (pH, texture, fertility), a specific FA application rate cannot be recommended.

Summurizing the impacts of FA on soil properties and soil fertility which increase plant growth and crop yield it can be said that FA can be a valuable source of readily available plant micro- and macro-nutrients such as N, P, K, S, Ca, and Mg and B, Mn, Se, Cu and Zn respectively. The use of FA on acidic soils can improve their physical, chemical and biological properties and depending on its characteristics, including its acidity/alkalinity, could be used, as an ameliorating agent for acidic and sodic soils may increase the productivity, and to convert the problematic soils including wasteland into agricultural land or for re-vegetation purposes.

Another mentionable case of FA use is the co-application of FA with sewage sludge as soil amendment. Combined use of FA and SS for land application could be beneficial. Because of their contrasting and complementary chemical properties and nutrient contents, land application of both products as mixture can improve soil quality and crop production. This could help alleviate waste disposal and management problems associated with land application of SS or FA separately. Use of alkaline fly ash for contaminated land remediation is also interesting for preserving soils from degradation and particularly from pollution by toxic metals and organic pollutants acting in this case as liming material and increasing soil pH and enhancing thus metals retention in the solid phase.

Selected references

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