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Contamination Of Soil, Water And Air With Special Reference To Fly Ash: A Glimpse

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Abstract:

Migration of contaminants from waste disposal sites to surrounding ecosystems is a complex process. Soil and water contamination around ash disposal site has recently been the subject of much research world over. Trace elements present on the surface of ash particles are readily leached and tend to contaminate the groundwater. Toxicity of surrounding ecosystem results due to increase in metal concentrations beyond their threshold values. Groundwater pollution due to landfills has been studied. It also studied that groundwater contamination index was used for mapping the degree of contamination. In this article, contamination of soil, water and air with special reference to fly ash has been discussed.

Keywords: Soil, Water, Air, Fly Ash

Introduction:

The effect of the incorporation of fly-ash into soil has been extensively investigated (Plank and Martins, 1973, 1974; Adriano et al. 1978, 1980; Elseewi and Page, 1984). The impact of fly-ash on soil largely depends upon the properties of the original coal and the soil examined. Fly-ash added to soil significantly increases the electrical conductivity of the soil mixture by increasing the levels of soluble major and minor inorganic constituents (Adrino et al., 1980; El-Mogazi et al., 1988; Eary et al., 1990). The initial increase in soil pH after alkaline fly-ash amendment is explained by the rapid release of Ca, Na, Al and OH ions from fly-ash (Hodgson et al., 1982; Wong and Wong, 1990). Excessive 'Fe' and 'Al' convert soluble Phosphate to insoluble Phosphate compounds, which are not readily available to plants. Fly-ash itself is not effective in retaining water, but it significantly increases water holding capacity of the soil mixture (Chang et al., 1977). Hydraulic conductivity of soils can be improved by the application of limited amounts of fly-ash, but it deteriorates rapidly when fly-ash input exceeds 20% (v/v) in calcareous soils and 10% in acidic soils.

Effect of fly-ash on soil properties:

Fly-ash is an inorganic substrate that is rich in electrolytes and does not contain significant organic matter; therefore, its addition to soil results in increased hydraulic activity limited at lower application doses. The impedance of water flow is related to the podzolonic reaction of fly-ash, which reacts with water to cement soil particles under wet conditions (Adriano et al., 1980). Fly-ash also reduces the modules of rupture (cohesiveness of soil particles) in all soils tested (Adriano et al., 1980). Further details for fly-ash properties and its impact on soil mixtures have been described in previous reviews (Adriano et al., 1980; Carlson and Adriano, 1993). Field research in recent years has investigated the application of fly-ash with other solid wastes (e.g. sewage sludge) to soils to serve as both a means of disposal and as a medium for plant growth. Organic amendments improve soil conditions by increasing the cation- exchange capacity and organic matter content of the soil, thereby resulting in increased immobilization of toxic elements, higher fertility and enhanced microbial activity. Certain inhibitory effects to soil microbes by toxic components of fly-ash may, furthermore, be attenuated by the application of organic materials (Chaney and Giordano, 1977). However, foliar application (2 and 4 gm per day) increased plant height, metabolic rate and photosynthetic pigment content in Zea mays and Glycine max. The highest foliar application at 8 gm per day caused reduced dry matter and pigment content. Ultimate analysis of G. max and Z. mays revealed that control plants were deficient in boron (Mishra and Shukla, 1986). The increased growth response and dry matter production of the two crops were attributed to the increased availability of boron. Mishra and Shukla (1986) and Rohrman (1971) studies that fly-ash consists of more than 10% water soluble components and there are reports of increased boron availability in fly-ash-amended soil (Martens, 1971). Boron from fly-ash was shown to be equally available to alfalfa as B from $Na_2B_4O_7.10H_2O$. This toxicity was caused by excessive boron uptake and the excessive alkalinity was caused by excessive soluble salts (Mishra and Shukla, 1986). Porosity is the air space between soil particles, which is usually occupied by water when available. So, the increase in water holding capacity is due to greater space between the soil particles. Electrical conductivity is positively correlated with pH and reflects the total concentration of soluble cations and anions (Elseewi et al., 1978) and it is quantitatively related to the concentration of salts. Normal values of electrical conductivity for vegetable crops range between 3 and 4 mmhos/cm, and higher values have adverse effects on crop production (Hodgson and Holliday, 1966). The addition of appropriate quantities of fly-ash can also alter the soil texture. Fly-ash addition at 70 t/ha has been reported to alter the texture of sandy and clayey soil to loamy soil (Fail and

Wochock, 1977). The grain size distribution, and especially the silt size range of fly-ash, affects the bulk density of soil. Chang et al. (1977) observed that among five soil types Reyes silty clay exhibited an increase in bulk density from 0.89 to 1.01, when the corresponding rates of fly-ash amendment increased from 0 (soil only) to 100% (fly-ash only). But in soils with bulk densities that varied between 1.25 and 1.60, a marked decrease in bulk density was observed with the addition of fly-ash. Page et al. (1979) reported that the amendment of fly-ash to a variety of agricultural soils tends to decrease bulk density. The optimum bulk density in turn improves soil porosity, root penetration and the moisture retention capacity of the soil.

The activity of certain metals may also be increased with an increase in pH. For example, aluminium (Al) is relatively insoluble as $Al(OH)_3$ at neutral pH, but it exists predominantly as highly soluble and toxic aluminate anions above a soil pH of 8.0. As soluble aluminium can exist in various ionic forms in aqueous solution, various researchers have tried to explain the mechanisms of Al phytotoxicity, but have been limited by a lack of understanding of Al speciation. At mildly acidic or neutral soil pH values, Al is primarily in the form of soluble alumino silicate/oxides; as the pH become more acidic a phytotoxic form of Al is released into the soil. Thus, Al toxicity is the major growth-limiting factor to crop cultivation on acid soils (Foy, 1984; 1988). Recent evidence shows that Al can readily enter the symplasm of root cells (Lazof et al.,1994). Al, when in a symplasmic solution of pH above 7, contains a mixture of various macromolecules and constitutes a crucial aspect of Al toxicity. It has been inferred that Al toxicity is better correlated with either some or all the monomeric hydroxy Al species, or is a combination of Al and certain other monomeric hydroxy-Al species, instead of $Al^{3}+$ alone (Balmey et al., 1983; Alva et al., 1986; Kochian, 1995). It has further been suggested that for dicots either $Al(OH)^{2}+$ or $Al(OH)^{3}+$ is the phytotoxic species and $Al^{3}+$ is much less toxic (Alva et al., 1986; Kochian, 1995).

This situation is prevalent in fly-ash that has higher pH values. Al^{3+} is the toxic species for monocots, e.g. in wheat roots, when Al activities were increased, the activities of the hydroxy-Al species were decreased (Kinraide and Parker, 1987; Kiniraide, 1991; Kochian, 1995). In India, most of the fly-ash produced is alkaline in nature. Hence, an application of this to agricultural soil increases soil pH. This property of fly-ash can be exploited to neutralise acidic soils (Elseewi et al., 1978; Phung et al., 1978). Jastrow et al. (1979) reported that while the addition of fly-ash improves soil pH, it also concurrently adds essential plant nutrients. Page et al. (1979) observed that experiments with calcareous and acidic soil revealed that fly-ash addition elevated the pH of the former from 8.0 to 10.8 and of the latter from 5.4 to 9.9. It must be noted here that the use of excessive quantities of fly-ash to alter pH can cause an increase in soil salinity, especially with unweathered fly-ash (Sharma et al., 1997).

Effects of fly-ash on plant growth and vegetation:

Fly-ash particles are very fine in nature and thus tend to remain airborne for a long period. Fly-ash dust, under certain conditions of humidity, sticks to the leaves and promotes chemical as well as physical damages and small necrotic dark brown spots appear on the leaves of many vegetables such as green beans, turnip, cabbage and tomato (Singh and Yunus, 2000). At lower fly-ash deposition rates fly-ash particles accumulate on the guard cell surface and stimulate the mechanism regulating stomatal opening and closure, and prevent them from closing (Fluckiger et al., 1979; Krajickova and Majstrick, 1984), thereby restricting increased transpiration rates. Foliar application of higher fly- ash deposition rates (8 gm per day) resulted in decreased transpiration rates due to the barrier created by a thicker layer, and thus reduced vapour loss from the leaves (Mishra and Shukla, 1986). Thick coating of fly-ash interferes with the light required for photosynthesis and thus reduces the photosynthetic rate. Leaves laden with fly-ash particles absorb heat more effectively and, consequently, the increased leaf temperature results in increased transpiration rates. Airborne fly ash particles may affect many functions of plant shoots as well as those of other living organisms. Changes in soil properties caused by fly-ash may directly or indirectly change microbial activity and the root growth of plants. Fly-ash increases water-holding capacity of soil mixtures, but this capacity does not appear to significantly increase the available water to plants (Chang et al., 1977).

Field and greenhouse studies suggest that many chemical constituents of fly-ash benefit plant growth due to micronutrients and can improve the agronomic properties of the soils (Chang et al., 1977). A lower application of fly-ash (5-10%) in soils accelerates seed germination as well as seedling growth, although higher application (20-30%) either delays or drastically inhibits plant growth, development and other specific parameters (Singh et al., 1997). When Beta vulgaris roots were grown in fly-ash-amended soil it was found that low fly-ash application of up to 2% (kg/m^2 plot) was stimulatory for sugar production whereas higher doses (4 and 8%) were inhibitory (Singh et al., 1994; Singh and Yunus, 2000;). Deleterious effects of larger applications of fly-ash on plants are primarily attributed to a shift in the chemical equilibrium of the soil (Singh and Yunus, 2000). Both the high alkaline pH and the excess levels of soluble elements released from fly-ash induce hazardous effects in plant roots and the rhizosphere. Increased soil pH results in a loss of applied and indigenous soil N. The high pH in fly-ash is hazardous to the major microbes that conduct N fixation and other important functions for plant growth. Fly-ash delays nodulation in plants, resulting in fewer nodules (Martensson and Witter, 1990). Evidence has been presented for the toxic effects of specific fly-ash constituents in plants. Especially, As, Se, Mo, V, Al, Cd and B are noticed to be highly hazardous to plants if accumulated in plant tissues. These elements are readily available to plants and accumulate in the tissues (Townsend and Hodgson, 1973; Hodgson and Buckley, 1975; Adriano et al., 1980; El-Mogazi et al., 1988; Inouhe et al., 1994;

Singh et al., 1997; Rai et al., 2000). Fly-ash has ppm level concentrations of heavy metals when applied to soil. These trace elements may be taken up by plants, which may slowly enter into the food chain. The data on trace metal uptake and accumulation are limited. Boron in fly-ash is readily available to plants and B has been considered to be a limiting factor in unweathered fly-ash utilization (Townsend and Gillham, 1975; Elseewi et al., 1978). The highest concentration of some metals, such as Cu, Fe, Zn and Ni, was recorded in plants grown in fly-ash amended with press mud, followed by fly-ash plus cow manure, raw fly-ash and fly-ash plus garden soil, respectively. The greater availability of metals has been correlated with a lowering of pH of fly-ash after the addition of press mud (Tripathi et al., 2000). Plants have various intracellular sites and/or metabolisms that are very sensitive to metal ions and, hence, may readily suffer from the additive and synergistic effects of different toxic metals (Woolhouse, 1983) present in fly-ash. In turn, plants that have a detoxification or immobilizing mechanism against specific heavy metals can be candidate members for reclamation on fly-ash soils. Here, roots are the first organ that comes in immediate contact with the toxic metals in soils and most of the toxic metals can be deposited in the root tissues. Metal deposition in the root may restrict movement of the toxic metals to the leaves and other shoot organs (Mishra and Shukla, 1986; Inouhe et al., 1994). Therefore, the different tolerance characteristics of roots can be an important factor limiting the overall plant growth responses to the fly-ash constituents. K deficiency in plants grown on lagoon ash was found to be mainly caused by the high Ca content of the ash. An increase in available Ca and Mg in the absence of an increase in available K may antagonize plant K uptake, and eventually cause K deficiency (Plank and Martens, 1973). The impact of fly-ash on plants has been also investigated at a larger scale in selected fly-ash landfills or sites with tree vegetation (Singh and Yunus, 2000). Scanlon and Duggan (1979) planted eight species of trees and shrubs in a dewatered fly-ash landfill in Tennessee. They found that survival varied among the species (12 to 84%) and the foliar tissues had elevated levels of B, Ni and Se, and, in some cases, As, Cd, Cu and Zn. In South Carolina, four tree species were planted on an abounded fly-ash basin that showed minimal natural re-vegetation (McMinn et al., 1982). These field experiments showed a high survival of plants on the alkaline fly-ash site than on the control site. They also reported elevated levels of some trace elements, including B, Cr, Co, Cu and V, but reduced levels of Mo and Mn in the trees grown on the fly-ash site. Carlson and Adriano (1991) also reported elevated trace element concentrations in sweet gum and sycamore (Platanus occidentalis L.) grown on two abounded coal fly-ash basins. Although there are some discrepancies in metal accumulation by plants in field conditions, it is evident that fly-ash has a dual effect in various plants, i.e. promotion and inhibition of growth in a dose-dependent manner. The nutrients from fly-ash have been reported previously to be beneficial to plants through soil application or foliar dusting (Mishra and Shukla, 1986). Because fly-ash lacks nitrogen, its application, especially at higher concentrations, results in severe deficiency of nitrogen in soil as well as in plant tissue, which is an important factor responsible for the suppressed growth and yield. Aluminium and manganese toxicity in fly-ash exhibits different degrees of responses from the various indicator plants employed. Three types of plant responses to excess aluminium in fly-ash may be distinguished by complete tolerance (Atriplex), partial tolerance with no phosphate problems (spinach) and great sensitivity (barley). Aluminium-induced root abnormalities were not evident with ash-barley, but were due no doubt to the high ash calcium. Acaciasp. And Leucaena leucocephala have been demonstrated to have high tolerance and survival in arid, infertile and metal-contaminated areas (Barnet et al., 1985; Mulhern et al., 1989; Muslin, 1993). In addition, legume plants and symbiotic N -fixing bacteria can improve the nitrogen (N) content of infertile soils (Sanginga et al., 1994). Acacia auriculiformis and Leucaena leucocephala are well adapted to the climate of southern China; thus, they were selected as the study species in the revegetation trial of Zhang et al. (1998). Leguminous vegetation, such as Cassia siamea and Pisum sativum, were found to accumulate Zn, Cu, Ni and Fe at various doses of fly-ash application (25, 50, 75 and 100% fly-ash in soil; Tripathi et al., 2000). Fly ash has been utilized to boost the productivity of a few agricultural crops and leguminous trees (Kumar et al., 2001; Rai et al., 2002; Tripathi et al., 2002). Cassia siamea has been found to have antioxidants and a metal detoxification potential when grown on fly-ash and fly-ash amended with press mud (Kumar et al. 2002).

Contamination of ground and surface water:

Water pollution stands for the contamination of water due to some external materials. Water may be polluted either from natural sources or human sources. Transport of pollutants through ground water flow is very complex phenomenon. A range of physical, chemical and biological processes can influence the tracer drift by the ground water flow. Wastewater discharge impacts on the receiving water can be grouped into chemical, biological, physical, hygienic, esthetic, hydraulic and hydrologic impacts. They can be further classified in terms of duration as acute, delayed or accumulating. Groundwater and surface water are fundamentally interconnected. It is often difficult to separate the two because they feed each other. This is why one can contaminate the other. Water is an ideal solvent, some products placed on or in the soil will eventually end up in the ground water (Dimter and Rukavina, 2007).

In India, industrial utilization of fly ash is about 38% of the total produced (Alam and Akhtar, 2011). The rest of the fly ash is disposed of either by dry methods of disposal in landfills or by wet methods of disposal where the ash is mixed with water and removed as slurry for settlement in ponds. The supernatants are discharged into a receiving system and the final effluents discharged into a natural aquatic drainage system like a river. Both the dry and wet disposal of fly ash can result in metal contamination of surface and groundwater.

Near the ash ponds, water quality is changed owing to the leaching of soluble ions present in fly ash. Addition of fly ash to the native soil leads to an increase in the availability of nutrient ions like Cu, Ni, Zn, Fe, P, K and Na and enhanced growth of plants. The leaching potential of these heavy metals from an open system (fly ash pond) is expected to be greater due to diurnal and seasonal variation in temperature, moisture content and other parameters.

Leaching, movement of water through materials containing soluble components significantly influences the surrounding soil, groundwater and surface water.

Variable chemical composition of fly ash can contain elements that will infiltrate ground water or surface water by leaching and ultimately can pose significant danger to the flora and fauna. Influence on water quality has the presence of heavy metals (As, Cd, Cu, Cr, Hg, Pb, Zn etc.)

A study of heavy metals in groundwater near a coal ash disposal site in Orissa, India showed that Zn, Cu and Pb were found in high concentration in tube well water located in the vicinity of an ash pond while Cu, Mn, Pb and Zn were the major contaminants in groundwater.

Most of the elements (As, Ca, Mg, Mn, Na, S and Zn) showed maximum concentrations in the leachate at low liquid solid ratio (L/S) of 4 and 8 and then decreased at higher L/S, indicating that with successive volumes of infiltrations of rainwater through the ash pile, the concentrations of these elements in the leachate would reduce significantly. It was also found that some elements, which were present in bulk fly ash, were insignificant in the leachates (Cu and Pb), while some others (Cd, Co, Cr and Ni) did not leach at all regardless of L/S ratio.

Due to leaching characteristics of fly ash, the heavy metals along with other constituents gradually and slowly get leached from the ash and percolate to nearby ground water. This raises the threat of percolation of hazardous elements contained in the fly ash to ground water and sub soil degradation from the ash ponds. The potential of leaching of these metals not only depends on the total metal contents of fly ash but also influenced by the crystal structure of fly ash. The release of metals in the leachate may be from the outer surface of fly ash particle or from inner matrix of the particle.

Earlier result shows that the fly ash is rich with calcium and has low sulphur contents. This composition of the ash results in very basic solution. When fly ash interact with water the pH increases to higher than 9.0 due to dissolution of calcium oxides which is contained in the outer surface of the ash particles because of its high volatility. The density of ash also influences the leaching efficiency due to water movement through it.

Impacts of fly ash on animals:

Impacts on animals inhabiting locations contaminated with coal fly ash have been demonstrated in many studies. For example, adult southern toads (Bufo terrestris), freshwater grass shrimp (Palaemonete spaludosus) and fish (Erimyzon sucetta) have been shown to accumulate trace elements from coal ash polluted areas, including arsenic and cadmium (Hopkins et al., 1999). Larval southern toads (Bufo terrestris) and larval bullfrogs (Rana catesbeiana) inhabiting similar sites have been shown to suffer elevated incidences of survival-threatening physiological impacts (Hopkins et al., 2000). Such effects are believed to result from the complex mixtures of pollutants in coal ash. Amongst these are elements such as selenium, chromium, cadmium and copper, known to have the potential to be teratogenic to such species.

Conclusion:

The ability of toxic elements to leach from coal fly ash has serious implications where such ash is added to agricultural land as soil stabilizers. Plants grown on soils amended with coal fly ash have been demonstrated to absorb a range of potentially toxic elements.

Furthermore, grasses and legumes grown on soil capped coal fly ash landfill sites can become enriched with potentially toxic elements (Weinstein et al., 1989).

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