Effect of flyash incorporation on soil properties and productivity of crops: A review

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Flyash can be used for reclaiming the problem soil and enhance the crop productivity depending upon the nature of soil and flyash. It may improve physical, chemical and biological properties of problem soils and enhance the available macro and micronutrients for plants. The high concentration of elements (K, Na, Zn, Ca, Mg and Fe) in flyash increase yield of agricultural crops. However, application of flyash, particularly unweathered ones, shows a tendency of accumulating elements like B, Mo, Se and Al. The accumulations of these elements to toxic levels are responsible for reductions in the crop yields and consequently influence animal and human health. This review explores the possibility of using flyash to improve the soil environment and subsequently increase the growth and yield of crops.

Keywords: Crop growth, Crop yield, Flyash, Toxic/trace elements

IPC Code: A01C9/00

Introduction

Every year Indian thermal power plants produce more than 100 million tons of flyash, which is expected to reach 175 million tons in near future⁶. Disposal of this huge quantity of ash is a great problem due to its limited utilization in manufacturing of bricks, cements, ceiling and other civil construction activities. This would further bring to changes in land-use pattern and contribute to land, water and atmospheric degradation, if proper management options for flyash handling are not undertaken⁵,⁴. The countries like Germany, Denmark, France, UK, USA, and The Netherlands utilize flyash (up to 70 %) as a building material and other construction purpose, but in India its utilization is less (<15 %)⁵. Use of flyash in agriculture provides a feasible alternative for its safe disposal to improve the soil environment and enhance the crop productivity. However, a judicious amendment strategy has to be developed to abate the land pollution from the heavy metals present in it⁶. More than 80 coal-fired thermal power plants installed at different parts of India generated 58651 MW of energy out of 96948 MW total power generation up to end of 2000⁷. Most of the thermal power plants use bituminous coal as a fuel, which contains high amount of ash (up to 40%), sulphur (0.2-06%) and heavy metals (Hg, Mn, Cu, Pb, Ni, Fe, Cr and Cd) in varying proportion⁸. Some of the thermal power plants are using lignite coal as fuel for power generation.

Flyash is disposed of either in wet slurry process or dry disposal process. In wet process, flyash is disposed in wet slurry form to a nearby ash pond site in which the ash settles and clear water is allowed to overflow from the ash pond. In dry disposal, flyash is stored in the large area assigned for the disposal of waste material⁹,¹⁰. In both the methods, flyash is dumped in open land, which degrades the soil and enhances the air and water pollution and ultimately affects the human health. Making the permanent structures of the ash disposal site by using bitumen and water spray and subsequent compaction and growing vegetation on these structures are to prevent the losses of the ash particles into the air and contamination of soil and water bodies due to leaching of heavy metals from the storage area¹¹. The fine particulates of flyash are potentially toxic to human health. Repeated exposure of flyash can cause irritation in eyes, skin, nose, throat and respiratory...
tract and gain entry into the blood stream.\textsuperscript{12-16} Flyash contains several nutrients including S, B, Ca, Mg, Fe, Cu, Zn, Mn, and P, which are beneficial for plant growth, as well as toxic metals\textsuperscript{17,18} such as Cr, Pb, Hg, Ni, V, As, and Ba. Its addition increases the availability of Na, K, Ca, Mg, B, SO\textsubscript{4}\textsuperscript{2-} and other nutrients\textsuperscript{19-21} except N. The paper reviews the various aspects of flyash for its application in agriculture.

### Characteristics of Flyash

#### Physical Characteristics

In general, flyash particles are spherical and have a size distribution with medium around 4 µm while the bottom ash has a medium around 70 µm and settle close to the plant site\textsuperscript{22}. Flyash generated at National Capital Power Project (NCPP), Dadri, Ghaziabad, Uttar Pradesh comprises: silt, 57.6; clay, 11.9; and sand, 30.5 % (Table 1). Its low bulk density increases the potential for dust formation, which creates problems in the transportation and storage of dry flyash. Water holding capacity (WHC) of flyash is generally 49-66 percent on weight basis. Flyash has unusually high surface area and light texture due to the presence of large, porous and carbonaceous particles. Flyash addition changes the physical properties of soil such as texture, bulk density, WHC, hydraulic conductivity (HC) and particle size distribution\textsuperscript{23-25}.

#### Chemical Characteristics

Major elements present in flyash\textsuperscript{24} (in the order of decreasing abundance) are Si, Al, Fe, Ca, C, Mg, K, Na, S, Ti, P and Mn and all exist in their oxidized states (Table 2). The concentration of various elements in flyash decreased with increasing particle
Table 3 — Leaching of metals and toxic metals from flyash application

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration in flyash, ppm</th>
<th>Total leach %</th>
<th>Leachate water quality, µg/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>500</td>
<td>9.67</td>
<td>2.75</td>
</tr>
<tr>
<td>Mg</td>
<td>4890</td>
<td>0.60</td>
<td>4.45</td>
</tr>
<tr>
<td>K</td>
<td>2500</td>
<td>2.80</td>
<td>3.98</td>
</tr>
<tr>
<td>Ca</td>
<td>6000</td>
<td>9.73</td>
<td>33.17</td>
</tr>
<tr>
<td>Cr</td>
<td>98</td>
<td>0.67</td>
<td>0.04</td>
</tr>
<tr>
<td>Fe</td>
<td>29300</td>
<td>0.15</td>
<td>1.10</td>
</tr>
<tr>
<td>Cs</td>
<td>8.6</td>
<td>2.12</td>
<td>0.01</td>
</tr>
<tr>
<td>Cu</td>
<td>77.3</td>
<td>0.47</td>
<td>0.021</td>
</tr>
<tr>
<td>Zn</td>
<td>93</td>
<td>3.52</td>
<td>0.186</td>
</tr>
<tr>
<td>Hg</td>
<td>8.2ppb</td>
<td>8.64</td>
<td>0.04 ng/ml</td>
</tr>
<tr>
<td>Pb</td>
<td>12.8</td>
<td>2.04</td>
<td>0.015</td>
</tr>
</tbody>
</table>

*Calculation based on maximum leachability conditions, dilution due to river flow, retardation in soil matrix etc. are not considered.

Flyash amended soils tended to have lower bulk density, higher WHC, lower HC (Table 4) and lower moduli of rupture. Flyash addition generally decreased the bulk density of a soil, which in turn improved soil porosity and better workability and enhances water retention capacity. It also increased organic carbon content but did not increase the amount of water availability to plants, i.e., more water was held in the ash by capillary actions. The cementing effects of flyash could possibly impede root development by creating hard areas near the soil-flyash interface in a closed ash disposal system. An alkaline (pH = 12.5) flyash reduced soil hydraulic HCs when added to acidic soils at rates greater than 10 percent or to calcareous soils at rates greater than 20 percent by volume. When flyash was added to sand or sandy loam soil, it increased its available water capabilities. The soluble calcium of the flyash provides congenial atmosphere for the flocculation of highly dispersed alkali soil particle and organic matter content of this ash provides much needed protective action to stabilize the physical environment improved by the calcium.

Effect of Flyash on Soil Environment

Soil properties as influenced by flyash addition in soil have been studied by several researchers. The concentrations of all elements (except N) were higher in flyash than in soil (Table 2). Therefore, flyash as an amendment for agricultural soils can improve the physical and chemical properties of deficient soil, thereby improving soil fertility and crop yield. Nonjudicial use, however, may lead to deterioration of soil texture and structure mainly in the upper soil layer, surface crust formation impeding the water intake capacity of the soil, addition of toxic elements and alteration in physico-chemical properties as pH, CEC and EC. These changes in the soil can affect the moisture availability, seedling emergence and crop establishment, root and shoot growth and consequent crop yields.

Physical Properties

Flyash amended soils tended to have lower bulk density, higher WHC, lower HC (Table 4) and lower moduli of rupture. Flyash addition generally decreased the bulk density of a soil, which in turn improved soil porosity and better workability and enhances water retention capacity. It also increased organic carbon content but did not increase the amount of water availability to plants, i.e., more water was held in the ash by capillary actions. The cementing effects of flyash could possibly impede root development by creating hard areas near the soil-flyash interface in a closed ash disposal system. An alkaline (pH = 12.5) flyash reduced soil hydraulic HCs when added to acidic soils at rates greater than 10 percent or to calcareous soils at rates greater than 20 percent by volume. When flyash was added to sand or sandy loam soil, it increased its available water capabilities. The soluble calcium of the flyash provides congenial atmosphere for the flocculation of highly dispersed alkali soil particle and organic matter content of this ash provides much needed protective action to stabilize the physical environment improved by the calcium.
under 30 percent flyash application and maximum under the control. 

Highly alkaline flyash, added to sample of acidic and alkaline soil mixture, actually decreased the amount of Fe, Mn, Ni, Co and Pb released from the acid soil, while the release of these metals from the alkaline soil remained unchanged. Fresh ash has been found more effective in raising soil pH to levels conducive to maximum plant growth than that of weathered ash in a given soil. The pH alone does not determine role of flyash as amendment but under certain situations composition of flyash plays a useful role. A significant increase in EC has been reported with increase in percentage of flyash after 25 days of incorporation. However, EC decreases after the harvesting of rice and further reduction was recorded after the harvesting of wheat. One possible reason for this may be that salts might have leached down with water and resulting in lower EC of the soil after a certain period. Boron has a tendency to accumulate in soils as a result of flyash addition. Flyash amendment can increase concentrations of trace elements, particularly Se. Ash has also been explored for removing contaminating metals from sewage effluents and aqueous solutions. Increased Se accumulation in plant tissues with increased flyash application warrants close monitoring and use if appropriate quantity of weathered flyash depending upon the end use of the produced biomass.

Ash samples from dumping site and directly from electrostatic precipitator of Bhatinda Thermal Power Plant indicated that Ca was the most dominant cation of the exchange complex, followed by Mg, Na and K. Contents of S were quite high. Amongst DTPA extractable micronutrients, only Fe was present in higher amounts. The rate of release of Na was found to be much less than Ca and Mg. Ash collected from ESP was relatively finer in texture, lower in pH and generally richer in nutrients when compared with ash from dumping site. An incubation study conducted with sandy loam and sandy soils amended with 0, 5 and 10% (w/w) flyash (acidic, pH 6.1 and bulk density of 0.8 g/cc) indicated decreased bulk density and pH but increased the salt content of soils. The plant available water content increased over control for sandy loam (52%) and sandy soils (124%) with the addition of flyash (10%). Though flyash used in study contained appreciable amount of P, but its application to soils decreased the available P content. Availability of S, Fe, B and Mo also increased whereas K and Mn remained almost unchanged.

<table>
<thead>
<tr>
<th>Table 4 — Soil physical and chemical properties as influenced by flyash addition at study sites after wheat harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash level</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>t/ha</td>
</tr>
<tr>
<td>Gulawathi village</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>CD, 5% level</td>
</tr>
<tr>
<td>Muthiani village</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>CD, 5% level</td>
</tr>
<tr>
<td>IARI Farm</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>CD, 5% level</td>
</tr>
</tbody>
</table>
Biological Properties

Application of any kind of pollutant such as flyash is likely to interfere with the microbe mediated processes operating in soil thus imbalancing the ecobalance. Addition of flyash to sandy soil and silt loam decreased microbial respiration and nitrification activity in soil. Total bacteria, actinomycetes, fungal counts as well as enzyme activities such as soil phosphates, sulphatase, dehydrogenase and invertase in the soil decreased with increased ash content attributed to very high pH of flyash or presence of toxic elements at potential toxic concentrations. However, the application of acidic flyash up to 100 tons/ha in an agricultural soil had no measurable impacts on soil heterotrophic microbial activity by higher levels of amendment (400-700 tons/ha) may adversely affect the soil microorganism. Amendments to flyash with organic matter such as sewage sludge may improve the soil conditions by increasing the cation exchange capacity, which may result in the immobilization of toxic metals and increase the availability of K, Mg and Ca. In addition to this, soil physical properties such as moisture retention and aggregation may also improve. Through sludge application increased microbial counts as well as enzyme activity but all populations were still lower at the highest ash rates (20% on wt basis) compared to untreated control. Thus high rates of flyash to soils may hinder normal decomposition and nutrient cycling processes which may be partially alleviated by the amendments with readily oxidizable organic subtracted such as sewage sludge. Cumulative microbial respiration (65 d) increased with flyash level up to 112.5 and 225 tons/ha in Gulawathi and Muthiani soils, respectively, whereas the increase was restricted up to 11.25 tons/ha only in IARI soil, which might be due to first time exposure to IARI soil with flyash.

Effect of Flyash on Crop Growth and Productivity

Many researchers added flyash in the soil to evaluate the long-term consequences of flyash on soil environment and crop productivity. Flyash incorporation in the sandy loam soil (up to 40%) modified the soil environment, mainly moisture retention, release and transmission behaviour, pH, EC and organic carbon. The texture of the soil-ash admixture remained sandy loam up to 10% ash application, beyond this level the texture turned to loamy soil. Microbial activity got modified favorably up to 10% ash in soil-ash admixture.

Flyash generally contains sufficient concentrations of the nutrient essential for plant growth. However, C and N are usually present in small amounts and it is medium in available K and high in available P. Lignatic flyash had a relatively higher K content than non-lignatic coal flyash. These constituents may prove good for reclaiming saline and alkali soils as well as may enrich the soil in due course of time. Numerous studies report the impact of flyash addition on the yields of different crops with either depressions or enhancements in yield. Whereas depression in yield have been largely reported to occur due to B toxicity, P and Zn deficiency, improvements have been attributed principally to enhancements in B supply in B deficient soils improvements in sulphur supply and available water capacity. Significant higher grain as well as straw yield of rice recorded with the application of flyash (up to 20%). However, flyash addition higher than 20 percent decreased the yield. Residual wheat crop also registered higher yield by using up to 20 percent flyash amendment. Uptake of N, P and K by rich and succeeding wheat was also increased with increasing flyash amendment (up to 20%).

Seed germination of maize, sorghum wheat and gram was treated in two soil types treated with flyash additions (0-100%, wt basis). Percentage germination in most crops increased in soils treated with ash (up to 10%) and decreased with higher flyash rates except in gram, which tolerated up to 30 percent flyash addition. Maize and soybean receiving flyash through aerial spray with different doses increased leaf area and metabolic rate, as well as photosynthetic pigments and dry matter compared with their respective controls. Lentil seed (cv. L 4076) showed 50 percent germination in more or less same time ranging from 72 h (control) to 94 h (40% flyash) with intermediate values averaging 83 h for rest of the treatments. The germination count (chickpea seed, cv. Pusa 362) differed significantly among ash application till 140 h after seedling, but thereafter differences were confined to a narrow range, except for 30 and 40% ash treatments showed considerable reduction in germination. Mustard crop was adversely affected in terms of delay as well reduced germination count. The extent of flyash addition in
the soil over a year basis amounts to less than one percent of the top (0-15 cm) soil layer, and thus the germination and stand establishment may not be a problem for these crops.

Deposition of flyash (up to 4g/m²/day) on crop canopies also increased dry weight and net primary productivity of maize and soybean. Deposition beyond this level, however, decreased the plant growth. In addition, flyash particles concentrate on the surface of guard cells, stimulate the mechanism regulating the opening and closing of the stomata and prevent them from closing, thereby, allowing increased transpiration. The decrease in transpiration rates of plants heavily dusted with flyash could have been due to physical barrier created by a thicker layer of flyash forming a boundary layer, which reduced water vapour loss from the leaves. Leaves dusted with flyash absorbed radiation more intensively, consequently temperature of the dusted leaves become higher resulting in higher respiration rate. Compost with 20 percent flyash amendment was found suitable in increasing the dry matter yields of collard greens and mustard. Application of this manure helped the farmers to conserve water, as the WHC of this manure is high.

Maize crop grown at IARI, New Delhi, India, under varying levels of flyash incorporation either through application in the soil at the time of sowing or through dusting the amounts splitted and applied in various stages of the crop growth showed increase in yields when compared with control in flyash treated plots through soil application up to 10 tons/ha application and thereafter decrease in trend was noticed. Dusting crop canopies with ash decreased the yield in proportion to amount have applied and the values were lower than obtained under control. The decreased yields obtained under dusting treatment might be due to reduced plant growth activity due to flyash deposition on the crop canopies. The increased yields obtained under flyash application in the soil up to 10 tons/ha rates might be due to improved soil structure and enhanced nutrient availability. Similarly, the various crops like rice, wheat, gram, lentil and mustard were grown on varying level of flyash encouraging the crop growth and subsequently its yield.

One of the aspects of interest is the content of toxic metals in the plants. The magnitude of heavy metal adsorption by plants depends upon heavy metal content in flyash, rate of addition, the soil type and its pH, the plant species, etc. Of all the species grown on flyash-amended soils, B showed a significant increase in the legume while Se increased principally in grasses and Mo showed consistent increase in all the species. Se, Cu and Pb contents of plants were high. Mo and S components of flyash also easily assimilable and are likely to show accumulation in plants. Kumar, however, did not observe any depressing effect of flyash application (upto 10%) on the Cd content of lettuce. Potentiality of alkaline flyash in detoxifying Cd in soil plant system can be exploited provided it is without any effect of other parameters of plant growth.

Trace elements (Zn, Cu, Fe, Mn, and Cd) were used as heavy metal indicators by crop grown under flyash added soil. Non-significant higher uptake (Table 5) of these metals in flyash treated plots was due to their presence in oxide form and so insoluble in water for becoming readily available for their uptake.

### Conclusions
Flyash vary 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. Flyash can be used as liming material on acid soils or acid mine soils or alkali soils for improving the pH of the soils depending on nature of soil and ash. Increases in pH induced by alkaline flyash addition is a desirable property and could be used for detoxifying elements like Cd, Al and Mn. Similarly, acidic flyash can successfully be used for reclaiming the alkali soils. The high concentration of elements like K, Na, Zn, Ca, Mg and Fe in flyash

### Table 5 — Metal uptake by wheat grains under different flyash application treatments

<table>
<thead>
<tr>
<th>Location</th>
<th>Flyash level tons/ha</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulawathi</td>
<td>0</td>
<td>38.4</td>
<td>5.7</td>
<td>762.3</td>
<td>15.8</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>41.6</td>
<td>6.1</td>
<td>809.8</td>
<td>20.1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>39.8</td>
<td>7.3</td>
<td>819.8</td>
<td>20.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Muthiani</td>
<td>0</td>
<td>40.4</td>
<td>5.3</td>
<td>612.1</td>
<td>23.4</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>44.6</td>
<td>5.8</td>
<td>663.3</td>
<td>30.8</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>46.6</td>
<td>6.1</td>
<td>683.3</td>
<td>27.1</td>
<td>0.5</td>
</tr>
<tr>
<td>IARI Farm</td>
<td>0</td>
<td>31.4</td>
<td>5.2</td>
<td>620.9</td>
<td>16.9</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>34.3</td>
<td>4.8</td>
<td>634.6</td>
<td>18.0</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>38.2</td>
<td>5.3</td>
<td>631.5</td>
<td>22.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Note: CD at 5% levels is insignificant
increases yield of agricultural crops. Due to fine nature of flyash, it improves the WHC of sandy soils removing the compaction of clay soils. Flyash improves the physical and chemical properties of soil as well as biological properties of problematic soils, which further improve the productivity of agricultural crops. However, application of flyash, particularly unweathered ones, shows a tendency of accumulating elements like B, Mo, Se and Al, whose toxic levels are responsible for reductions in the crop yields and consequently influence animal and human health. However, when it is added in B, Mo and Se deficient soils, it acts as an excellent source. All these situations need to be carefully assessed while recommending applications of flyash in agriculture for reclamation of soils.

References


