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FLYASH CHARACTERISTICS AND ITS INCORPORATION EFFECTS ON SOIL HEALTH

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ABSTRACT

The disposal of huge amounts of ash produced in modern society is a major concern. Although this material finds uses in civil construction, cost considerations have limited such applications. The use of ash as landfill or for reclaiming acid/sodic soils are major disposal options, but these are not able to utilize the appreciable amount of ash produced. Thermal power stations thus require large spaces for storage, which may bring drastic changes in land-use patterns in the areas nearby. Authorities may have to maintain stricter associated air and water pollution limits. This article reports ash characteristics, ambient air quality, and ash incorporation effects on soil health at the National Capital Power Project (NCPP), Dadri, Ghaziabad, Uttar Pradesh, which is the only single dry ash disposal unit using electrostatic precipitation collection devices in India. The low particle density of ash establishes its potential for dust formation. The high water-holding capacity of ash is due to characteristic silt and clay size fractions. Ninety-three percent of the ash is composed of oxides of silicon, aluminium and iron. pH is neutral to slightly alkaline, whereas electrical conductivity was 0.65 mmhos/cm. Heavy metals, present in the oxide forms, in flyash exhibited concentrations considerably higher than in coal and in normal soils. Dust fall rate, averaged annually, in adjoining villages lay in a range of 4.91-15.92 $g/m^3/30d$, indicating ash fall, on annual basis, of less than 1 percent of surface soil mass. The fall rates were high during dry summer season, decreased in rainy season, and thereafter increased as winter progressed. Ambient air quality in villages

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adjoining NCPP was maintained well within safe limits, due to management controls adopted by the authorities. Addition of flyash (up to 40% ash in the soil-ash admixture) decreased bulk density and hydraulic conductivity, whereas enhanced moisture retained at field capacity, wilting point and surface mechanical impedance, primarily due to modifications in pore size distribution from ash addition. Differences in physico-chemical characteristics over the Control (no ash) due to ash incorporation were narrowed with time, indicating a high buffering capacity of the soil. Microbial activity was enhanced by ash incorporation up to 5 percent ash level in the soil-ash admixture. Thereafter inhibitory symptoms in the microbial activities were noticed. This trend was not observed in agricultural fields around Thermal Power Station, which were exposed to ash-added environments for longer periods of time.

INTRODUCTION

The energy sector is a primary engine of economic growth and industrialization. Thermal power plants play major roles in energy production. The combustion of coal generates flyash as particulate matter and oxides of nitrogen (NOx) and sulphur (SOx) as gaseous pollutants. A 210 MW capacity power plant burning E and G grade coal daily emits through stack about fifty to eighty tons of flyash, 350-430 kg SOx and 150-200 kg NOx [1]. With present advanced technology, it is possible to keep these pollutants within specified limits. The high ash content in Indian coal (around 40%), compared to very low values for developed countries, generates large quantities of residual ash. The amount of ash produced annually in India was approximately ninety million tons during 1995 and is likely to cross 140 million tons by 2020 A.D. This material finds some use in the manufacture of cement, bricks, and other civil construction materials. However, cost considerations have limited such applications in India. The use of ash as landfill and for reclaiming acid/sodic soils are major disposal options, but are not able to utilize the major amounts of ash produced. Consequently, thermal power stations need space for ash storage, amounting, in India, to some 30,000 hectares by 2000 A.D. This can bring drastic changes in land-use patterns in areas adjoining power plants [2]. Authorities have to maintain air and water conditions around thermal power sites within safer limits, and must ensure minimum ash carriage to the surrounding areas, by means of effective electrostatic precipitators and by adopting management practices such as the compaction of ash at storage sites. Evaluations of coal-burnt ash-mediated effects on flora and fauna, and assessments of management options to sustain productivity, are required. There is a need to evaluate ash characteristics, ash-disposal, and associated pollution problems, and ash-incorporation effects on soil and crop productivity. Various research studies in past were conducted on these lines, but most of them were confined to research laboratories or experimental farms [3-6]. In this article, we report ash characteristics, ambient air quality in adjoining areas, and ash-incorporation effects on soils health for a recently installed Thermal Power Plant, the National Capital Power Project (NCPP), at Dadri, Ghaziabad, Uttar Pradesh, which is the only unit in India with a dry ash disposal system using electrostatic precipitation collection devices.

MATERIALS AND METHODS

Flyash samples collected from the site were analyzed for physical, chemical and physico-chemical characteristics [7, 8]. Heavy metals present in coal and ash were analyzed by atomic absorption spectro-photometer by the project sponsoring agency, the Environment Management Group of NCPP. The air pollution monitoring of suspended particulate matter (SPM) and oxides of nitrogen (NOx) and sulphur (SOx) were made with a High Volume Sampler (Model Envirotech APM 415-411). Ash fall characteristics were measured by an Envirotech Dust Collection Device installed at nearby villages. Data was compiled during 1995-96 by the Environment Management Group of NCPP.

Flyash was mixed with sandy loam soil for the Indian Agricultural Research Institute Farm, New Delhi in varying levels—up to 40 percent by weight of ash in the soil-ash admixture—to evaluate modifications in physical (bulk density, saturated hydraulic conductivity and moisture retained at field capacity, and permanent wilting point), physico-chemical (pH, electrical conductivity and organic carbon), and biological (CO_2 evolution rate) characteristics of the soil [7-9].

RESULTS AND DISCUSSION

Coal and Ash Characteristics

Coal used at NCPP consisted of ash (45%), volatile material (15.2%), and fixed carbon (28.6%). Lime reactivity was 62 kg/cm^2. Sixty-nine percent of the ash was of silt- and clay-size fractions (Table 1). The low particle density results in a high potential for dust formation. The ash's high water-holding capacity is due to lower-size fractions (i.e., silt and clay dominance). The flyash, an amorphous ferro-alumino silicate, contained about 93 percent silica, Al_2O_3 and Fe_2O_3. In the remaining portion, Ca was the dominant cation followed by Mg, Na, and K. Total sulphur was low. Chlorides, sulphides, and phosphorus pentoxide constituted about 0.05 percent of the total mass. Electrical conductivity (EC) was 0.65 mmhos/cm. Heavy metals in the flyash, compared with literature values [10], exhibited concentrations considerably higher than in coal as evidenced by ash-to-coal ratios higher than one for most of the metals (Table 2). The major metals present in coal and flyash were Fe, Ni, Mn, Cd, Cu, and Zn. The concentration of

Table 1. Characteristics of Flyash Produced at NCPP, Dadri

Physical		Chemical	(%)
Textural class	Silt loam	Loss of ignition	0.72
Particle density (Mg/m^3)	2.02	Silica	56.68
Bulk density (Mg/m^3)	1.01	Al_2O_3	31.62
Hydraulic conductivity (cm/d)	3.57	Fe_2O_3	4.74
Saturated moisture content (%)	56.9	CaO	1.0
		MgO	0.4
		TiO_2	2.0
		Na_2O	0.48
		K_2O	2.07
		Chloride	<0.05
		SO_3	<0.05
		P_2O_5	<0.05
		Organic Carbon	0.36
		EC (mmhos/cm)	0.65
		Ph	6.98
		Total sulphur	0.05

Table 2. Presence of Heavy Metals in Flyash and Effluents at the Study Site

	Flyash, ppm			
Heavy Metal	Actual	Literature Value	Ash/Coal Ratio	Effluent, ppm
Hg	1.23	0.02-1.5	2.19	—
Mn	219.2	58-3000	2.21	—
Cu	77.6	14-2800	3.21	0.018
Pb	137.2	3.1-5000	5.96	0.071
Zn	88.2	10-3500	4.03	0.026
Ni	230.0	6.3-4300	1.63	—
Fe	63237	1-29	1.11	1.524
Cr	13.3	10-1000	4.41	0.056
Cd	23.8	0.7-230	0.31	0.031

heavy metals in effluents of the adjoining drains were very low, which might be due to lower solubility of metals as present in the oxide form.

Ash Fall Characteristics

Average dust fall rates (g/m3/30d) ranged on an annual basis, from 4.91 (Rasulpur) to 15.92 (Gulawathi). The fall rate values were high during dry summer season (April to mid-June), because of higher wind speeds and more ash present in loose form (being dry). During the monsoon season, fall rate values decreased appreciably. Although the season's south-westerlies have higher speeds, more ash is present as aggregate, due to greater moistness. Fall rate values increased as the season progressed toward winter, due to northeasterly winds and westerly weather disturbances. Dust fall in adjoining villages had larger variations in pH (6.96 to 8.07), whereas EC values for villages lay in the narrower range of 0.149 to 0.285 mmhos/cm. Dust fall values were negligible compared to the quantity of ash produced at NCPP, because of the use of effective ash storage techniques. Dust fall also was small compared to the soil mass of even the soil surface layer (0-20 cm). Ambient air quality in villages adjoining NCPP, as monitored through SPM, SOx, and NOx (Table 3), was maintained well within safe limits as prescribed by the Central Pollution Control Board of India.

Soil Characteristics as Modified by Ash Addition

The addition of flyash, dominant in silt+clay size fractions, to the soil resulted in decreased bulk density compared to the control values, ranging from –1.3 percent of the 1 percent ash level to –11.2 percent at the 40 percent ash level (Table 4). Hydraulic conductivity decreased rapidly as ash levels in soil-ash admixture increased from 1 percent to 5 percent, and thereafter gradually decreased by –53.1 percent from control values at the 40 percent ash level. The decreased hydraulic conductivity resulting from incorporation of ash in the light- to medium-textured soils could be attributed to increased micro-pores at the cost of reduction in the larger-sized pores. Modifications in pore size distribution also resulted in increased soil moisture retention at field capacity (0.8% increase over control at 1 percent ash to 11.9% increase at 40% ash) and permanent wilting point (2% increase over control at 1% ash to 9.5% increase at 40% ash). Since both the moisture retention constants are elevated by ash incorporation, the available water showed lower variations amongst various ash level treatments. Soil strength increased rapidly with increase in ash content, which may result in delayed germination and reduced crop-stand establishment at higher levels of ash addition in agricultural fields.

The decrease in pH with increased ash content in soil-ash admixture (Table 5) was primarily due to wide difference in the pH values of soil and ash. The EC and organic carbon content of the soil-ash admixture increased in accordance with the ash content. The range of variations in pH and EC values among various ash

Table 3. Characteristics of Dust Fall and Ambient Air Quality at Various Villages Adjoining NCPP, Dadri (Averaged Annually)

	Dust Characteristics			Ambient Air		
Village Name	Fall Rate ($g/m^3/30d$)	pH	EC (mmhos/cm)	SPM	SOx µg/nm3	NOx
Jarcha	11.36 (17.64)	7.6 (0.92)	0.258 (0.255)	256.6 (34.5)	6.11 (1.38)	3.36 (0.77)
Gulawathi	15.92 (11.41)	7.7 (1.21)	0.239 (0.104)	—	—	—
Muthiani	12.05 (7.47)	8.07 (0.96)	0.285 (0.165)	—	—	—
Upralsi	—	—	—	252.5 (42.0)	4.38 (0.48)	2.98 (0.51)
Salarpur	13.26 (19.56)	7.3 (0.76)	0.233 (0.155)	305.1 (45.4)	5.85 (0.81)	4.01 (0.91)
Bisoda	—	—	—	287.9 (32.7)	6.65 (0.54)	3.80 (0.14)
Piyavli	5.01 (3.59)	7.05 (0.88)	0.157 (0.91)	273.9 (64.2)	6.54 (0.39)	3.75 (0.53)
Rasulpur	4.91 (2.91)	6.96 (1.04)	0.149 (0.98)	271.8 (35.8)	6.36 (0.52)	3.95 (0.67)
Khangoda	8.16 (4.25)	6.93 (0.82)	0.174 (0.108)	332.1 (28.6)	5.56 (1.49)	3.44 (0.69)

*Values in parentheses indicate standard deviation.

application treatments was narrowed with time, as monitored at regular intervals up to 90 d of soil-ash admixture, while maintaining soil moisture up to field capacity (data not reported), indicating a high buffering capacity of the soil.

Flyash-mediated effects on soil microbial activity were evaluated through cumulative CO_2 evolution after 65 d of inoculation. The value under control conditions (no flyash) for the sandy loam soil of the IARI Farm was 1.296 µg CO_2/g soil, and was increased by 28.8 percent under 0.5 percent ash. Thereafter, up to 5 percent ash level, the values were higher than for controls, but significantly lower than the value under 0.5 percent ash level treatment. For ash

Table 4. Changes in Soil Physical Characteristics of a Sandy Loam Soil by Adding Varying Levels of Flyash

Flyash Level (%)	Bulk Density (Mg/m^3)	HC cm/d	Field Capacity (w/w, %)	Wilting Point (w/w, %)	Soil Strength (kg/cm^2)	Available Water (mm/cm)
Control	1.48	11.7	15.7	4.6	1.57	1.66
% change over control						
1	–1.3	–17.8	0.8	2.0	0.63	—
5	–3.4	–38.1	3.0	5.0	5.73	0.2
10	–6.8	–38.9	4.1	7.6	14.0	0.7
20	–10.8	–45.8	7.1	8.8	28.7	1.4
40	–11.2	–53.1	11.9	9.5	42.0	2.4

Table 5. Changes in Soil Physico-Chemical Characteristics by Adding Varying Levels of Flyash

Flyash Level (%)	pH	EC (mmhos/cm)	Organic Carbon (%)
Control	8.31	0.467	0.280
% change over control			
1	–0.3	15.1	0.5
5	–0.9	27.4	2.1
10	–2.5	28.9	3.9
20	–2.5	38.1	7.8
40	–3.9	59.7	11.8

levels higher than 5 percent, microbial activity was inhibited as seen from the 16.8 percent reduction over control at the 20 percent ash level. Sandy loam soils of Muthiani and Gulawathi villages with relatively higher organic carbon content than the IARI soil, when continuously exposed to the ash in soil-plant-air system, showed significantly higher CO_2 evolution than did controls. In these two soils, resistance to ash-mediated effects was made clear through higher microbial activity up to the 20 percent ash level.

CONCLUSIONS

The use of coal-burnt ash as civil construction material, landfill, or for reclaiming acidic and sodic soils needs to be encouraged. Since these activities are not able to utilize the large amounts of ash produced, authorities have to resort to environmentally friendly storage of ash in the form of ash-mounds. The storage site has to be on land not suitable for cultivation, so that its acquisition does not create any socioeconomic problem or decrease cultivable area in the region. The low value of particle density of ash establishes its potential for dust formation. The high water holding capacity of ash is due to dominance of the silt+clay size fraction. Heavy metals in ash are present as oxides, as such insoluble in water and not readily available for uptake by plants. The toxicity of heavy metals in the admixture needs evaluation on a long term basis. Annual dust fall near the NCPP was less than 1 percent of surface soil mass, and showed significant seasonal variations. At low levels of ash addition, soil characteristics are not expected to change significantly, although some pore size modifications were noticed. Ash addition at higher levels (up to 40%), simulating landfill/soil amendment conditions and the long-term effects of gradual ash additions, had influences on soil properties. Keeping in view the high buffering capacity of soil, there is a need to evaluate the long-term consequence of continuous ash addition on soil health and crop productivity.

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