Environmental Monitoring and Assessment (2005) **107:** 1–9
DOI: 10.1007/s10661-005-2021-x

USE OF FLYASH AND BIOGAS SLURRY FOR IMPROVING WHEAT YIELD AND PHYSICAL PROPERTIES OF SOIL

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(Received 17 May 2004; accepted 2 August 2004)

Abstract. This study explores the potential use of by-products of energy production, i.e., (i) flyash from coal-powered electricity generation and (ii) biogas slurry from agricultural waste treatment, as nutrient sources in agriculture. These residues are available in large amounts and their disposal is a major concern for the environment. As both residues contain considerable amounts of plant nutrients, their use as soil amendment may offer a promising win-win opportunity to improve crop production and, at the same time, preventing adverse environmental impacts of waste disposal. Effect of flyash and biogas slurry on soil physical properties and growth and yield of wheat (*Triticum aestivum*) was studied in a field experiment. Leaf area index, root length density and grain yield of wheat were higher in plots amended with flyash or biogas slurry compared to unamended plots. Both types of amendments reduced bulk density, and increased saturated hydraulic conductivity and moisture retention capacity of soil. The study showed that flyash and biogas slurry should be used as soil amendments for obtaining short-term and long-term benefits in terms of production increments and soil amelioration.

Keywords: biogas slurry, bulk density, flyash, hydraulic conductivity, moisture retention capacity, wheat

Abbreviations: CEC, Cation Exchange Capacity; CD, Critical Difference; DAS, Days After Sowing; DMRT, Duncan's Multiple Range Test; LAI, Leaf Area Index

1. Introduction

The ever-growing demand for energy creates various environmental problems such as air, water and soil pollution. In industrialized countries, gas and petrol have become the pre-dominant types of fossil fuel, but for the Indian economy, combustion of coal is still a major source of energy. Annual production of flyash, generated from thermal power plants during combustion of coal, is around 90 million tons in India and is likely to increase to 140 million tons by 2020 (Deshpande *et al.*, 1993). Disposal of flyash in this quantity is a great problem because, at present, there are no large-scale recycling options. Previous attempts to use flyash in the

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construction sector, like brick making and road foundation, were economically not viable and can potentially only recycle limited fraction of the total amount of ash generated annually. Thus, the bulk of the flyash is dumped on land in the form of ash mounds. This practice creates large land area of wasteland and also causes environmental pollution, particularly through eolian deposition on vegetation and human settlements (Page *et al.*, 1979). As an alternative, fly ash could be used as soil amendment in agriculture as it contains many essential plant nutrients (Singh and Singh, 1986; Singh and Kansal, 1994; Raman *et al.*, 1996). But before disseminating this practice, detailed studies should be carried out to assess the impact of fly ash application on crop yield and soil properties.

The disposal of biogas slurry, a by-product of biogas production generating from cattle dung, represents a very similar case as the flyash disposal. Due to propagation of biogas plants in many Asian countries, including India, the amount of slurry to be disposed has drastically increased. As for fly ash, the biogas slurry is a good source of plant nutrients and can improve crop yield and soil properties (Smith and Elliot, 1990; Prasad and Power, 1991; Pathak *et al.*, 1992). The objective of the study was to evaluate the effects of flyash and biogas slurry on soil physical properties and growth and yield of wheat (*Triticum aestivum*).

2. Materials and Methods

2.1. Experimental site and soil

A field experiment was conducted in the winter season (November 2001 to April 2002) growing wheat at the experimental farm of the Indian Agricultural Research Institute, New Delhi, India. The site is located in the Indo-Gangetic alluvial tract at 28°40′N and 77°12′E, with an altitude of 228 m above mean sea level. The climate of the region is subtropical with annual rainfall of 750 mm, of which 80% occur from June to September. The mean maximum and minimum temperatures during November to April are 22.6 and 6.7 °C, respectively. The alluvial soil of the experimental site was *Typic Ustochrept*, sandy loam comprising of three horizons. The Ap horizon, from 0 to 21 cm depth, is dark yellowish brown (10YR 5/4 D), moderate angular blocky structure, slightly firm, slightly sticky with a smooth boundary. Soil in this horizon has a pH (1:2 soil:water) 8.1, electrical conductivity (1:2 soil:water) 0.48 d S m^{-1}, CEC 7.3 cmol kg^{-1}; and organic carbon, total N, Olsen P, and ammonium acetate extractable K contents 4.5 g kg^{-1}, 0.30 g kg^{-1}, 0.007 g kg^{-1}, and 0.13 g kg^{-1}, respectively. The next B11 horizon, from 21 to 52 cm depth, is yellowish brown (10YR 4.5/4 M), moderate angular blocky structure, slightly firm, slightly sticky with a clear and wavy boundary. The lower most horizon was B12 from 52 to 93 cm depth, is dark yellowish brown (10YR 4/4 M), moderate angular blocky structure, slightly firm, slightly sticky with a gradual and smooth boundary.

TABLE I
Physico-chemical properties and composition of flyash used in the experiment

Properties	Values
Particle size range (mm)	0.002–0.02
Texture	Silt loam
Particle density (Mg m^{-3})	2.0
Bulk density (Mg m^{-3})	1.0
Hydraulic conductivity (cm h^{-1})	3.6
pH	7.0
Composition (g kg^{-1}):	
Organic C	3.6
P	3.0
K	18.0
SiO_2	566.8
Al_2O_3	316.2
Fe_2O_3	47.4
CaO_4	47.4
MgO	4.0
Na_2O	4.8
TiO_2	20.0
S	0.5

2.2. Amendments, treatments and crop management

Physico-chemical properties and composition of the flyash used in the experiment have been given in Table I. Biogas slurry contained 15.0, 5.0, and 10.0 g kg^{-1} N, P, and K, respectively, on an oven-dry basis. The experiment included low to high doses of flyash and biogas slurry consisting six treatments: unamended control (C), 4.5 Mg ha^{-1} biogas slurry (S_L), 15 Mg ha^{-1} biogas slurry (S_H), 4 Mg ha^{-1} flyash (F_L), 8 Mg ha^{-1} flyash (F_M) and 12 Mg ha^{-1} flyash (F_H); with three replications in a randomized block design (Table III). The quantities of slurry and flyash were derived from previous experiences (Pathak *et al.*, 1992; Kalra *et al.*, 1998). Flyash and biogas slurry were incorporated into the soil 15 days before sowing of wheat. Wheat (variety HD 2285) at 100 kg seed ha^{-1} was sown in rows 22.5 cm apart in plots of 6-m long and 5-m wide. Urea at 120 kg N ha^{-1} was applied in three equal splits at 0, 20 and 35 days after sowing (DAS) while P (26.2 kg ha^{-1}) as single super phosphate and K (50 kg ha^{-1}) as KCl were incorporated into the soil at the time of sowing in all the plots. Five irrigations (6-cm water each) were given to the crop. Weeds, pests, and diseases were controlled as required.

2.3. Estimation of yields

Grain yield was measured from a 20 m^2 harvest area at maturity. Grain moisture was determined immediately after weighing and subsamples were dried in an oven at 65 °C for 48 h. The grain weight was adjusted to 120 g kg^{-1} moisture.

2.4. Measurement of soil and plant parameters

At tillering and harvest of wheat crop, soil samples were collected from 0–15, 15–30 and 30–45 cm depths for determination of bulk density, volumetric moisture content, and hydraulic conductivity using standard methods (Page *et al.*, 1982). Soil samples were also collected from the 0–15 soil layer at harvest for determination of volumetric moisture content at different tensions using pressure plate method.

Leaf area index (LAI) of wheat at different periods of growth (20, 31, 55, 66, 75 and 89 DAS) was measured using a leaf area meter (Model LI-3100). For studying the root growth at 75 DAS, core samples of soil were collected with an auger of 7-cm diameter at progressive soil depth of 15 cm up to 90 cm. The collected samples were spread on a 30-mesh sieve and cleaned with a fine spray of water to remove soil and dead organic debris. The roots from the sieve were collected with the help of forceps and preserved in 5% formalin plus methanol solution. Root length density was determined following the line interception method of Newman (1966).

3. Results and Discussion

3.1. Soil physical parameters

At tillering stage of wheat, the bulk density of the 0–15 cm soil layer varied between 1.35 to 1.47 Mg m^{-3} (Table II). Application of biogas slurry at 15 Mg ha^{-1} (S_H) decreased the bulk density by 0.12 Mg m^{-3} over the unamended control treatment (C), whereas flyash treatments (F_L, F_M and F_H) and application of slurry at 4 Mg ha^{-1} (S_L) had no significant effect on bulk density of surface soil. The deeper soil layers (15–30 and 30–45 cm) had higher bulk densities compared to that of the surface soil layer. However, there was no effect of slurry or flyash amendment on the bulk density at deeper soil layers at tillering stage of wheat. Amendment of soil with flyash and biogas slurry had significant effect on bulk density at the harvest stage of wheat. Biogas slurry amendment at 4 and 15 Mg ha^{-1} (S_L and S_H, respectively) decreased bulk density by 0.12 and 0.20 Mg m^{-3}, respectively, over the unamended control treatment. Flyash application at 12 Mg ha^{-1} (F_H) also decreased soil bulk density by 0.11 Mg m^{-3} over the control, whereas the other flyash treatments (F_L and F_M) had no significant effect. Like the tillering stage, at harvest also biogas slurry and flyash application had no significant effect on bulk density of soil at lower depths. The lowering of bulk density in the surface soil layer with the application flyash and biogas slurry might be due to low density of these amendments (Chatterjee *et al.*, 1988; Amer *et al.*, 1997; Sale *et al.*, 1997; Shakweer *et al.*, 1998). Shinde *et al.* (1995) observed that flyash application at 7.5% of soil

TABLE II
Effect of soil amendments on bulk density and hydraulic conductivity of soil at tillering and harvesting stages of wheat crop

Treatment	Acron.	Bulk density (Mg m^{-3})						Hydraulic conductivity (cm h^{-1})					
		Tillering stage			Harvesting stage			Tillering stage			Harvesting stage		
		Soil depth (cm)											
		0–15	15–30	30–45	0–15	15–30	30–45	0–15	15–30	30–45	0–15	15–30	30–45
Control	C	1.47a[a]	1.59a	1.62a	1.52a	1.58a	1.62a	0.52b	0.41a	0.38a	0.51c	0.41a	0.40a
Slurry (4.5 Mg ha^{-1})	S_L	1.42a	1.58a	1.61a	1.40b	1.57a	1.60a	0.64a	0.41a	0.38a	0.65b	0.42a	0.40a
Slurry (15 Mg ha^{-1})	S_H	1.35b	1.57a	1.60a	1.32c	1.54a	1.59a	0.65a	0.42a	0.39a	1.01a	0.43a	0.41a
Flyash (4 Mg ha^{-1})	F_L	1.47a	1.55a	1.60a	1.46ab	1.55a	1.58a	0.54b	0.42a	0.38a	0.61b	0.44a	0.40a
Flyash (8 Mg ha^{-1})	F_M	1.45a	1.54a	1.58a	1.44b	1.53a	1.57a	0.62a	0.45a	0.40a	0.66b	0.45a	0.41a
Flyash (12 Mg ha^{-1})	F_H	1.42a	1.53a	1.57a	1.41b	1.52a	1.55a	0.63a	0.45a	0.41a	0.90a	0.47a	0.42a
[b]CD (P = 0.05)		0.06	NS	NS	0.07	NS	NS	0.06	NS	NS	0.09	NS	NS

[a]Means in a column followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.
[b]CD is critical difference.

(weight basis) decreased soil bulk density. Lower bulk density of soil indicates less soil compaction, better aeration, better drainage and good crop growth.

Amendments, except at the lowest level of flyash (F_L), increased the hydraulic conductivity of surface soil at tillering stage of wheat (Table II). Slurry at 15 Mg ha^{-1} increased hydraulic conductivity by 0.13 cm h^{-1}, whereas flyash at 12 Mg ha^{-1} increased it by 0.11 cm h^{-1}. At the harvest stage of wheat also similar trend was observed and the magnitudes of increase in hydraulic conductivity were 0.50 and 0.39 cm h^{-1}, in S_H and F_H treatments, respectively. The differences in hydraulic conductivity, however, were not significant in lower soil layers. Increased hydraulic conductivity by incorporation of biogas slurry and flyash might be due to improvement in soil structure (Shakweer *et al.*, 1998; Cox *et al.*, 2001). Shinde *et al.* (1995) also observed that flyash at 7.5% increased soil porosity and hydraulic conductivity indicating improvement in physical condition of soil. Sale *et al.* (1997) reported that addition of flyash up to 12.5–25% of soil (weight basis) resulted in the highest percentage of aggregates within the ideal range (0.5 to 4.0 mm) and lowered modulus of rupture, thus reducing cloudiness.

Volumetric moisture content of surface soil layer at saturation (0.00 M Pa moisture tension) increased from 42.1% in the unamended control treatment (C) to 44.1 and 43.5% with 15 Mg ha^{-1} slurry (S_H) and 12 Mg ha^{-1} flyash (F_H) treatments, respectively (Table III). Other levels of amendments had no effect on soil water content at saturation. At 0.01 M Pa soil moisture tension also only the highest levels of slurry (S_H) and flyash (F_H) improved soil water content. At 0.33 M Pa soil moisture tension, however, both the levels of slurry and the highest level of flyash (F_H) increased soil water content but at 1.5 M Pa the amendments had no effect on

TABLE III
Volumetric water content of 0–15 cm soil layer at different tensions at harvesting stage of wheat crop

	Volumetric water content (%)			
	Soil moisture tension (M Pa)			
Treatment	0	0.01	0.33	1.5
Control (C)	42.1b[a]	33.7b	21.1b	7.5a
Slurry (S_L)	42.5b	34.1b	25.9a	7.9a
Slurry (S_H)	44.1a	36.9a	26.2a	8.6a
Flyash (F_L)	42.2b	34.0b	22.7b	7.8a
Flyash (F_M)	42.6b	34.2b	23.2b	8.1a
Flyash (F_H)	43.5a	36.2a	25.7a	8.5a
[b]CD ($p = 0.05$)	0.7	1.2	2.2	NS

[a]Means in a column followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.
[b]CD is critical difference.

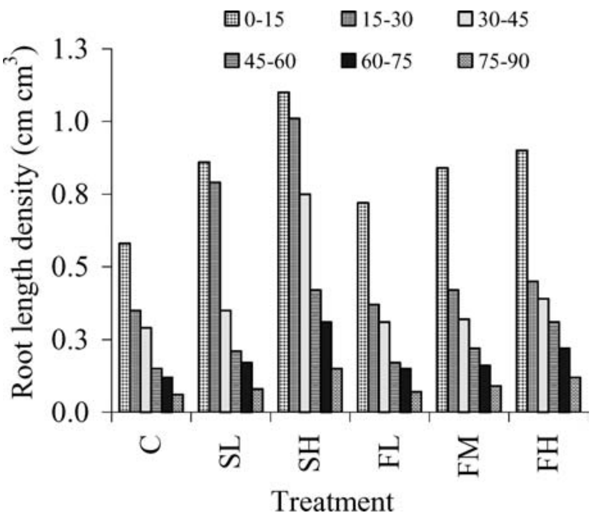

Figure 1. Root length density of wheat crop with slurry and flyash amendments in different layers of soil. Treatments: unamended control (C), 4.5 Mg ha^{-1} biogas slurry (SL), 15 Mg ha^{-1} biogas slurry (SH), 4 Mg ha^{-1} flyash (FL), 8 Mg ha^{-1} flyash (FM) and 12 Mg ha^{-1} flyash (FH).

soil water content. Increase in soil water retention capacity with soil amendments could be attributed to the greater organic carbon content (Rajput and Sastry, 1984) and better aggregation (Rajput and Sastry, 1987) of amended soil.

3.2. Plant parameters and yield

Root length density at wheat harvest was highest in the upper soil layer and decreased gradually in the lower layers (Figure 1). Application of biogas slurry improved root growth followed by flyash application and unamended control. Maximum root length density at 0–15 cm soil layer was observed with 15 Mg ha^{-1} slurry application (1.10 cm cm^{-3}) and lowest was in the unamended control (0.58 cm cm^{-3}). The trend was similar at lower soil layers also. The higher root growth under biogas slurry and flyash treatment could be attributed to the improvement in soil physical properties.

The LAI of wheat increased with the advancement of crop growth up to 75 DAS with slurry, and up to 66 DAS in flyash and control treatments, after which it decreased (Figure 2). In biogas slurry treatments LAI was higher compared to flyash treatments. Higher levels of amendments resulted in higher LAI due to higher nutrient availability and better soil physical condition.

Amendments of soil with biogas slurry and flyash increased the yield of wheat over the unamended control (Table IV). Highest grain yield of 6.21 Mg ha^{-1} was observed in 15 Mg ha^{-1} biogas slurry treatment (S_H). The increase in grain yield with amendments could be attributed to the improvement of soil physical properties in terms of lower bulk density, higher hydraulic conductivity and greater moisture

TABLE IV
Grain yield of wheat at different levels of biogas slurry and flyash amendments

Treatment	Yield (Mg ha^{-1})
Control (C)	4.40c[a]
Slurry (S_L)	5.17b
Slurry (S_H)	6.21a
Flyash (F_L)	5.09b
Flyash (F_M)	5.10b
Flyash (F_H)	5.49b
[b]CD ($p = 0.05$)	0.45

[a]Means in a column followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.
[b]CD is critical difference.

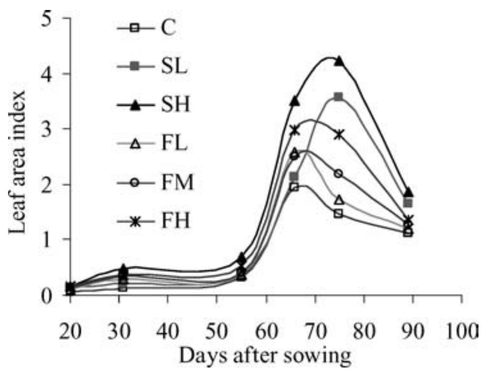

Figure 2. Leaf area index (LAI) at different stages of wheat crop as affected by biogas slurry and flyash amendments in soil. Treatments: unamended control (C), 4.5 Mg ha^{-1} biogas slurry (SL), 15 Mg ha^{-1} biogas slurry (SH), 4 Mg ha^{-1} flyash (FL), 8 Mg ha^{-1} flyash (FM) and 12 Mg ha^{-1} flyash (FH).

retention of soil (Tables II and III). Addition of nutrients through these amendments also contributed to higher yield.

The study showed that biogas slurry and flyash could be used as soil amendments to improve soil physical condition, and growth and yield of wheat. It was revealed that fly ash application in agriculture has a good promise but the impact of its application on soil health needs to be established in long-term basis.

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