

## Amelioration of Coal Mine Spoils through Fly Ash Application as Liming Material

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The feasibility of fly ash as compared to lime to ameliorate the low pH of acidic coal mine spoils under controlled pot culture conditions are reported using Sudan grass (*Sorghum sudanens*) and Oats (*Avena sativa*) as indicator crops. It is observed that at all levels of applications, fly ash and lime significantly increase the pH of mine spoils, available phosphorus, exchangeable potassium, available sulphur and also uptake of phosphorus, potassium, sulphur and oven-dried biomass of both these test crops. The fly ash significantly decreases the bulk density of coal mine spoils, but, there is no effect on bulk density due to lime application. However, when the spoils are amended with either fly ash or lime, the root growth occurs throughout the material. Fly ash and lime do not cause elemental toxicities to the plants as evidenced from the dry matter production by the test crops. The results indicate that fly ash to be a potential alternative to lime for treating acidic coal mine spoils.

### Introduction

Acidic coal mine spoils frequently occur in many of the coal mining areas of India. Accelerated coal mining has aggravated this problem further. Awareness in recent times of environmental pollution associated with coal mining has resulted in increased attention to the problems of acidic spoils, which was not considered an area of much consequence. The acidification of spoils and top soil is primarily due to the oxidation of iron sulphide minerals. Oxidation and hydrolysis occur when pyrite ( $\text{FeS}_2$ ) overburden is disturbed and brought to the surface during mining. The formation of sulphuric acid by oxidation and hydrolysis of  $\text{FeS}_2$  results in a drastic reduction in pH of spoils. Acidic conditions limit mined land revegetation, thus exposing it to further degradation due to lack of plant cover.

The increasing dependence on coal as an energy source has resulted in an unabated generation of colossally large quantities of coal residues in many countries<sup>1</sup>, including India, disposal of which has created environmental, social and ecological problems. Fly ash is a major waste product of coal-based power plants and industries. Fly ash readily escapes to the atmosphere along with flue gases because of its fine particle size and it pollutes

the air. As most of the thermal power facilities are located in coal mining areas where coal mine spoils occur, it was considered worthwhile to ameliorate and revegetate these spoils using fly ash as an amendment.

The present investigation was therefore, carried out to compare the effectiveness of various levels of fly ash and lime in alleviating the acidity of coal mine spoils and enhancing revegetation, and to evaluate the potential accumulation of nutrients in plants.

### Materials and Methods

Acidic coal mine spoils were collected from a dumped site of Patratu coal mine, District Hazaribagh (Bihar), and the currently generated fly ash was obtained from the National Thermal Power Corporation Plant, Dadri, Ghaziabad (UP). Both materials were air dried, sieved and thoroughly mixed. The coal mine spoils were examined for bulk density, pH (1:2 spoils water ratio), sodium bicarbonate extractable phosphorus, neutral normal ammonium acetate exchangeable potassium and calcium chloride extractable sulphur<sup>2</sup>. The dehydrogenase activity was estimated by the method stated by Klein *et al.*<sup>3</sup>. Total elemental analysis of fly ash was carried out following the method outlined by Page *et al.*<sup>4</sup>. Initial characteristics of coal mine spoils and fly ash are presented in Table 1. Four kg of coal mine spoils was taken

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in the earthen pots and spoils amendment rates were 0, 33, 66 and 100 g fly ash kg<sup>-1</sup> of spoils and 0, 1/3, 2/3 and 1.0 L.R. (lime requirement) of lime. The lime requirement (L.R.) of coal mine spoils was measured through the procedure described by Shoemaker *et al.*<sup>5</sup>.

Ten seeds of Sudan grass (*Sorghum sudanensis*) were sown in each pot in kharif season ( summer) and ten seeds of Oats (*Avena sativa*) were sown in rabi season (winter). Sudan grass, first in the cycle of crops received a basal dose of 30 kg N ha<sup>-1</sup> through urea. The successive Oats for the residual study received a recommended basal dose of 30 kg N ha<sup>-1</sup> through urea and 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> through single super phosphate. Following germination and emergence, seedlings were thinned to five uniform sized plants per pot to provide initially consistent plant establishment for both the test crops. The containers were watered as needed to prevent moisture stress but care was taken to prevent leaching. Two cuttings of Sudan grass were taken at 60 and 120 days after sowing (DAS) while in the case of Oats, plants samples were

taken at harvesting stage which is a usual practice for cultivation of these crops.

The plant samples were dried at 60°C, weighed, ground and digested in a di-acid mixture (HNO<sub>3</sub>:HClO<sub>4</sub> in 10:4) on an electric hot plate. Phosphorus was estimated by vanadomolybdate yellow colour method<sup>6</sup>, potassium concentration was read in a flame photometer and sulphur concentration through precipitating by BaCrO<sub>4</sub> in HCl medium and by measuring the intensity of yellow color<sup>7</sup> using Spectronic 20 spectrophotometer.

Coal mine spoils samples were collected at 60 and 120 days after sowing of Sudan grass and at harvesting stage of Oats. Coal mine spoils were analysed for bulk density<sup>8</sup>, pH<sup>9</sup>, dehydrogenase activity<sup>3</sup>, sodium bicarbonate extractable phosphorus<sup>10</sup>, neutral normal ammonium acetate exchangeable potassium<sup>11</sup> and calcium chloride extractable sulphur<sup>12</sup>.

For statistical analysis of data, the experimental design was a completely randomised block ( 2 factor) with 16 treatments and 3 replications. All statistical tests were performed at 5% level.

Table 1 — Characteristics of coal mine spoils and fly ash used

Properties	Coal mine spoils	Fly ash
Bulk density, Mg m <sup>-3</sup>	1.40	1.10
pH 1:2 (Spoils : Water)	5.14	8.23
Total phosphorus, %	11.96	0.45
(Available phosphorus kg ha <sup>-1</sup> )		
Total potassium, %	164.30	0.87
(Exchangeable potassium kg ha <sup>-1</sup> )		
Total sulphur, %	5.28	0.07
(Available sulphur kg ha <sup>-1</sup> )		
Dehydrogenase activity, µg TPF g <sup>-1</sup> h <sup>-1</sup>	3.16	-

## Results and Discussion

The initial characteristics of the coal mine spoils and fly ash differed widely (Table 1). The spoils were highly acidic (pH 5.14) whereas fly ash had an alkaline (pH 8.23) reaction. The phosphorus, potassium and sulphur status of the acidic coal mine spoils indicated major deficiencies of these nutrients.

### Soil Response

The fly ash amendment resulted in reduction in the bulk density of the coal mine spoils, but lime was not

Table 2 — The effect of fly ash and lime on bulk density of coal mine spoils growing Sudan grass and Oats

Fly ash (g kg <sup>-1</sup> )	Bulk density (Mg m <sup>-3</sup> )			Lime (L.R.)	Bulk density (Mg m <sup>-3</sup> )		
	Sudan grass		Oats		Sudan grass		Oats
	60 DAS	120 DAS	At harvesting		60 DAS	120 DAS	At harvesting
0	1.41	1.40	1.40	0	1.31	1.30	1.31
33	1.34	1.33	1.33	1/3	1.32	1.30	1.30
66	1.28	1.27	1.26	2/3	1.32	1.30	1.30
100	1.22	1.22	1.20	1.0	1.30	1.30	1.30
CD	0.05	0.04	0.05	CD	NS	NS	NS
(P=0.05)				(P=0.05)			

DAS = Days after sowing; Mg = mega gram

Table 3 — The effect of fly ash and lime on available phosphorus, exchangeable potassium, and available sulphur in coal mine spoils growing Sudan grass and Oats

Fly ash (g kg <sup>-1</sup> )	Available phosphorus (mg kg <sup>-1</sup> )			Exchangeable potassium (mg kg <sup>-1</sup> )			Available sulphur (mg kg <sup>-1</sup> )		
	Sudan grass		Oats	Sudan grass		Oats	Sudan grass		Oats
	60 DAS	120 DAS	At harvesting	60DAS	120 DAS	At harvesting	60 DAS	120 DAS	At harvesting
0	7.81	7.08	5.66	92.07	86.30	81.07	5.91	5.80	5.74
33	9.02	8.23	6.59	97.09	90.76	86.23	6.27	6.09	6.17
66	9.93	9.15	7.31	100.52	94.56	90.05	6.77	6.80	6.67
100	10.87	10.05	8.04	103.30	97.91	92.56	7.30	7.37	7.22
CD (P=0.05)	0.90	0.88	0.70	2.65	2.60	2.47	0.47	0.46	0.50
Lime(L.R.)									
0	8.21	7.42	5.93	91.46	85.99	80.82	5.85	5.88	5.81
1/3	9.12	8.34	6.67	97.52	91.73	86.69	6.14	6.22	6.02
2/3	9.81	9.03	7.22	100.60	94.58	89.85	6.85	6.72	6.71
1.0	10.49	9.72	7.78	103.39	97.23	92.56	7.42	7.24	7.26
CD (P=0.05)	0.70	0.69	0.56	2.80	2.76	2.75	0.52	0.51	0.53

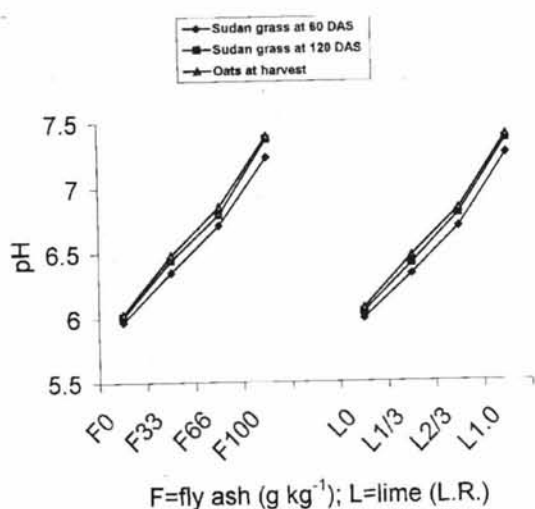


Figure 1— Effect of fly ash and lime on pH of coal mine spoils growing Sudan grass and Oats

effective in this regard. The 100 g fly ash kg<sup>-1</sup> spoils treatment had a significantly lower bulk density (Table 2) which may be attributed to lighter and porous nature of fly ash, since it has amorphous ferro-alumino silicate minerals. The addition of the finer textured fly ash to spoils caused a reduction in the bulk density. Fly ash application to spoils makes them porous and less compact, improving their drainage and aeration<sup>13</sup>.

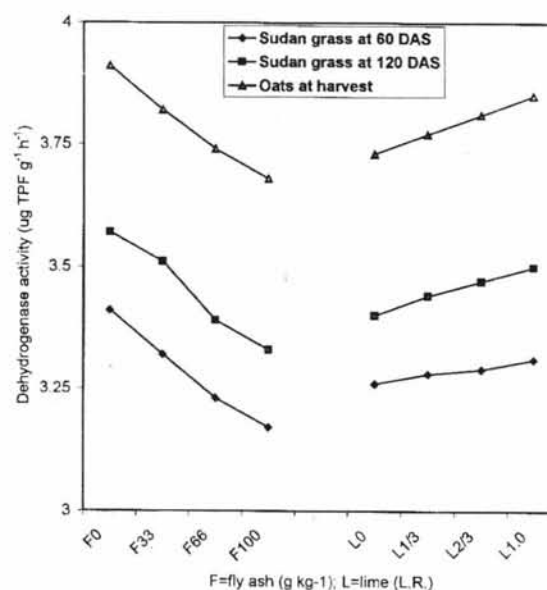


Figure 2 — Effect of fly ash and lime on dehydrogenase activity of coal mine spoils growing Sudan grass and Oats

Fly ash and lime amendment increased the pH of the acidic coal mine spoils. The 100 g fly ash kg<sup>-1</sup> spoils treatment resulted in a significantly higher pH of 7.9 (Figure 1). This can be attributed to a larger reactive surface area of fly ash, as reported by Taylor and Schuman<sup>14</sup>. The results indicated that the fly ash (used

Table 4 — The effect of fly ash and lime on phosphorus uptake by Sudan grass and Oats grown on coal mine spoils

Fly ash (g kg <sup>-1</sup> )	Phosphorus uptake (g pot <sup>-1</sup> )			Lime (L.R.)	Phosphorus uptake (g pot <sup>-1</sup> )		
	Sudan grass		Oats		Sudan grass		Oats
	60 DAS	120 DAS	At harvesting		60 DAS	120 DAS	At harvesting
0	0.07	0.12	0.16	0	6.4	8.6	11.4
33	0.10	0.15	0.21	1/3	7.4	9.7	12.8
66	0.12	0.17	0.25	2/3	8.2	10.5	14.0
100	0.14	0.19	0.28	1.0	9.0	11.3	15.0
CD (P=0.05)	0.017	0.018	0.02	CD (P=0.05)	0.7	0.8	1.0

Table 5 — The effect of fly ash and lime on uptake of potassium and sulphur by Sudan grass and Oats grown on coal mine spoils

Fly ash (g kg <sup>-1</sup> )	Potassium uptake (g pot <sup>-1</sup> )			Sulphur uptake (g pot <sup>-1</sup> )		
	Sudan grass		Oats	Sudan grass		Oats
	60 DAS	120 DAS	At harvesting	60 DAS	120 DAS	At harvesting
0	0.17	0.20	0.29	0.05	0.10	0.13
33	0.22	0.24	0.35	0.08	0.12	0.17
66	0.25	0.27	0.39	0.10	0.14	0.20
100	0.28	0.30	0.43	0.11	0.15	0.22
CD (P=0.05)	0.02	0.02	0.03	0.008	0.008	0.02
Lime (L.R.)						
0	0.18	0.19	0.28	0.06	0.10	0.14
1/3	0.21	0.24	0.34	0.08	0.12	0.17
2/3	0.25	0.27	0.39	0.09	0.14	0.19
1.0	0.28	0.30	0.45	0.10	0.15	0.21
CD (P=0.05)	0.02	0.02	0.03	0.01	0.01	0.02

in our experiments) and lime were effective in ameliorating the acidic coal mine spoils.

The dehydrogenase activity decreased with the increase in the rates of fly ash amendment but the reverse was observed with lime amendments which is indicative of reduced microbial activity in soil due to the application of fly ash at higher rates (Figure 2). This is possible as increased concentration of iron and aluminium might prove toxic to soil organisms<sup>15</sup>. However, the addition of lime is likely to create favourable conditions unlike fly ash where toxic elements get added.

The available phosphorus, potassium and sulphur were significantly increased in coal mine spoils due to application of fly ash and lime (Table 3). The maximum increase was noticed at highest rates of application for all the nutrients. Increase in available phosphorus, potassium and sulphur may be due to the additions through flyash<sup>16,17</sup>.

### Biomass Response and Nutrients Uptake

Oven-dried biomass of both Sudan grass and Oats increased when acidic coal mine spoils were amended with fly ash or lime (Figure 3). Fly ash (100 g kg<sup>-1</sup> spoils)

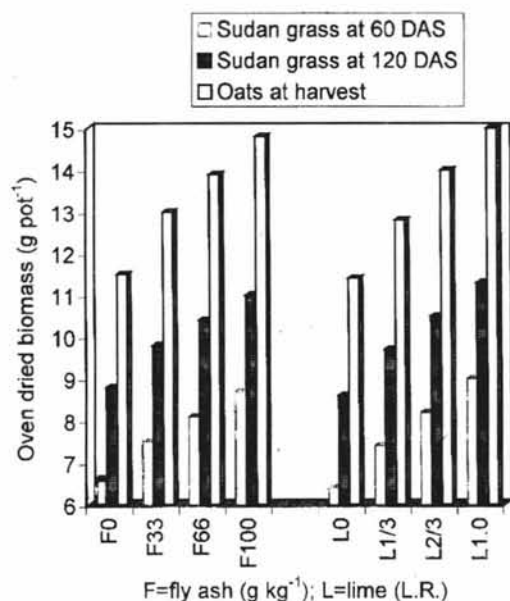


Figure 3 — Effect of fly ash and lime on oven-dried biomass production of Sudan grass and Oats grown on coal mine spoils

and of lime (1.0 L.R.) significantly increased the oven-dried biomass of both the crops. Fly ash amendment at all levels resulted in significantly higher oven-dried biomass over the untreated one. This can be attributed to increase in pH which increased nutrient availability.

There were no differences among fly ash and lime amendments; indicating that both amendments were equally effective in ameliorating the acidic spoils problems, as indicated by biomass turnover. The uptake of phosphorus potassium, sulphur by Sudan grass and Oats significantly increased with increasing rates of fly ash and lime (Tables 4 and 5). The 100 g fly ash kg<sup>-1</sup> spoils had a significantly higher uptake of phosphorus, potassium and sulphur than any other treatment, other than the control. These differences in elemental concentration of sequential crops of Sudan grass and Oats can be attributed to pH effects, nutrient distribution in the spoils, and root distribution within the pots. The response could also be attributed to increased availability of phosphorus, potassium and sulphur from fly ash to plants<sup>16,17,18</sup>.

### Summary and Conclusions

In a study conducted to determine the effectiveness of fly ash and lime as amendments for revegetation of coal mine spoils with Sudan grass and Oats has indi-

cated that both are effective in increasing the pH of coal mine spoils. Fly ash has a good ameliorative property and has proved to be a good source for nutrients. Lime at all rates of application and fly ash up to 100 g fly ash kg<sup>-1</sup> spoils have resulted in adequate neutralisation of the acidic coal mine spoils with an initial pH of 5.14. These amendments have shown significantly higher biomass production of Sudan grass and Oats and also increased nutrient uptake by these crops.

The study shows that fly ash is a feasible alternative to lime for amelioration of acidic coal mine spoils. However, because of the variability in spoils and fly ash characteristics, specific site conditions need to be considered when determining the amount of fly ash required for the treatment of coal mine spoils.

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