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ABSTRACT

Percent calcium carbonate equivalent (neutralizing value) of five fly ash samples ranged from 34 to 41. Field soils at three sites were treated with fly ash at rates that ranged from 1 to 6 tons per acre. Fly ash applications had opposite effects on extractable P, B, Fe, and Cu at Sites 1 and 2. A three-fold increase in total B occurred in wheat plants taken from one field treated with fly ash. At Site 3 test results of soil samples collected three, six, nine and twelve months after treatment showed that 2 tons of agricultural limestone was equivalent to 4 to 6 tons of fly ash in raising soil pH. Most of the chemical changes occurred in the upper 2.5 cm of soil and within three months after treatment.

INTRODUCTION

Large quantities of fly ash are being produced by the burning of powdered coal by electric power generating plants at three locations in Arkansas. Three years of agronomic research with this product by Professors Spooner and Brown, associated colleagues, and graduate students at the University of Arkansas has indicated that it may be used as a liming material for acid soils (Davis, 1982; Hodgson, 1982; and Hodgson, Dyer, and Brown, 1982). At least one commercial company is marketing the by-product as an agricultural liming substitute. Questions remain as to preferred rates and longevity of fly ash applications and to the beneficial or detrimental effects of heavy metals and essential plant nutrients (Adriano et al., 1978; Bern, 1976; Martens, 1971; and Plank, Martens, and Hallock, 1975).

MATERIALS AND METHODS

Samples of fly ash were collected in August and September, 1982, from the Arkansas Power and Light electric power generating plant at Redfield, Arkansas, by Chem-Ash, Inc.

Total chemical analysis was conducted on three samples by the Arkansas State Plant Board at Little Rock. Calcium carbonate equivalent was determined on these and two additional samples from the Redfield plant by methods commonly used to evaluate the neutralizing capacity of agricultural liming materials.

Fly ash was surface applied to silt loam field soils at two locations in Jefferson County (Sites 1 and 2) and one location in Pulaski County (Site 3). Application rates ranged from 1 to 6 tons per acre. A 2-ton per acre rate of ground agricultural limestone was compared to three rates of fly ash at Site 3. Treated and untreated soils were tested before and after treatment. Soil samples were tested for extractable plant nutrients by the University of Arkansas Soil Testing Laboratories at Fayetteville and Marianna using procedures outlined in *Southern Cooperative Series Bulletin 289* (Kriz et al., 1983).

Wheat plant samples were collected at the tillering stage at one location and analyzed for total plant nutrients by the University of Arkansas Agricultural Diagnostic Lab at Fayetteville.

RESULTS AND DISCUSSION

Chemical Composition of Fly Ash

Total chemical analysis of three fly ash samples revealed calcium concentrations that range from 13 to 18 percent. Other elements ranged in concentration from around 4 percent for iron to 130 ppm for copper (Table 1). One particular concern with fly ash is the potentially phytotoxic concentration of boron at high application rates (Plank and Martens, 1974). Boron concentrations range from 820 to 970 ppm or an average of 1.72 pounds per ton of material. Most silt loam soils contain less than 10 ppm of total boron, of which only a small fraction is available to growing plants at any one time.

The average percent calcium carbonate equivalent (neutralizing value) of five fly ash samples was 38.2. The values ranged from 34.3 to 40.8, compared to 95 for good-quality agricultural limestone.

Table 1. Chemical Composition of Fly Ash From Redfield, AR[1]

Ingredient	Analysis of 3 Samples [2] Average	Range
	-------- % --------	
Phosphorus (as P_2O_5)	0.23	0.18-0.31
Potassium (as K_2O)	0.23	0.20-0.25
Calcium	16.17	13.15-17.85
Magnesium	2.45	1.94-2.81
Sodium	2.79	1.87-2.94
Sulfur	0.74	0.50-0.89
Iron	4.19	3.65-4.51
	-------- ppm --------	
Manganese	277	220-310
Zinc	293	220-330
Copper	152	130-163
Boron	860	820-970

Effect of Fly Ash on Soil at Sites 1 and 2

Fly ash applied to Site 1 raised the soil pH from 5.5 to 6.2 (Table 2). Extractable iron and copper were considerably lower where fly ash

[1]Samples collected in late August, 1982, by Chem-Ash, Inc.
[2]Analysis by Arkansas State Plant Board.

Table 2. Extractable Plant Nutrients in Treated and Untreated Soils.

Soil Test Parameter	Treatment 1/			
	Site 1		Site 2	
	Check	Fly Ash	Check	Fly Ash
	ppm			
Phosphorus	40	81	17	10
Potassium	75	85	60	45
Calcium	150	150	350	450
Magnesium	40	25	25	25
Sulfate	37	39	34	38
Manganese	8	8	5	5
Iron	120	75	30	70
Zinc	0.7	0.65	0.65	0.3
Copper	0.65	0.4	0.3	0.45
Boron	0.14	0.28	0.26	0.22

was applied. This is to be expected since heavy metals become more difficult to extract as soils become less acid. Boron and phosphorus were twice as high in the fly ash treated soil. The other elements tested were essentially the same for both the check and the fly ash treated soil.

Fly ash applied to Site 2 raised the soil pH from 6.4 to 6.8. The effect on extractable plant nutrients was almost the opposite of that from Site 1. Extractable iron and copper were more than 50 percent higher than the check. Phosphorus and zinc were considerably less than the check. However, all of the extractable plant nutrients were relatively low in both the check and the fly ash treated soils.

Except for iron, copper, zinc, and boron, there was little difference in chemical composition between wheat plants from the check and from the fly ash treated soils (Table 3). Zinc and copper concentrations were cut in half by the fly ash treatment, while iron and boron concentrations were increased. Boron concentrations in the wheat tissue were increased three-fold. Davis (1980) observed a four- to six-fold increase in boron concentrations in alfalfa plants treated with high rates of fly ash. Boron uptake by wheat appears to be much greater than is indicated by extractable soil test levels. There were no obvious visual differences in appearance or yield of wheat from the fly ash treated plots and the remainder of the field which was not treated.

Effect of Fly Ash on Soil at Site 3

Average test results of soil samples collected three, six, nine, and twelve months after treatment with one rate of agricultural lime and three rates of fly ash showed the fly ash was effective as a liming material on Leadvale silt loam soil (Table 4). However, 2 tons of agricultural lime was equivalent to 4 to 6 tons of fly ash in raising soil pH. This is in agreement with what most researchers have reported. Agricultural lime was much more éffective than even the highest rate of fly ash in increasing available calcium One advantage to fly ash was that it increased the extractable magnesium level by about 40 percent over the check and the lime treatment. There was very little difference in levels of soluble salts (E.C.) and extractable P,K, and Ņa between treatments. For the most part, the effects of the various treatments were manifested within three months after treatment.

Extractable sulfates and micronutrients in soil samples collected from the surface 15 cm of depth showed that boron was the only element that increased linearly with increasing rates of fly ash (Table 5). The high level of copper in the highest fly ash treatment was attributed to contamination from a previous treatment of that plot with copper sulfate.

Table 3. Chemical Composition of Wheat Plants From Fly Ash Treated and Untreated Soils.

Element	Treatment 1/	
	Check	Fly Ash
	%	
Phosphorus	0.24	0.19
Potassium	1.7	1.6
Calcium	0.35	0.35
Magnesium	0.17	0.15
Sulfur	0.11	0.13
	ppm	
Iron	440	770
Manganese	85	83
Zinc	20	10
Copper	5.0	2.5
Boron	5.9	18.5

Table 4. Soil Test Results of Leadvale Silt Loam Topdressed With Ground Agricultural Limestone and Different Rates of Fly Ash.[1]

Soil Test Parameter	Treatment				
	Check	Limestone (2 T/A)	Fly Ash 2 T/A	Fly Ash 4 T/A	Fly Ash 6 T/A
pH	5.2	5.8	5.5	5.7	5.9
	µmhos/cm				
E.C.	37	51	36	41	40
	ppm				
Phosphorus	37	38	39	37	45
Potassium	45	55	55	50	47
Calcium	213	338	213	238	238
Magnesium	58	54	79	81	82
Sodium	52	53	56	55	55

The greatest chemical change occurred in the upper 2.5 cm of soil (Table 6). The agricultural lime was much more effective than the same rate of fly ash in promoting chemical changes. The pH change in favor of the agricultural limte is to be expected since its neutralizing value is about 2½ times that of the fly ash. The lone exception to this was the two-fold increase of extractable boron from the fly ash treated plot. A two-fold increase in extractable calicium and sulfate occurred with the agricultural lime treatment. The extractable magnesium was decreased by the treatment with agricultural lime. This was probably due to mass action and dilution of the magnesium by excess calcium. The

[1]Fly ash was applied to raise the soil pH of Site 1 from 5.5 to 6.2; of Site 2 from 6.4 to 6.8.

[1]Fly ash applied to raise soil pH of check from 5.7 to 6.4.

[1]Fly Ash and lime applied in October, 1982. Values are averages of 3 replications and 4 sampling periods.

Table 5. Extractable Sulfates and Micronutrients in Leadvale Silt Loam 3 Months After Surface Application of Fly Ash[1].

Soil Test Parameter	Application Rate (Tons Per Acre) 2	4	6
	ppm		
Sulfates	51	54	54
Iron	118	123	123
Manganese	10	8	10
Zinc	11	10	10
Copper	0.4	0.4	2.0
Boron	0.35	0.7	0.8

Table 6. Soil pH, % Organic Matter, and Extractable Plant Nutrients in the Surface 2.5 cm of Leadvale Silt Loam 3 Months After Surface Applying Fly Ash and Agricultural Limestone[1].

Soil Test Parameter	Check	Two Tons Per Acre Treatment: Fly Ash	Agri Lime
pH	5.6	5.9	6.7
		ppm	
Calcium	300	300	650
Magnesium	110	120	65
Phosphorus	64	34	41
Potassium	60	75	85
Sulfate	30	48	63
Boron	0.3	0.65	0.3
		%	
Organic Matter	1.4	2.8	2.8

levels of sulfate corresponded closely to levels of organic matter. However, the 2.8 percent organic matter in the limed and fly ash treated soils as compared to half that amount in the check soil could not be explained. One of the benefits of liming may have been the stimulation of microbial decay of organic matter, increasing available sulfates.

CONCLUSIONS

It may be concluded from this study that fly ash may be used as a liming material for silt loam soils. It has limited value as a plant nutrient source depending on the needs of a particular soil. The liming value of fly ash is about 40 percent of that of agricultural limestone. Thus, about 2½ times as much material must be applied to neutralize the same level of soil acidity. Rates of up to 6 tons per acre of fly ash should not be toxic to growing plants. Multiple application rates totaling more than 10 tons per acre may be toxic to some seedlings due to high concentrations of boron. Additional research is needed to define the conditions for most efficient use of the material.

[1]Fly ash applied in October, 1982. Values are averages of 3 replications for each treatment rate.

[1]Fly ash and agricultural limestone applied in October, 1982. Soil test values are averages of 3 replications for each treatment.

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