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SOYBEAN GROWTH ON FLY ASH–AMENDED STRIP MINE SPOILS

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SUMMARY

The use of fly ash as an amendment for strip mine soils has been studied under field conditions. Spoils ranging in pH from 4.0–6.0 were tested. The addition of fly ash in all cases was effective as an acid soil neutralizer and substantially enhanced the growth and development of all experimental plants. The parameters used in growth analyses were plant height, dry weight, root/shoot ratios, nodulation, pod production, and nitrogen fixing capacity for legumes.

INTRODUCTION

During the past several years the national need for energy self sufficiency has resulted in increased surface mining for coal. Vast areas of the United States have rich deposits of coal, and increasingly it has been found economically advantageous to mine coal via stripping methods. It is estimated that more than 1,000,000 hectares of land remain as virtual wastelands due to damage incurred from stripping operations[1]. Paradoxically, coal ash has been found of potentially great value in the reclamation of devasted, surface-mined lands[9].

Strata overlying coal seams contain pyrites and other forms of iron sulfide, which upon oxidation in the presence of water forms sulfuric acid[18]. During strip-mine operations, topsoil is removed and subsoil and rock layers are exposed and mixed with displaced topsoil resulting in acidic spoils which generally cause profound chemical changes in exposed sub-soils[3 5 6]. Aluminum and manganese are considered to be the elements most limiting to plant growth on strip-mines when present at relatively high concentrations[3]. Soluble Al in soil increases as pH decreases. Manganese increasingly comes into solution as pH decreases. Manganese is present in the soil as tetravalent or trivalent ions, but in acid conditions the ion is reduced to the bivalent form, the ion form most available to plants. Excess Mn is thought to interfere with magnesium metabolism in the production of chlorophyll and also to interfere with iron metabolism[12]. On the other hand, calcium, magnesium, and phosphorous are less available to plants as the pH drops and deficiency symptoms are not uncommon in plants grown on stripmine soils[5 8 14 18].

Coal spoils characteristically lack nitrogen primarily because of loss of topsoil with its organic matter, together with the fact that nitrogen availability rapidly drops with a decrease in pH[8 12]. Since spoils usually lack nitrogen, legumes appear to be a logical choice for quick cover. On the other hand, legumes face severe difficulties both in growth and nodulation on acid spoils since many studies of legumes seeded on acid soils indicate that poor growth under acid conditions often can be attributed to toxicities caused by excess manganese and aluminum brought into solution by the acid conditions[4 16].

The effects of acidity are obviously a major factor for consideration in the reclamation of strip-mine spoils, and it was primarily these effects and how to neutralize them that led to experimental studies with the use of fly ash as a soil ameliorant in strip mine reclamation. Fly ash is a solid waste resulting from the combustion of pulverized coal. Fly ash is composed of relatively high amounts of compounds of silicon, aluminum, iron, and calcium, smaller amounts of compounds containing magnesium, titanium, sodium, and potassium, and traces of other elements. These compounds occur in fly ash primarily as silicates, oxides, and sulfates, and borates along with lesser amounts of phosphates and carbonates. Soluble salts also occur in fly ash and those most often encountered are sulfates of potassium, magnesium, sodium, and calcium[23].

Fly ash ranges from extremely basic to acidic; usually in the range 6.5–11.0 pH and thus vary greatly in their neutralizing capacity depending on the source of the coal[2]. Most experimental studies in the United States have centered on the use of fly ash as an ameliorant, that is, as an amendment to be physically mixed with soils in concentrations ranging from 1% to 60% by weight of the top 15 cm layer of soil on strip-mines[1 9]. As regards physical change in soils, fly ash application results in lower bulk density of soil, increased pore space, and increased available water.

The purpose of this paper is to discuss the growth and development of soybeans, an important commerical crop, on fly ash amended coal spoils.

MATERIALS AND METHODS

Experimental area

An active mine site, approximately 25 km northeast of Tuscaloosa, Alabama, was used for the study. The mine site had been under excavation for about six months prior to the start of the project and was active until four months later. The mined area had been an abandoned cultivated field with some pine and old-field herbaceous vegetation. The duration of the project was from May 15, 1975 to October 25, 1975.

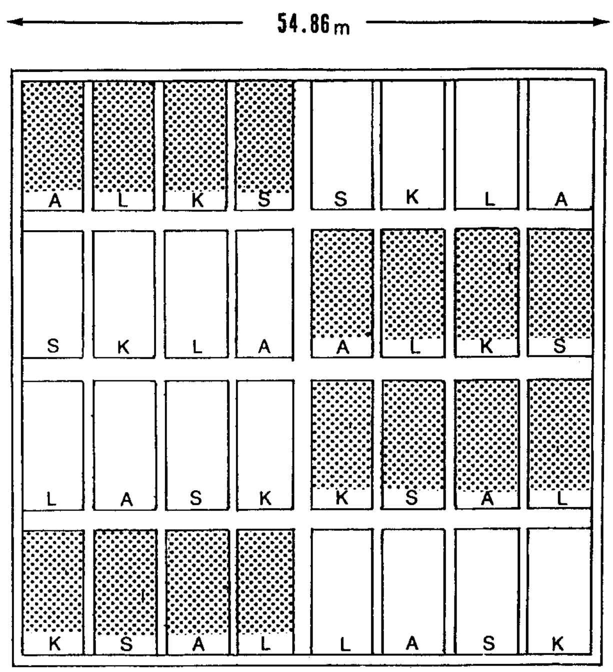

Fig. 1. Diagram of test plot.
Each transect was 67.05 m^2. Stippled areas – with fly ash; clear areas-control. A = *Agrostis tenuis*; L = *Lespedeza cuneata*; K = *Festuca arundinacea* (Kentucky 31); S = *Glycine max* cv. Bragg (soybeans).

The test area was 55 m^2 within which were 32 transects, each 5.8 m × 11.6 m (Fig. 1). One meter medians were allowed between each of the eight transects across, with a two meter median down the center and between the lengths of transects.

Soil characteristics

Most of the test area consisted of B22t and B3 soil horizons, which are layers of soil found generally from 50–100 cm deep, usually strongly acid, classed as red, sandy-clay loam, coarse and friable. The pH for the area prior to fly ash application ranged from 4.4–5.0.

Fly-ash-application

A total of 7,258.6 kgs of fly ash (source – Wilsonville, Alabama, Power Plant) were used. The fly ash was distributed alternately across the test area, such that one-half of the total area was covered with an equivalent of 70 metric tons of fly ash per hectare. The fly ash was spread with a shovel to provide an even cover of about 7–8 cm of fly ash on the surface. The soil was disced twice and the fly ash thoroughly mixed with the upper 15–20 cm of soil.

There were eight replicates (four with fly ash, four without) of four species of plants, one species per transect distributed evenly (spatially) throughout the test area. The species selected were: *Agrostis tenuis* var. Highlander (bentgrass), *Lespedeza cuneata* (*Sericea lespedeza*), *Festuca arundinacea* (Kentucky 31 fescue), and *Glycine max* cv. Bragg (soybeans). This report will be restricted to a discussion of the response of soybeans to the treatments, although significant enhancement of growth was noted in all species subjected to fly ash treatment.

Seeds were sown on 23 May 1975 according to recommended rates – soybeans at 92.17 kgs per hectare – 752.5 grams per transect, utilizing a hand seeder. 18.65 kgs of ammonium nitrate were dispersed over the entire test area, and finally seeds were lightly covered by dragging a log pulled by a tractor across the area.

Soil analysis

Elemental analysis of the fly ash may be seen in Table 1. Studies in our own laboratory were conducted to test pH, neutralizing capability, and bulk density of the fly ash and fly/ash soil mixtures. The pH of the fly ash was determined to be 11.0. To test neutralizing capability, various percentages of fly ash were mixed with a solution of known pH, and the changes in pH against per cent fly ash recorded[1]. Bulk densities of fly ash and soil mixtures taken directly from the mine were determined, as well as measurements on untreated strip-mine for soil comparison. Sand/silt/clay contents and pH were monitored throughout the study as well as soil moisture and temperature.

Growth analysis

To record and monitor growth, biweekly measurements of height, of randomly selected soybean plants in each transect were made and observations as to appearance were noted, and photographs were taken on a monthly basis.

Harvesting of soybeans was done by dividing each fly ash amended plot into 65 one-meter-square quadrats. A random numbers table was used to decide which quadrats to sample and ten such square meter samples were taken in each of the fly ash treated transects. Within the quadrats selected, a point frame estimate of per cent cover was taken and entire plants were collected in plastic bags, and stored under refrigeration prior to analysis. Since relatively few plants survived on control transects the entire crop in each transect was harvested.

Growth analysis of soybean plants was done by measuring dry weight of shoots and tabulating the number of seed pods and root nodules.

Acetylene reduction assay

Nitrogen fixation by soybeans growing on barren spoils and those supplemented with fly ash was analyzed gas chromatographically by the acetylene reduction method. In this assay, roots of field grown plants were washed free of dirt, wrapped in a moist towel and stored at 4°C. The nodulated roots were incubated with acetylene for 30 minutes. The incubation vial was flushed with a gas mixture of 78% argon, 21.96% oxygen, and 0.04% carbon dioxide to improve acetylene reduction to ethylene (13–15%). After a 30 minute incubation time a sample of the gas evolved was analyzed in a Becker – Delft gas chromatograph. Results were expressed as μmoles C_2H_4 (ethylene) produced per total nodule fresh weight of a plant per unit of time[7 25].

RESULTS AND DISCUSSION

Analysis of growth

Plants from fly ash treated transects showed superior growth rates as measured by the change in height as seen in Fig. 2. After one month, plants from treated transects showed an average of about one cm increase in height as compared to control plants. By the end of two months, differences were very pronounced between the two treatments. By August 15 the control plants had begun to senesce while plants grown in fly ash treated transects, were still growing, and the differences in average height were in excess of 6 cm. By the beginning of September, plants from fly ash treated transects averaged over 10 cm taller than control plants.

Percent cover was taken at harvest time by the pointframe method and showed an average of 35% coverage on fly ash treated transects and less than 10% on control transects.

Several growth parameters are compared in Fig. 3. The data indicate that plant growth was superior in fly ash treated spoils as com-

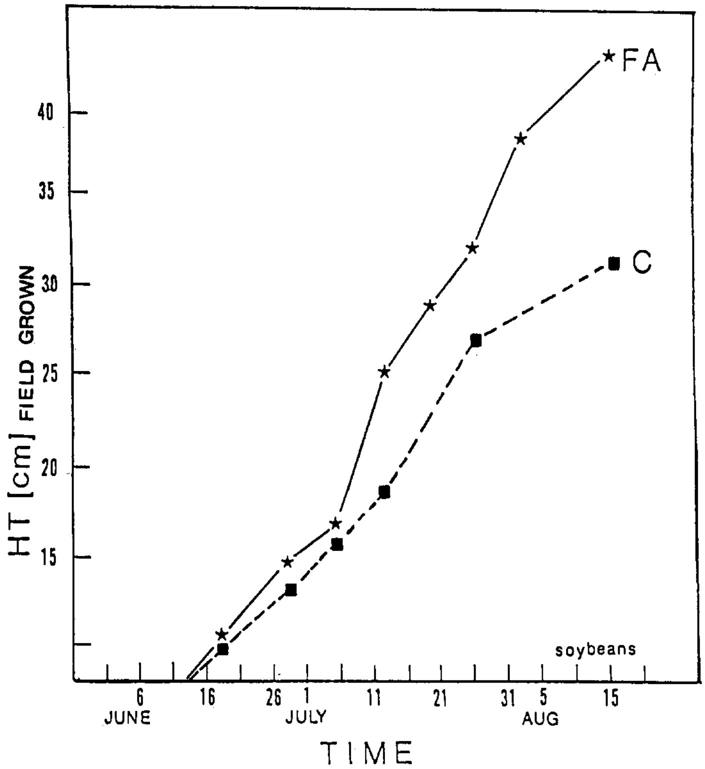

Fig. 2. Soybean growth as measured by height increase.
FA = Average height of randomly selected plants on fly ash treated transects;
C = Average height of randomly selected plants on control transects.

pared to controls. Total dry weight per plant on fly ash treatment was an average of 9 times greater than plants grown without treatment. Average shoot weight was 5 times greater and root weight 6 times greater for fly ash treated plants. There were 12 times more nodules per plant on fly ash transects and the average number of seed pods per plant were 6 times greater on fly ash transects.

Changes in soil composition and elemental availability

Soil analysis performed prior to addition of fly ash showed the soil to be low in phosphorous (2.7–5.4 kgs/hectare), low to medium in calcium (41.50–214.75 kgs/hectares), very low in total nitrogen (0.05%) and organic matter, copper: 1.1 to 5.6 ppm, iron: 1.9–121.0 ppm, manganese: 3.0 to 41.0 ppm, zinc: 0.3 to 19.0 ppm, and aluminum: 200 ppm.

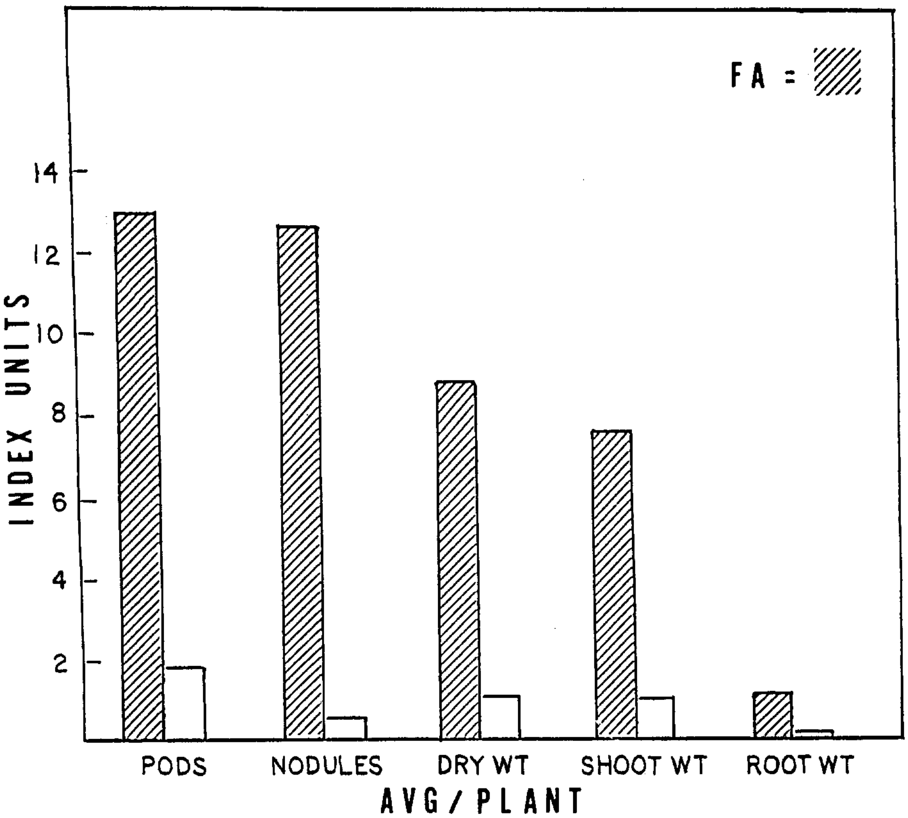

Fig. 3. Growth parameters from harvested soybeans.
Transects – Index units refer to numbers of pods or nodules and weight in grams of whole plants, shoots or roots, Pods in units; nodules in units; dry weight in grams; shoot weight in grams; root weight in grams.

In studies of coal mine spoil reclamation, Adams *et al.*[1] reported much higher concentrations of possibly toxic micronutrients than were found in this study. Our data show the site to be relatively infertile, non-toxic, with primary deficiences in nitrogen, phosphorus, and potassium.

Other studies[3 4 6 17 18] have shown that strip mines may contain high and possibly toxic amounts of soluble aluminum, iron, manganese.

Soluble aluminum is generally accepted as being the most common toxic element in acid spoils and toxic concentrations of other ele-

TABLE 1

Wilsonville fly-ash analysis (%) May, 1975

Silica (SiO_2)	51.18
Alumina (Al_2O_3)	27.96
Ferric oxide (Fe_2O_3)	8.81
Sulfur trioxide (SO_3)	0.36
Magnesium oxide (MgO)	1.00
Calcium oxide (CaO)	3.36
Titanium dioxide (TiO_2)	1.00
Phosphate (PO_3)	0.38
Moisture	0.90
Loss on ignition	3.05
% Retained on 325 mesh sieve	5.86

ments as iron, manganese, copper, zinc and nickel may occur on some spoils of extreme acidity[3].

Retarded growth of legumes on acid soils often can be attributed to toxicities caused by excess aluminum and manganese brought into solution[4]. Symptoms usually include conspicuous chlorosis of the leaf margins.

Table 1 shows a typical analysis of fly ash from the Wilsonville Power Plant obtained in May, 1975. The major constituents are silicon (51%), aluminum (28%), and iron (9%) with a pH of 11.0. Spectrographic and conventional chemical analysis of fly ash used here showed the presence of several micronutrients, particularly copper, sodium, and manganese. Fly ash may thus serve as a source of necessary micronutrients, to plants and in fact several researchers have expressed concern over the presence of excessively high levels of micronutrients in fly ash[1 10 11 19]. High levels of boron (450 ppm), copper (40 ppm), manganese (200 ppm), molybdenum (20 ppm), and zinc (90 ppm) in fly ashes from various sources including Alabama have been reported[1 10 11 17 18].

Although toxic effects due to micronutrient excess, particularly from boron, have been documented in several studies[1 10 11 20], the levels of such elements as boron, molybdenum, and zinc have not been determined for the fly ash used in this experiment and plants have not been tested for uptake of any elements. Amounts of fly ash used in this study are far below those used in tests of toxic fly ash effects and it is doubtful whether any toxicity symptoms were present.

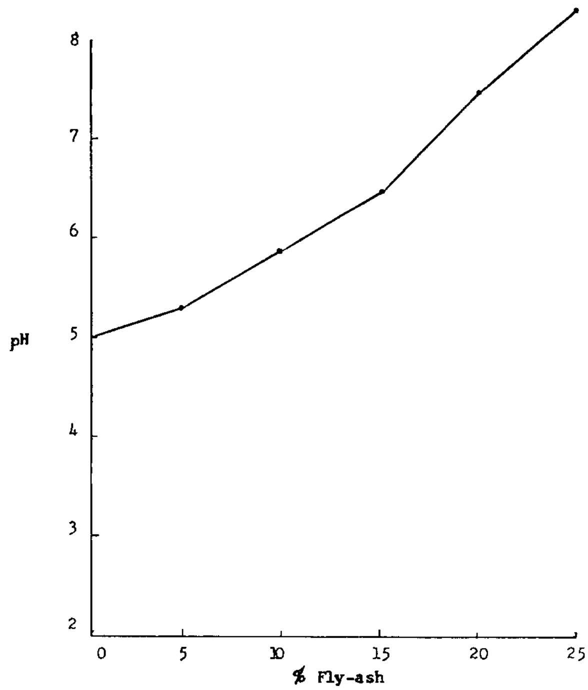

Fig. 4. Neutralization by fly ash of a solution buffered to pH 5.

The primary reason for the addition of fly ash to stripmine spoils is the alleviation of acidity. For this reason, the neutralizing capacity of fly ash is important. The neutralizing capacity of the fly ash used in this study is shown in Fig. 4 which shows that it would require a 16.5% fly ash treatment to bring the pH to an ideal level of pH 6.5. Soil tests recommended 1.0–4.0 tons/acre lime treatment. Other investigators have found the neutralizing power of bituminous coal ash ranged from 15 to 200 tons (average 56 tons) of ash equivalent to one ton of lime, and they further report that fly ash will neutralize approximately 1.10 meq H_3O^+/g (1). Thus it may be seen there is close agreement between the laboratory test of neutralizing capability and soil test recommendations. Figure 3 shows that at the rates of fly ash applied here (3.1%), a rise in pH of 0.1 would be expected and this is about what was observed. Because the change in pH was so small, it is felt that this was not a primary factor enhancing growth of the soybeans in this study.

Organic matter was present in only very small amounts prior to planting, 0.228% average, compared to a rich soil suitable for agriculture containing about 4.3% of organic matter. Total nitrogen was similarly very low, 0.038% compared to 0.155%. The low amount of organic matter and nitrogen was obviously a factor in both growth and yield of the soybeans. It was noted, however, that the soybeans produced healthy and numberous nodules, and that nitrogen fixation was apparently proceeding vigorously. Nitrogen fixing capacity was also measured by the acetylene reduction assay by gas chromatography[7 13 15 25]. This assay showed nitrogen fixation in nodules proceeding at a rate of 13.1 μMoles C_2H_4/hr/g nodules in 80-day old plants.

A significant difference in seed yield was noted between the 2 treatments. The fly ash treated transects yielded an average of 470.75 kg/hectare (7 bu/ac) compared to a yield of 43.0 kg/hectare (0.64 bu/acre) on control transects. The yield from fly ash treated transects is considerably below that expected for good farmland in this area (26 hektoliters/hectare = 30 bu/ac) but is quite good considering the harsh environmental conditions encountered on a strip mine.

Determination of sand/silt/clay percentages for each transect in the experimental plot were made via the Buoyoucos method. Before fly ash application the soil was predominantly sand (approximately 70%), with about equal percentages of silt and clay (15%–20%). The pH ranged from 4.4–5.0.

Because of the high percentage of silt-size particles in fly ash, it would be expected that large-scale applications of fly ash would tend to change the soil texture in the direction of increasing silt content. In other studies the addition of 1,385 metric tons/hectare was found to change a spoil from a sandy-clay texture to a silt-loam[21], and this trend toward increasing silt content has been observed in the present study. Specifically it was found that the silt content increased an average of 3% and sand and clay contents decreased an average of 1.5% each.

Fly ash treated soil was definitely more friable (looser) and not as compacted on drying as untreated soil. Subsurface (5–8 cm) soil, particularly, was much looser in the fly ash treated areas. It was also noticed visually and through measurement with soil moisture blocks, that the soil retained more moisture and resisted drying to a much greater extent than untreated areas. Apparently, the great difference in soil friability and soil moisture content was a major factor in the difference in growth between the two treatments. Some support for this view may be gained by looking at average root dry weights in fly ash versus control plants (Fig. 3). Roots from plants grown in fly ash treated plots averaged at least six times the root dry weights from untreated plots.

In summary, the superior growth of soybean plants grown in fly ash treated areas is due, at least in large part, to two main effects: 1) increase in soil moisture holding capability, and 2) improvement of the soil texture. Evidence that these are primary effects may be seen in a comparison of root dry weight data and in a comparison of growth between the two treatments. The progress of growth between the two treatments was similar for the first 30–40 days after which the plants on fly ash treated areas showed marked increases over controls. Less compaction and increased soil moisture may have allowed for more vigorous and healthier growth on fly ash treated areas.

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