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USE OF LIGNITE FLY ASH AS A SOIL AMENDMENT

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USE OF LIGNITE FLY ASH AS A SOIL AMENDMENT

by

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INTRODUCTION

As the United States enters the last quarter of the twentieth century, the development and conservation of our energy resources has become a leading national priority. Today, there is increased emphasis being placed on the development of our coal resources to replace, where possible, reliance on dwindling reserves of domestic oil and gas. Historically, electric power plants have been the largest users of coal (Brackett 1970). After World War II, however, electric utilities shifted toward the use of cheaper and cleaner oil and gas. Then, following the energy crisis of 1973-1974, the subsequent creation of the Organization of Petroleum Exporting Countries, and the spiraling oil prices that ensued, national interest in domestic coal as an energy resource has grown tremendously. Through the end of this century, bituminous coal and lignite will undoubtedly be the dominant fossil fuels used to generate electricity.

Unfortunately, coal and lignite have two big disadvantages which oil and gas do not have. First of all, considerable disturbance of the land is necessary in order to get coal out of the ground. Secondly, coal and lignite are considerably "dirtier" fuels. They produce more airborne pollutants than oil and gas and they leave an ash residue which can be as much as 20% by weight.

Fly ash is that portion of the total ash content of coal or lignite which leaves the area of combustion with the flue gases and is collected before emerging from the stack, generally by the use of electrostatic precipitators.

Physically, lignite and bituminous fly ashes are mainly spherical, hollow, glass particles termed "cenospheres" that generally range in size from 0.02 to 0.05 mm. There are also variable but lesser amounts of irregular crystalline grains, unburnt lignite or coal, and coke. The crystalline constituents include quartz, lime, hematite, and alumina (Manz 1974). The mineralogical analyses of three Texas lignite fly ashes are presented in Table 1.

The quantities of fly ash produced from the burning of coal and lignite in the United States are increasing each year and will undoubtedly continue to do so in the foreseeable future. During the period from 1966 to 1980, fly ash production in the United States is expected to increase from 17 million tons to an estimated 40 million tons per year (Brackett 1974). There are three reasons put forth for this increase:

1. The rapid degradation in the quality of coal being burned in general. Prior to 1965, the ash content of coal burned seldom reached 10%. Today, it is not uncommon to use coals with ash contents of 14-16%.
2. The conversion of many utilities from gas and oil to coal and the increased use of lignite, particularly in the West and Southwest.
3. The increased efficiency of fly ash collection in order to comply with air quality standards. (Brackett 1974)

Table 1. Mineralogical analysis of fly ash from three Texas lignite burning power plants.*

Ash Analysis**	Big Brown Plant Fairfield, Texas	Monticello Plant Mt. Pleasant, Texas	Martin's Lake Plant Tatum, Texas
	Percent**		
SiO_2	46.1	51.8	31.3
	(21.58 - 60.95)***	(32.7 - 64.4)	(17.7 - 51.7)
Fe_2O_3	4.7	3.7	8.2
	(1.95 - 27.26)	(2.1 - 6.5)	(3.8 - 37.2)
Al_2O_3	15.2	17.7	15.0
	(10.02 - 21.48)	(10.5 - 22.3)	(10.0 - 19.0)
TiO_2	1.2	1.4	1.1
	(0.90 - 1.87)	(0.8 - 2.1)	(0.8 - 1.6)
CaO	16.6	12.1	19.3
	(9.78 - 31.82)	(5.8 - 21.2)	(8.4 - 30.9)
MgO	3.2	2.7	4.5
	(1.51 - 4.85)	(1.1 - 6.9)	(2.9 - 7.0)
SO_3	12.6	8.7	18.0
	(7.81 - 24.03)	(3.6 - 21.7)	(1.2 - 32.3)
P_2O_5	0.1	0.1	0.2
	(0.01 - 0.13)	(0.03- 0.11)	(0.0 - 0.8)
K_2O	0.6	0.6	0.5
	(0.00 - 0.91)	(0.1 - 1.0)	(0.2 - 1.2)
Na_2O	0.4	0.4	1.0
	(0.17 - 1.39)	(0.1 - 1.2)	(0.2 - 2.1)
Undetermined	0.3	0.8	0.9
	(0.02 - 1.29)	(0.1 - 1.0)	(0.0 - 1.1)

*Analysis provided by Texas Utilities Generating Company.

**Percent by weight.

***Range from samples.

The vast quantities of fly ash being produced are a considerable burden for electric utilities. The cost of disposal of this material ranges from $.50 to $2.00 per ton (Meikle 1975). This translates into tens of millions of dollars per year for landfilling fly ash. Obviously, if fly ash could be put to some worthwhile use, the burden of disposal could be reduced. But, while the production of this material increases every year, that portion which is utilized has remained near 10% (Brackett 1974, Meikle 1975).

There has been, nevertheless, extensive research conducted into possible uses for fly ash. Indeed, current uses of fly ash include ready-mixed concrete, concrete products, bricks, load-bearing fill under pavement, remote sealing of underground passages, mine fire control, removing phosphates from water, and as a mineral filler in asphalt (Slonaker and Leonard 1974, Capp and Spencer 1970). In addition, there is research being conducted world-wide on possible uses for fly ash, ranging from the making of soap to the extraction of iron and aluminum (Secretariat, Economic Commission for Europe 1974).

Agricultural applications of fly ash are not new. Some of the earliest work with fly ash concerned attempts at revegetating old ash dumps in England during the 1940s and 1950s (Rees and Sidrak 1955, 1956, Holliday et al. 1958, Jones and Lewis 1960). However, the possibilities of using fly ash as a soil amendment are still being explored. While there has been research conducted on agronomic uses of fly ash, nearly all of these inquiries have used fly ash from bituminous coal. With ever increasing quantities of lignite being consumed throughout the western and southwestern United States, it seems imperative to develop similar studies on lignite fly ash. Consequently, this research project was conceived in order to explore the potential of using fly ash from Texas lignite as a soil amendment.

Objectives

The objective of this thesis was to determine the effect of various proportions of lignite fly ash on the physical and chemical properties (exchangeable cations, available phosphorus, reaction, Kjeldahl nitrogen, texture, cation exchange capacity, and base saturation) of soils. Survival and height growth of loblolly pine (*Pinus taeda* L.) seedlings grown in all mixtures was determined with needle and root tissue being analyzed for phosphorus and cations.

The results of this study cannot be taken as representative of the characteristics of all fly ashes in general. There is considerable diversity throughout the United States in the qualities of fly ash, just as there are in the coals or lignite they came from. Nevertheless, this study should help to define some of the characteristics of lignite fly ash which are important to its use as a soil amendment.

LITERATURE REVIEW

As an industrial waste product, fly ash has been with us for many years. The earliest method of disposal was simply to create an ash dump. Today, all of our technological advances and concerns about recycling notwithstanding, between 80 and 90% of the fly ash produced in the United States is still being hauled to a dump, landfilled, or dropped into the ocean (Hodgson and Holliday 1966, Brackett 1974).

There are, to be sure, many practical industrial uses for fly ash. One of the first uses found for fly ash was as a pozzolan. Manz (1974) defines a pozzolan as "a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties." As early as 1942, the Bureau of Reclamation was using fly ash as a pozzolan in the concrete at Hoover Dam (Elfert 1974).

But while there have been a number of industrial applications developed for using fly ash, and the number of tons utilized each year has increased, the quantity of fly ash being produced has grown much faster. It took until 1966 for the United States to produce 17 million tons per year. It has been estimated that within ten years that production will have doubled (Brackett 1974).

Therefore, research has expanded beyond industrial uses to other fields, including agriculture, in order to find more possible outlets for a material which is, to say the least, becoming plentiful. As a result, most of the investigations concerning fly ash as a soil amendment have been conducted within the last ten years. While much has been learned in this short period of time, many facets of soil-fly ash-plant interactions are yet to be understood.

Physically, fly ash from lignite, bituminous, and sub-bituminous coal differs very little. Rees and Sidrak (1956), in an investigation into the revegetation of fly ash dumps in England, found the ash to have a very uniform physical composition. Fine sand and silt (particle diameter 0.2 - 0.002 mm) accounted for 76% of the total, with approximately 20% being coarser sand and 4% clay-size material.

In the United States, Manz (1974) also found various samples of lignite and bituminous fly ash to be composed mostly of silt and fine sand-size particles. He also determined that fly ash consists mainly of hollow glass spheres ranging in size from 0.02 to 0.05 mm, with lesser and variable amounts of irregular crystalline grains, unburnt lignite or coal, and coke.

When dry, fly ash has a flour-like texture and will, when aerated, flow much like a fluid. In such a dry state, fly ash is also extremely susceptible to wind erosion. The finer particles of fly ash will become airborne at wind speeds of 10-11 miles per hour, with the bulk of the material eroding at wind speeds over

20 miles per hour (Hodgson and Holliday 1966). When fly ash is moistened, however, it becomes rather pasty.

Jones (1976) applied various quantities of weathered bituminous fly ash to three soils: a loamy fine sand, a silt loam, and a clay loam. He found that the incorporation of 192 tons/acre altered the particle size distribution of all the soils. The percentage of sand increased in the silt loam and clay loam soils, while in the loamy fine sand soil, there was a decrease in the percentage of sand and an increase in silt and clay. He concluded that the application of up to 20% by weight of weathered fly ash did not adversely affect the physical properties of soils.

Likewise, several researchers have found that fly ash applications of from 150 to 800 tons/acre to coarse textured, compacted strip mine spoils decreased bulk density, which in turn resulted in more pore space and greater moisture holding capacity (Capp and Adams 1971, Adams _et_ _al_. 1971, Adams _et_ _al_. 1972, Capp and Gilmore 1974, Plass and Capp 1974). Plass and Capp (1974) also found that it increased infiltration and aided water percolation to a depth of four feet. They also found increased formation of soil aggregates, which was attributed to the pozzolanic activity of the fly ash. Capp and Gilmore (1974) generalized their findings to say that the addition of fly ash to a soil modifies particle size distribution toward fine sand and silt, regardless of the texture of the soil.

One of the biggest differences between lignite and bituminous fly ash is the presence of free lime in lignite fly ash (Manz 1974, Gronhovd et al. 1969). This characteristic, along with the pozzolanic nature of fly ash, results in a tendency for lignite fly ash to set after being moistened. This property of lignite fly ash, which bituminous fly ash does not have, is an important consideration in handling and in any surface applications to soils (Shannon and Fine 1974). A thorough mixing of lignite fly ash and soil is necessary to prevent lump or crust formation.

While there is a general uniformity in the physical characteristics of fly ash, regardless of the source, the chemical properties can vary radically, depending on source (i.e. lignite, sub-bituminous coal, bituminous coal). Nevertheless, the chemical properties of a fly ash can also fluctuate at any given consuming facility (Martens et al. 1970a). This can be due to the burning of coal from different mines or even from variations in the quality of coal from any given seam. For this reason, a mineralogical analysis of fly ash from any given source will consist of average levels for the various constituents. Consequently, the amount of any given mineral in a particular sample of fly ash may differ to a greater or lesser extent from the average.

A number of researchers have found that most fly ash contains all of the macro- and micronutrients necessary for plant growth with the exception of nitrogen (Rees and Sidrack 1956, Hodgson and Holliday 1966, Plank and Martens 1973). Nevertheless, it has also been noted that the levels of any given plant nutrient will vary considerably from ash to ash (Martens et al. 1970a).

The possibility of using fly ash as a soil amendment to alleviate nutrient deficiencies has been pursued by a number of investigators. A number of both macro- and micronutrients are present in fly ash in plant-available form. Since most fly ash contains relatively high levels of boron, the first studies involved applications of fly ash to boron deficient soils. Mulford and Martens (1971) showed that boron deficiencies in plants are corrected equally well by applications of fly ash or sodium borate, a common boron fertilizer. It has also been demonstrated that the availability of boron in fly ash is equal to that of sodium borate (Plank and Martens 1974).

Since many temporary boron deficiencies are induced in soils through the practice of liming, Martens and Plank (1974) determined that the use of fly ash in such applications could prevent such induced deficiencies from developing. They also demonstrated that boron was released from fly ash over a period of many years, thus making it a more effective treatment than sodium borate, which must be applied every two or three years.

In their analysis of fly ash from 15 different locations in the United States, Martens et al. (1970a) determined that potassium levels ranged up to 3.19%. It was shown, however, that the extractable levels of potassium were considerably lower and that the potassium from fly ash was absorbed by plants at a lower rate than from potassium chloride amended soils (Martens et al. 1970b).

The lesser rates of potassium availability in fly ash did not indicate fly ash to be an important source of this nutrient.

There have been some more positive results, however, in correcting zinc deficiencies in soils through the application of acidic bituminous fly ash (Schnappinger _et al_. 1975, Martens 1971). It has also been demonstrated that zinc in acidic fly ash is just as available to plants as from zinc sulfate, a form commonly used in fertilizer (Plank and Martens 1973, Schnappinger _et al_. 1975). Nevertheless, Schnappinger _et al_. (1975) showed that fly ash with an alkaline reaction reduced zinc uptake in plants. This was attributed to decreased zinc availability through increased soil pH. It was stressed that soil reaction is probably the single most important factor in zinc availability. Therefore, the effect which any given fly ash has upon soil pH will probably be at least as important a factor as the amount of zinc being supplied by the fly ash.

Another micronutrient which is often found deficient in agricultural soils is molybdenum. Molybdenum deficiencies are most commonly associated with fairly acid soils (Brady 1974). Doran and Martens (1972) found that application of alkaline fly ash increased the availability of molybdenum, not only through providing more molybdenum to the soil, but also by increasing pH. They attributed the increased molybdenum availability to decreased retention of the molybdate anion by hydrous hydroxides and oxides of aluminum and iron. It was also shown that the molybdenum in fly ash is just as available to plants as the form used in commercial fertilizers, sodium molybdate.

Efforts at increasing phosphorus levels in soils through the addition of fly ash have met with mixed results. One of the biggest determining factors in phosphorus availability in soils is pH. Phosphorus is generally most available in soils at a pH of about 6.5 (Brady 1974). While most fly ash contains a certain amount of phosphate, several researchers have had negative results when attempting to increase soil phosphate levels through addition of alkaline fly ash (Hodgson and Holliday 1966, Plank and Martens 1974, Martens 1971). This was attributed to a rise of soil pH to above 7 and the consequential formation of insoluble phosphates of aluminum, iron, and calcium.

When researchers applied alkaline fly ash to a very strongly acid mine spoil, however, available levels of phosphate increased significantly (Capp and Gilmore 1974, Plass and Capp 1974). Since phosphorus is also quite unavailable under very strongly acid conditions, the addition of alkaline fly ash raises soil pH to levels where phosphorus becomes more readily available (Plank and Martens 1973). Consequently, it is imperative when applying fly ash to soils that the probable effects on pH be known. This also indicates the importance of knowing the characteristics of the fly ash used in each situation.

Lignite fly ash, with its generally higher levels of free lime, may in some cases be suitable as an agricultural lime substitute. While there has not been a great deal of research done pursuant to this, Plank and Martens (1973), using basic bituminous fly ash, showed that acidic mine spoils could be neutralized through the application of such ash. In another study, they showed that a rather alkaline bituminous fly ash had about one-fifth the acid neutralizing ability as dolomitic limestone (Martens and Plank 1974). Other researchers found that acidic mine spoils, neutralized by an application of fly ash, had maintained a relatively favorable pH (5 to 6) after eight years (Capp and Adams 1971, Capp and Gilmore 1974). It was also shown that forage yields from fly ash reclaimed spoil material compared well with that of undisturbed soil (Adams *et al*. 1972).

When attempting to neutralize acidity in materials such as mine spoils and wastes, it is desirable to use a fly ash with large quantities of bases such as magnesium, potassium, sodium, and particularly calcium. While some bituminous fly ashes do contain high levels of these elements, many do not. On the other hand, lignite fly ash nearly always contains high levels of calcium, which in some cases exceeds 30%.

While there have been a number of studies performed concerning the possible benefits of using fly ash as a soil amendment for various nutrient deficiencies, there have also been several investigations into the apparent toxic nature of pure fly ash or soils with heavy fly ash applications.

After noting the limited success of vegetation growing on fly ash dumps in England, Hodgson and Holliday (1966) undertook a series of tests to determine the probable causes of fly ash toxicity. They determined that three factors, alone or in combination, prevented or limited the growth of various plants on fly ash:

1. High levels of soluble salts
2. High pH
3. Specific toxicities

These three basic problems associated with soil materials high in fly ash content have also been emphasized by researchers in the United States (Martens 1971, Plank and Martens 1973).

High levels of soluble salts in a soil solution can limit plant growth due to high osmotic pressures. Investigations have shown that growth can be reduced on saline soils which have a soluble salt content of 0.1 to 0.2% (USDA 1954). Fly ash will commonly consist of at least 1.5% soluble salts with many lignite fly ashes containing as much as 5 or 6% (Hodgson and Holliday 1966, Shannon and Fine 1974, Martens et al. 1970a).

The problem of soluble salts can be alleviated through the leaching and weathering of fly ash for a period of two to three years (Jones and Lewis 1960). Thus, the problem of high levels of soluble salts, which is likely to be encountered when incorporating fly ash into soil, is lessened if weathered rather than fresh ash is used (Martens 1976).

The effect which high pH has on plant growth is mostly an indirect one. High soil pH (over about 7) can reduce the availability of zinc, iron, manganese, and phosphorus to deficiency levels (Brady 1974). It has been shown that the addition of alkaline fly ash to soil in quantities sufficient to raise the pH to 7.9 will decrease the availability of phosphorus and zinc to deficiency levels (Martens 1971).

The high levels of pH which are characteristic of many fly ashes, lignite fly ash in particular, are due primarily to great relative quantities of salts and oxides of sodium and calcium (Shannon and Fine 1974). The large quantities of calcium salts and the smaller but highly soluble sodium fraction accounts for the extremely basic reaction of lignite fly ash, which will commonly have a pH of 11 or 12. It can be anticipated, however, that as fly ash weathers and many of the soluble bases are leached out, the pH will drop somewhat. In England, on the other hand, Hodgson and Holliday (1966) found that the pH of weathered fly ash was, in some cases, the same as for fresh ash (e.g. 8.5). There are, to be sure, many factors which affect the pH of fly ash, most of which are probably yet to be understood.

A number of researchers have investigated the occurrence of specific toxicities in fly ash. In England, Rees and Sidrak (1956) found that several species of plants showed toxic levels of both aluminum and manganese in their leaf tissues. On the other hand, Martens (1976) found that a fly ash amended soil caused a significant decrease in the uptake of manganese by plants. While there is evidence that some plants may be sensitive to aluminum and manganese in alkaline fly ash, this phenomenon needs further investigation.

Several studies have dealt with the presence of boron toxicities in fly ash. Holliday _et al_. (1958) found that boron toxicity was the main limiting factor in growing barley on an ash dump site in England. Jones and Lewis (1960) found that boron availability decreased over time but still remained higher than in natural soil for 20 years. Nevertheless, the high levels of boron which induced toxicity symptoms in plants usually disappeared after one or two years of weathering. The best means of offsetting boron toxicity, which occurs primarily in pure fly ash, was shown to be the diluting of the surface ash by mixing with soil (Hodgson and Holliday 1966).

In addition to elements which cause outright toxic reactions in plants, there are also many elements which are absorbed by plants from fly ash which, although not necessarily toxic to the plant, may build up in the tissues of animals consuming those plants. Furr _et al_. (1976) found 32 elements which were present in higher concentrations in fly ash than in soil. Of these elements, they found that levels of arsenic, boron, calcium, copper, iron, mercury, iodine, potassium, magnesium, molybdenum, nickel, antimony, and selenium were higher in the edible portions of at least three crops grown in fly ash amended soils as compared to the control. Gutenmann _et al_. (1976) found significantly higher levels of selenium in the tissues of animals which had ingested such plant material. The possibilities of introducing harmful levels of heavy metals into soil by fly ash treatments is a problem which is just now being explored. This will certainly be of critical importance in judging the possible usefulness of fly ash in any sort of agricultural context.

METHODS AND PROCEDURES

Material Collection

Fly ash from two lignite-fired electric generating facilities owned by Texas Utilities Generating Company (TUGCO) was used: the Monticello Steam Electric Station (MOSES) at Mt. Pleasant, Texas, and the Big Brown Steam Electric Station (BBSES) at Fairfield, Texas. The fly ash at both locations is collected by means of electrostatic precipitators and is transported pneumatically to storage silos. The ash for this study was taken from these silos and transported to Stephen F. Austin State University in Nacogdoches, Texas, in February, 1976.

The two soils used in this study were selected because of their prevalence in an area to be strip-mined for lignite by TUGCO near Tatum, in Panola County, Texas. The first was a Troup soil (loamy, siliceous, thermic family of Grossarenic Paleudults) and the second was a Sacul soil (clayey, mixed, thermic family of Typic Paleudults). In each case, samples were collected from the A horizon. The Troup sample was collected from an old pasture which was reverting to brush and trees. The Sacul sample was collected from a pasture which was approximately one-half mile from the Troup location.

In addition to these two soils, a third soil material having a higher clay content was collected from a lignite strip mine spoil in Harrison County, approximately 12 miles north of the area where the other two soils were collected. This spoil had been exposed for about three years and had no vegetation growing on it. The spoil material and the two surface soils were also collected in February, 1976 and transported to Stephen F. Austin State University.

Greenhouse Procedures

The fly ash-soil mixture combinations used in this study are presented in Table 2. All materials were sieved through a No. 10 mesh sieve (2 mm) before mixing. The spoil, however, was found to be hard and massive and required extensive crushing before screening was attempted.

During early March of 1976, three one-year-old loblolly pine (Pinus taeda L.) seedlings were planted in each of 57 standard 10-inch clay pots, resulting in three replications of each of the 19 combinations. The seedlings were grown in order to provide nutrient uptake data to correlate with laboratory analyses of the fly ash-soil combinations. The pots were watered three to four times weekly so that moisture would not be a limiting factor in seedling growth. Loblolly pine, obtained from the Texas Forest Service nursery at Alto, Texas, was chosen because of its probable use in strip mine reclamation efforts in East Texas.

Seedling heights were recorded at the time of planting and again after six months, in September, 1976. They were then removed for analysis, with the three trees in each pot constituting one sample. Seedlings which died during the growing season were removed when all green color in the needles was gone. Those which

Table 2. Mixture combinations of soil, spoil and fly ash.*

Tr	FA-MOSES	Sa	FA-MOSES	Sp	FA-MOSES
100%	0%	100%	0%	100%	0%
75%	25%	75%	25%	75%	25%
50%	50%	50%	50%	50%	50%
25%	75%	25%	75%	25%	75%
0%	100%	0%	100%	0%	100%

Tr	FA-BBSES	Sa	FA-BBSES	Sp	FA-BBSES
50%	50%	50%	50%	50%	50%

Tr	Sp
75%	25%
50%	50%
25%	75%

*Tr = Troup soil.
Sa = Sacul soil.
Sp = Mine spoil.
FA-MOSES = Fly ash from Monticello Steam Electric Station at Mt. Pleasant, Texas.
FA-BBSES = Fly ash from Big Brown Steam Electric Station at Fairfield, Texas.

died during the first four weeks were replaced, with all dead seedlings being saved for analysis. Each dead seedling was treated as a separate sample.

Tissue samples were also divided into roots and tops. Root samples consisted of all tissue below the root collar while the top samples were made up of all needles which still had some green color. In the case of the dead seedlings, the top samples consisted of all needles still attached at the time of death.

Soil samples were taken from each pot after the seedlings had been removed. Each pot constituted one sample with material from all parts of the pot being mixed thoroughly before sampling.

Laboratory Procedures

All plant tissue collected, tops and roots, from both live and dead trees was dried at 60°C for 24 hours. The tissue was then ground in a Wiley mill to pass a 1 mm mesh sieve. A 0.5 gram portion was taken from each sample and ashed at 480°C for 20 hours. Several samples weighed less than 0.5 gram and in those cases the portion consisted of the entire sample. The ashed samples were then dissolved in a few drops of 6 $\underline{N}$ hydrochloric acid and diluted to 100 ml with distilled water.

Soil samples were dried at 60°C for 48 hours and again screened through a 2 mm sieve. Exchangeable cations were extracted with 1 $\underline{N}$ ammonium acetate and available phosphorus was extracted using 0.002 $\underline{N}$ sulfuric acid.

Cations (calcium, magnesium, sodium, potassium, manganese, and zinc) were determined using standard atomic absorption procedures with a Jarrell-Ash Atomic Absorption/Flame Emission Spectrophotometer (Appendix B). Phosphorus concentrations in the solutions were determined colorimetrically on a Bausch and Lomb Spectrophotometer using the sulfomolybdic blue color method (Appendix B).

Cation exchange capacity (C.E.C.) was measured through distillation of adsorbed ammonium (U.S.D.A. 1972) (Appendix B). Nitrogen was determined through the Kjeldahl method with the Winkler modification (Appendix B). Soil reaction (pH) was measured with a Fisher glass electrode in a 1:1 soil-water suspension. The textures of the soils, fly ash, and soil-fly ash mixtures were determined by the Bouyoucos method (Appendix B). The results of tissue and soil analyses are presented in Appendix A.

Statistical Analysis

The data were examined using a nested, one-way analysis of variance. The sources of variation were between treatments (% soils:% fly ash) and within treatments. The degrees of freedom in this model were four and ten respectively for soil:fly ash-MOSES and Troup soil:mine spoil treatments. However, in the case of 50%:50% mixtures of soil:fly ash-BBSES there was one degree of freedom between treatments and three degrees of freedom within treatments. The Student-Newman-Keuls Procedure was used to group together treatments which were not significantly different at the

95% level of confidence. A T-test was performed to determine whether there was a significant difference in nutrient levels between dead seedlings and corresponding live seedlings.

RESULTS AND DISCUSSION

Seedling Survival and Growth

Within one month after the seedlings had been planted in the various mixtures, it became apparent that growing conditions for the loblolly pine seedlings varied drastically from treatment to treatment. Of the 54 seedlings growing in pots containing no fly ash fraction, there had been no mortality. In mixtures containing at least 25% fly ash-MOSES, eight out of 90 seedlings (9%) had died and were replaced. Survival in pots containing fly ash-BBSES, however, was considerably poorer inasmuch as 14 of 27 seedlings (52%) had died.

It was also noted that terminal bud elongation and growth varied similarly between treatments. One month after planting, 96% of the seedlings growing in pots containing soil only had broken dormancy and commenced growth. In mixtures containing some fraction of fly ash-MOSES, 59% of the seedlings had resumed growth. However, only 12% of the seedlings in mixtures containing fly ash-BBSES had initiated growth, reflecting an obvious difficulty in adjusting to their media.

Noted at about this time was the formation of a light-colored powder on the outer surface of most pots. It was primarily found on pots which held mixtures containing fly ash. The nine pots which contained fly ash-BBSES mixtures seemed to develop the heaviest coating. This powdery residue was undoubtedly composed of soluble salts which had leached through the pots with water and that were subsequently deposited on the pots as the water evaporated. This process continued throughout the duration of the six-month experiment.

During the ensuing months, growth and vigor of the seedlings followed much the same pattern which had been established in the first month. Seedlings growing in Troup and Sacul soil, mine spoil, and mixtures of Troup soil and mine spoil definitely displayed the best color and vigor. Those growing in mixtures containing fly ash-BBSES performed quite poorly with a high rate of mortality and little growth. Seedlings in mixtures of fly ash-MOSES were generally intermediate between these extremes.

After the first month, 18 more seedlings died, of which 13 had been in fly ash-BBSES mixtures and five had been in fly ash-MOSES mixtures. Overall seedling survival in soils containing no fly ash amendment was 100%. Survival in soils amended with fly ash-MOSES was 87% while only 34% of those seedlings grown in fly ash-BBSES amended soils survived. Overall seedling survival is shown in Table 3.

It must be emphasized that while 87% of the seedlings grown in mixtures of fly ash-MOSES and 34% of those grown in mixtures of fly ash-BBSES survived, they were by no means healthy. On the contrary, nearly all seedlings grown in mixtures containing any fly ash fraction were declining at the conclusion of the experiment and probably would have succumbed in the following months. Beginning the second month, the needles of these seedlings began to turn brown at the tips and the necrosis progressed steadily down the needles

Table 3. Seedling Survival by Treatment.

	Number of Seedlings, including replacements	Mortality	% Survival
1.00 Troup	9	0	100
.75 Tr .25 FA-MOSES	9	0	100
.50 Tr .50 FA-MOSES	9	2	78
.25 Tr .75 FA-MOSES	9	0	100
1.00 Sacul	9	0	100
.75 Sa .25 FA-MOSES	9	0	100
.50 Sa .50 FA-MOSES	9	0	100
.25 Sa .75 FA-MOSES	11	2	82
1.00 Spoil	9	0	100
.75 Sp .25 FA-MOSES	9	0	100
.50 Sp .50 FA-MOSES	9	0	100
.25 Sp .75 FA-MOSES	11	5	58
1.00 FA-MOSES	12	4	67
.50 Tr .50 FA-BBSES	13	9	31
.50 Sa .50 FA-BBSES	15	11	27
.50 Sp .50 FA-BBSES	13	7	46
.75 Tr .25 Sp	9	0	100
.50 Tr .50 Sp	9	0	100
.25 Tr .75 Sp	9	0	100

SUMMARY

	Number of Seedlings, including replacements	Mortality	% Survival
Soils containing no fly ash	54	0	100
Mixtures containing fly ash-MOSES	98	13	87
Mixtures containing fly ash-BBSES	41	27	34

throughout the growing season. When the experiment was concluded after six months, the needles on these seedlings were alive only from their base to about half their length with many being green for less than an inch at the base. Consequently, the distinction between live and dead seedlings was, in some cases, arbitrary. Had the experiment continued another few months, the number of dead seedlings would have been considerably greater.

The overall height growth of the seedlings reflected the differences in growing conditions among the treatments. As can be seen in Table 4, height growth varied considerably with fly ash content in those mixtures containing fly ash-MOSES. In general, the higher the fly ash-MOSES content of the soil mixture, the less height growth which occurred. Likewise, those seedlings grown in soil not amended with fly ash-MOSES showed more growth than those in fly ash-MOSES amended soils.

In comparing the height growth of seedlings grown in 50%:50% mixtures of soil:fly ash-MOSES and soil:fly ash-BBSES, a difference between the two fly ashes became evident. In two of the three soil materials, seedlings grown in fly ash-BBSES amended soils grew considerably less than those in fly ash-MOSES amended soils. While both fly ashes seemed to depress growth, fly ash-BBSES definitely had a more detrimental effect than fly ash-MOSES.

In mixtures of Troup soil and mine spoil, seedling height growth was not shown to vary significantly with changes in soil mixture composition. This reflects the fact that the seedlings generally

Table 4. Mean Seedling Height Growth.

	Mean Height Growth (inches)
1.00 Troup	6.74
.75 Tr .25 FA-MOSES	4.96
.50 Tr .50 FA-MOSES	4.86
.25 Tr .75 FA-MOSES	3.90
1.00 FA-MOSES	2.69
1.00 Sacul	7.21
.75 Sa .25 FA-MOSES	5.18
.50 Sa .50 FA-MOSES	3.13
.25 Sa .75 FA-MOSES	3.74
1.00 FA-MOSES	2.69
1.00 Spoil	5.53
.75 Sp .25 FA-MOSES	4.99
.50 Sp .50 FA-MOSES	4.10
.25 Sp .75 FA-MOSES	2.98
1.00 FA-MOSES	2.69
.50 Tr .50 FA-MOSES	4.86
.50 Tr .50 FA-BBSES	2.10
.50 Sa .50 FA-MOSES	3.13
.50 Sa .50 FA-BBSES	3.69
.50 Sp .50 FA-MOSES	4.10
.50 Sp .50 FA-BBSES	1.92
1.00 Troup	6.74
.75 Tr .25 Sp	6.93
.50 Tr .50 Sp	5.13
.25 Tr .75 Sp	6.65
1.00 Spoil	5.53

grew well in all of these treatments in addition to experiencing no seedling mortality.

Soil Analysis

Texture

Mechanical analysis revealed the Troup and Sacul soils to be of sandy and sandy loam textures respectively. The mine spoil was determined to be a sandy clay loam. As can be seen in Table 5, when fly ash-MOSES was added to the three soil materials, the particle size distribution of each was progressively modified toward the silt loam texture of the fly ash. In mixtures containing soil of the Troup and Sacul series, there was a decrease in sand and an increase in silt and clay content as the percentage of fly ash increased. In the spoil material, there was a decrease in sand and clay while the silt fraction increased. These results would, therefore, conform to the findings of Jones (1976) and Capp and Gilmore (1974) that whatever the texture of a particular soil, the addition of fly ash will modify the particle size distribution toward that of the fly ash.

The particle size distributions of the fly ash from BBSES and MOSES were very similar with fly ash-BBSES having a higher clay content and slightly lower percentages of sand and silt (Table 5). Consequently, the 50%:50% mixtures of soil:fly ash-BBSES showed little textural difference from those of soil:fly ash-MOSES. Nevertheless, it was noted during the course of the experiment that the mixture of 50% Troup soil:50% fly ash-BBSES formed a very pronounced surface crust. This crust was very brittle and would break into smaller

Table 5. Mechanical Analysis.

	Sand	Silt	Clay	Texture
	------------Percent----------			
1.00 Troup	91.1	6.4	2.5	sand
.75 Tr .25 FA-MOSES	75.2	18.8	6.0	sandy loam
.50 Tr .50 FA-MOSES	63.2	30.8	6.0	sandy loam
.25 Tr .75 FA-MOSES	47.2	44.8	8.0	loam
1.00 FA-MOSES	31.2	56.0	12.8	silt loam
1.00 Sacul	71.2	23.8	5.0	sandy loam
.75 Sa .25 FA-MOSES	61.2	32.8	6.0	sandy loam
.50 Sa .50 FA-MOSES	49.6	42.4	8.0	loam
.25 Sa .75 FA-MOSES	43.2	46.4	10.4	loam
1.00 FA-MOSES	31.2	56.0	12.8	silt loam
1.00 Spoil	52.6	24.8	22.6	sandy clay loam
.75 Sp .25 FA-MOSES	45.6	35.4	19.0	loam
.50 Sp .50 FA-MOSES	41.2	43.4	15.4	loam
.25 Sp .75 FA-MOSES	37.2	48.8	14.0	loam
1.00 FA-MOSES	31.2	56.0	12.8	silt loam
.50 Tr .50 FA-MOSES	63.2	30.8	6.0	sandy loam
.50 Tr .50 FA-BBSES	62.2	27.4	10.4	sandy loam
.50 Sa .50 FA-MOSES	49.6	42.4	8.0	loam
.50 Sa .50 FA-BBSES	51.2	37.4	11.4	loam
.50 Sp .50 FA-MOSES	41.2	43.4	15.4	loam
.50 Sp .50 FA-BBSES	43.2	42.4	14.4	loam
1.00 Tr	91.1	6.4	2.5	sand
.75 Tr .25 Sp	83.2	9.8	7.0	loamy sand
.50 Tr .50 Sp	74.6	13.4	12.0	sandy loam
.25 Tr .75 Sp	64.2	18.8	17.0	sandy loam
1.00 Sp	52.6	24.8	22.6	sandy clay loam
1.00 FA-MOSES	31.2	56.0	12.8	silt loam
1.00 FA-BBSES	27.6	53.4	19.0	silt loam

fragments which were rather hard upon drying. All mixtures containing fly ash-BBSES were difficult to remove from the pots after the six-month growing season. These mixtures were hard and massive and had apparently "set up" to greater or lesser degrees.

This characteristic of the fly ash from BBSES was also noted when a quantity of it was inadvertently wetted in the greenhouse. After a couple of days, that part which had absorbed water was quite hard and appeared similar to plaster of paris. This was most likely due to the pozzolanic characteristics of fly ash in conjunction with fly ash-BBSES having considerably higher levels of calcium than fly ash-MOSES. This is discussed in the section Cations.

The combination of sandy soil of the Troup series with sandy clay loam mine spoil produced mixtures which were of loamy sand and sandy loam textures. Thus, either of these two soil materials could be viewed as modifying the particle size distribution of the other as in the soil:fly ash-MOSES mixtures.

Reaction

The Troup and Sacul soils were both determined to have reactions near pH 7 while the mine spoil had a pH of 5.7. There was a significant and clearly defined relationship evident between fly ash content of the mixtures and pH, as can be seen in Figure 1 and Table 6. Soil pH increased steadily as the percentage of fly ash-MOSES in the mixtures increased until a pH of 10.6 was reached in 100% fly ash-MOSES.

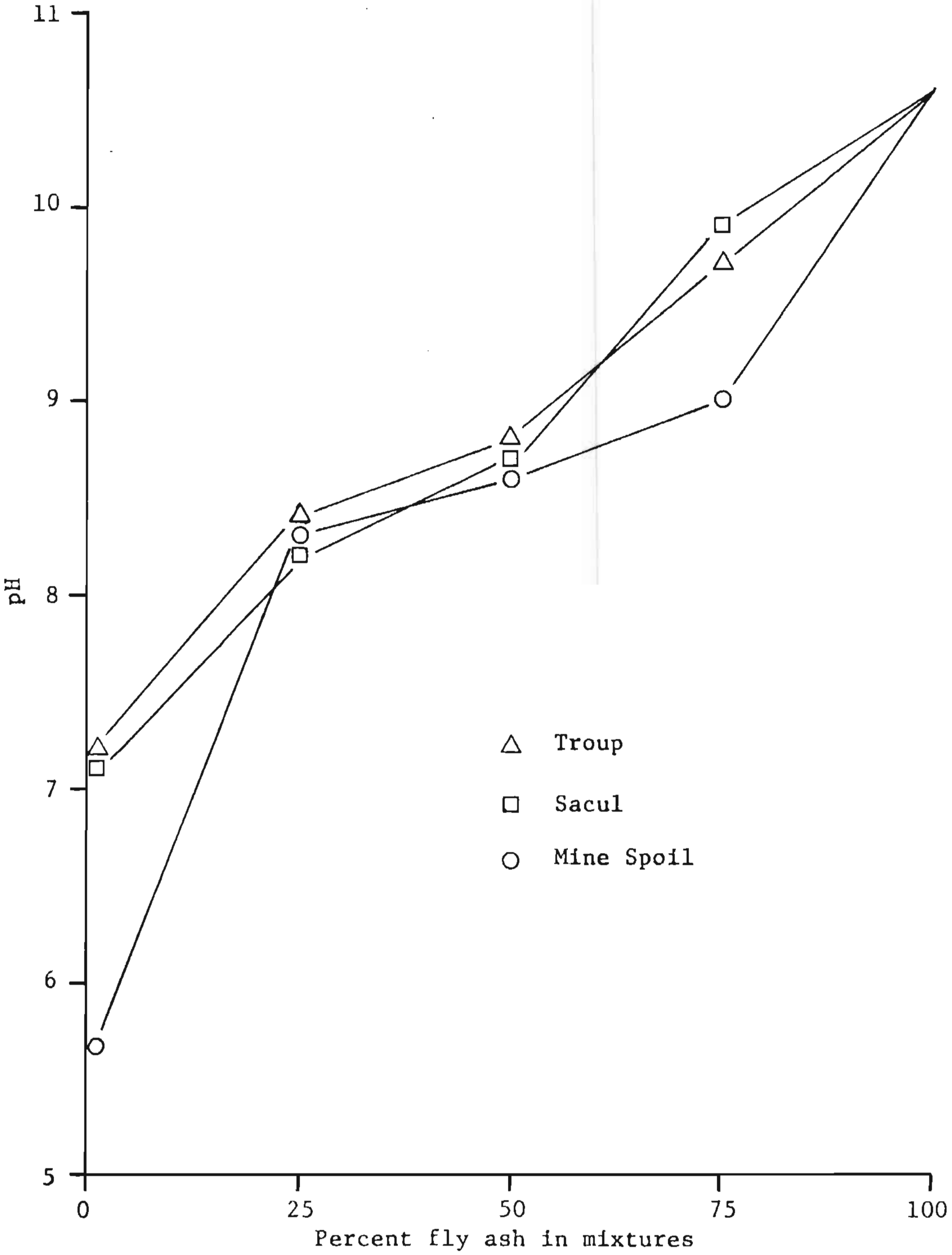

Figure 1. pH of mixtures of Troup, Sacul, and mine spoil with fly ash-MOSES.

Table 6. Comparison of Mean Reaction, Nitrogen and Phosphorus at End of Growing Period.*

	pH	%N	P (ppm)
1.00 Troup	7.2 a	.0376 a	25 a
.75 Tr .25 FA-MOSES	8.4 b	.0274 b	1 b
.50 Tr .50 FA-MOSES	8.8 b	.0162 c	1 b
.25 Tr .75 FA-MOSES	9.7 c	.0089 d	1 b
1.00 FA-MOSES	10.6 d	.0014 e	1 b
1.00 Sacul	7.1 a	.0636 a	7 a
.75 Sa .25 FA-MOSES	8.2 b	.0376 b	1 b
.50 Sa .50 FA-MOSES	8.7 b	.0228 c	1 b
.25 Sa .75 FA-MOSES	9.9 c	.0125 d	1 b
1.00 FA-MOSES	10.6 d	.0014 e	1 b
1.00 Spoil	5.7 a	.0451 a	100 a
.75 Sp .25 FA-MOSES	8.3 b	.0325 b	1 b
.50 Sp .50 FA-MOSES	8.6 c	.0214 c	1 b
.25 Sp .75 FA-MOSES	9.0 d	.0120 d	1 b
1.00 FA-MOSES	10.6 e	.0014 e	1 b
.50 Tr .50 FA-MOSES	8.8 a	.0162 a	1 a
.50 Tr .50 FA-BBSES	10.9 b	.0130 a	2 a
.50 Sa .50 FA-MOSES	8.7 a	.0228 a	1 a
.50 Sa .50 FA-BBSES	10.6 b	.0214 a	3 b
.50 Sp .50 FA-MOSES	8.6 a	.0214 a	1 a
.50 Sp .50 FA-BBSES	10.3 b	.0223 a	1 a
1.00 Troup	7.2 a	.0376 b	25 a
.75 Tr .25 Sp	7.4 a	.0315 a	39 b
.50 Tr .50 Sp	6.6 b	.0371 b	67 c
.25 Tr .75 Sp	6.3 b	.0437 c	90 d
1.00 Spoil	5.7 c	.0451 c	100 d

*Values in each group followed by the same letter are not significantly different at the 95% level of confidence.

The basic soil reactions which were present in all mixtures containing as little as 25% fly ash are of concern when attempting to manage vegetation on such materials. The moderately alkaline reactions present in 25% fly ash mixtures undoubtedly played an important role in the poor vigor exhibited by the loblolly pine seedlings in these mixtures. Loblolly pine, like most natural vegetation in East Texas, is best adapted to soils which are neutral to medium acid in reaction. Consequently, the application of quantities of fly ash equivalent to those used in this study to neutral or medium acid soils would result in a soil reaction not conducive to the growth and perpetuation of native species. It is entirely possible that smaller applications of fly ash or applications of fly ash to soils more acidic than those used in this project would not be detrimental. This was, however, beyond the scope of this investigation and may warrant further research.

The 50%:50% mixtures of soil:fly ash-BBSES were shown to be significantly more alkaline than the 50%:50% mixtures of soil: fly ash-MOSES. As can be seen in Table 6, the pH of these mixtures was as high as that of 100% fly ash-MOSES--approximately 10.6. It could, therefore, be anticipated that chemical problems in soils amended with fly ash-BBSES would be similar to, though more acute than, those found in fly ash-MOSES amended soils.

Mixtures of the medium acid mine spoil and the neutral Troup soil produced soils which were slightly acid or neutral. As can be seen in Table 6, the higher the percentage of mine spoil in the mixtures, the more acidic the mixtures became. Likewise, the greater the percentage of Troup soil in the mixtures, the more the reaction approximated that of the Troup soil.

Nitrogen

The nitrogen content of the soil:fly ash-MOSES mixtures was quite dependent upon the quantity of fly ash present. As is shown in Table 6 and Figure 2, the nitrogen levels of the soil:fly ash-MOSES combinations decreased significantly with each increase in percent fly ash until there was only 0.0014% nitrogen in 100% fly ash-MOSES. The low nitrogen content of fly ash results from the process by which it is created. The high temperatures at which lignite is burned volatilizes nearly all nitrogen which may be present in the lignite. Consequently, any fly ash will be virtually devoid of nitrogen. Therefore, mixing of fly ash and soil will reduce the nitrogen content of the resulting mixture with the extent of the nitrogen dilution being dependent upon the quantity of ash added.

Fly ash from MOSES and BBSES showed similar nitrogen levels when each were mixed 50%:50% with the various soils. Both sources of fly ash contained very low levels of nitrogen and the analyses of the respective mixtures revealed no significant difference in nitrogen content between soils amended with fly ash-MOSES and fly ash-BBSES (Table 6).

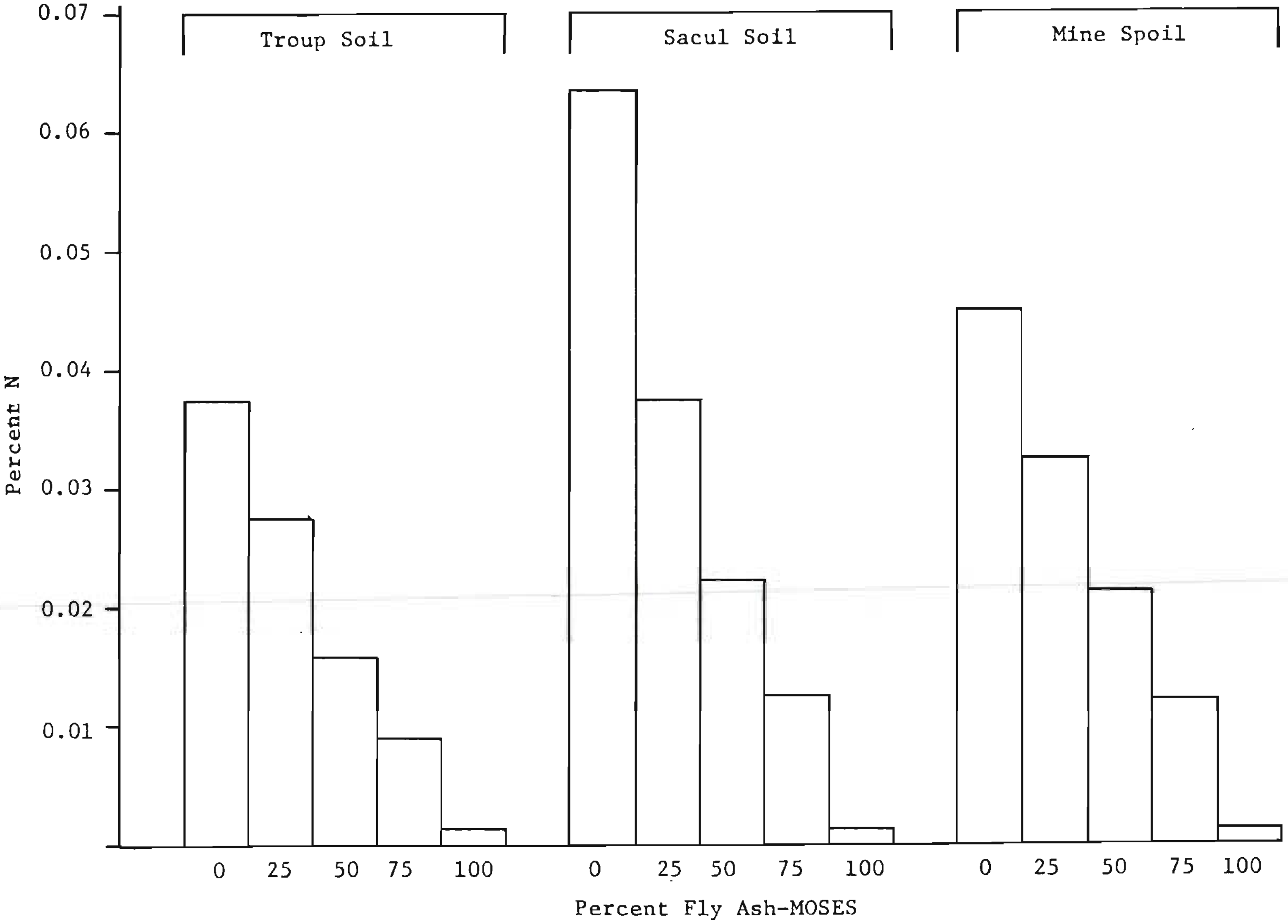

Figure 2. Nitrogen content of soils:fly ash-MOSES mixtures.

The range of nitrogen levels in the Troup soil:mine spoil mixtures was much more narrow than in the fly ash amended groups. In general, the levels tended to progress from 0.0376% in 100% Troup soil to 0.0451% in the 100% mine spoil. Such a range of values would not be unexpected.

Phosphorus

After nitrogen, the most important nutrient for plant growth is probably phosphorus. The levels of extractable phosphorus in all three soils dropped off dramatically with the addition of fly ash-MOSES. From 25, 7 and 100 ppm in the 100% Troup, Sacul, and mine spoil controls respectively, the levels of available phosphate consistently dropped to 1 ppm in all treatments amended with fly ash-MOSES (Table 6). This dramatic and significant drop in available phosphorus was, at least partially, related to the inadequacy of the procedure used to extract phosphorus from alkaline materials. Mixtures containing as little as 25% fly ash-MOSES had a pH exceeding 8, while phosphorus is generally most available between pH 6 and 7. Likewise, the presence of free calcium in the soil mixtures most likely resulted in the formation of calcium phosphate, which is quite insoluble. Consequently, in alkaline soil situations, most phosphorus exists as insoluble phosphates and is unavailable to plants.

The analyses of fly ash-BBSES amended soils revealed some small difference in available phosphate levels from the soils amended with fly ash-MOSES. There was a significantly higher level of phosphate in 50%:50% mixtures of Sacul soil:fly ash-BBSES than in corresponding mixtures with fly ash-MOSES. This amounted to 3 ppm for Sacul soil amended with fly ash-BBSES and 1 ppm for the fly ash-MOSES amended mixtures. Combinations of Troup soil and mine spoil with the two types of fly ash revealed no such significant differences. On the whole, all of the phosphate levels were quite low and, the significant difference in the Sacul mixtures notwithstanding, little real variation in plant growth should be expected due to differences of phosphate availability in the two types of fly ash.

The combinations of Troup soil with mine spoil revealed another clear progression. From 25 ppm phosphorus in 100% Troup soil, the available phosphorus increased steadily with increasing percentages of mine spoil until there were 100 ppm in 100% mine spoil. As was the case with many plant nutrients in this group of mixtures, the progression in the levels of available phosphorus was probably due primarily to the fact that there was a sufficiently large difference between the phosphate levels of the Troup soil and mine spoil.

Cations

After nitrogen and phosphorus, the quantities of extractable base cations (calcium, magnesium, potassium, and sodium) present in a soil can give a fairly good indication of that soil's natural fertility. Likewise, the cation levels present in fly ash-MOSES are important factors in assessing its possible use as a soil amendment. It was found that magnesium, potassium, and sodium were all present at levels of less than 100 ppm. Calcium, on the other hand, was present at concentrations of 3,000 ppm. This high content of soluble calcium is important in understanding the effects of fly ash-MOSES and fly ash-BBSES when they are used as soil amendments.

As can be seen in Table 7, the levels of calcium and magnesium increased significantly in the Troup soil:fly ash-MOSES mixtures with increasing fly ash content. On the other hand, there was no appreciable change in potassium and sodium. In the Sacul soil:fly ash-MOSES mixtures, there was also an increase in calcium and magnesium levels with greater quantities of fly ash. In this instance, however, the potassium and sodium content fell with the addition of 25% fly ash-MOSES. In mixtures of mine spoil and fly ash-MOSES the calcium content increased with the addition of fly ash while levels of magnesium, potassium, and sodium dropped significantly. It became evident that where the fly ash had a higher concentration of a given cation than the soil to which it was added, the level of that cation in the resulting mixtures increased as the content of the fly ash was increased. Likewise, where the concentration of a cation was lower in the fly ash than in the soil, the level of that cation in the mixtures fell as the fly ash content of the mixture increased. Thus, the concentration of any given cation can be either supplemented or diluted by fly ash application.

Table 7. Comparison of Mean Extractable Base Cations at End of Growing Period.*

	Ca	Mg	K	Na
	ppm			
1.00 Troup	673 a	21 a	19 a	45 a
.75 Tr .25 FA-MOSES	1150 a	62 b	20 a	31 b
.50 Tr .50 FA-MOSES	1525 a	80 d	19 a	28 b
.25 Tr .75 FA-MOSES	2625 b	69 c	18 a	39 ab
1.00 FA-MOSES	3000 b	95 e	16 a	33 ab
1.00 Sacul	625 a	63 a	41 a	115 a
.75 Sa .25 FA-MOSES	1225 ab	72 a	26 b	34 b
.50 Sa .50 FA-MOSES	1700 b	91 b	22 b	37 b
.25 Sa .75 FA-MOSES	2575 c	96 b	22 b	41 b
1.00 FA-MOSES	3000 c	95 b	16 b	33 b
1.00 Spoil	1475 a	558 a	163 a	254 a
.75 Sp .25 FA-MOSES	2725 b	304 b	112 b	139 b
.50 Sp .50 FA-MOSES	2475 b	164 c	70 c	86 bc
.25 Sp .75 FA-MOSES	2575 b	131 d	42 d	65 bc
1.00 FA-MOSES	3000 b	95 e	16 e	33 c
.50 Tr .50 FA-MOSES	1525 a	80 a	19 a	28 a
.50 Tr .50 FA-BBSES	6600 b	228 b	17 a	32 a
.50 Sa .50 FA-MOSES	1700 a	91 a	22 a	37 a
.50 Sa .50 FA-BBSES	6625 b	247 b	20 a	42 a
.50 Sp .50 FA-MOSES	2475 a	164 a	70 a	86 a
.50 Sp .50 FA-BBSES	7125 b	197 b	64 a	83 a
1.00 Troup	673 a	21 a	19 a	45 a
.75 Tr .25 Sp	690 a	113 b	53 b	121 ab
.50 Tr .50 Sp	1062 b	271 c	96 c	178 bc
.25 Tr .75 Sp	1175 c	371 d	115 d	180 bc
1.00 Spoil	1475 d	558 e	163 e	254 c

*Values in each group followed by the same letter are not significantly different at the 95% level of confidence.

Fly ash-BBSES was shown to contain significantly higher levels of calcium and magnesium than fly ash-MOSES, while the extractable potassium and sodium fraction was about equal (Table 7). In all three soil materials, the addition of 50% fly ash-BBSES resulted in at least three times more extractable calcium than was present in corresponding mixtures containing fly ash-MOSES. It was also determined that fresh, unweathered fly ash-BBSES contained in excess of 13,000 ppm (1.3%) extractable calcium. Such a high level of easily dissolved calcium in fly ash-BBSES was undoubtedly the cause of the "setting up" which was previously noted in these pots and the salt residue which formed on the outside of these pots.

The levels of extractable cations were generally rather predictable in the Troup soil:mine spoil mixtures. The various combinations contained cation concentrations which were intermediate between the levels in 100% Troup soil and 100% mine spoil. The spoil material contained higher levels of all cations than the Troup soil with all mixtures having progressively higher levels of extractable cations as the percentage of mine spoil increased.

Zinc and Manganese

The micronutrients zinc and manganese were found to be present at very low levels in all mixtures. There was likewise very little significant variation in the extractable amounts of these elements from treatment to treatment. One exception to this was in the Sacul soil:fly ash-MOSES mixtures where 100% Sacul soil had a significantly higher level of manganese than any of the treatments amended with fly ash-MOSES. Nevertheless, all zinc and manganese levels were below 10 ppm, so it would be impossible to draw any conclusions concerning the effect of fly ash application on available levels of zinc and manganese.

Cation-Exchange Capacity

The changes which occur in C.E.C. as fly ash-MOSES content increased in the various soil mixtures were opposite to what would normally be expected. In both the Troup and Sacul soils, the addition of fly ash-MOSES decreased the sand content while increasing the percent silt and clay (Table 5). Ordinarily, one would associate such a change in texture with an increase in C.E.C. since smaller soil particles generally have more exchange sites than the larger sand-sized particles. Nevertheless, the C.E.C. of all three soils fell sharply and significantly with an increase of fly ash-MOSES content (Table 8). The most likely explanation of this behavior lies in the physical composition of fly ash--cenospheres, crystalline grains, unburnt lignite, and coke. The major portion of fly ash is composed of cenospheres (hollow glass spheres) which, by the nature of their structure (amorphous, uncharged), would have few exchange sites. Likewise, the crystalline grains, composed primarily of calcium, sodium, and magnesium salts, could not provide exchange sites since in the presence of moisture the exposed surfaces would tend to go into solution. Fly ash is also extremely low in organic matter; that which is present being primarily unburnt lignite and coke. Consequently, while fly ash has a silt

Table 8. Mean Cation-Exchange Capacity and Percent Base Saturation at End of Growing Period.*

	C.E.C. (meq./100 g)	% B.S.
1.00 Troup	3.53 a	108.2 a
.75 Tr .25 FA-MOSES	2.48 b	262.0 a
.50 Tr .50 FA-MOSES	1.95 c	434.9 b
.25 Tr .75 FA-MOSES	1.72 c	806.8 c
1.00 FA-MOSES	1.82 c	872.3 c
1.00 Sacul	4.67 a	91.3 a
.75 Sa .25 FA-MOSES	3.15 b	220.8 a
.50 Sa .50 FA-MOSES	2.18 c	435.0 b
.25 Sa .75 FA-MOSES	1.92 d	724.8 c
1.00 FA-MOSES	1.82 d	872.3 c
1.00 Spoil	13.48 a	100.6 a
.75 Sp .25 FA-MOSES	11.80 b	144.6 ab
.50 Sp .50 FA-MOSES	8.40 c	170.2 ab
.25 Sp .75 FA-MOSES	4.93 d	291.2 b
1.00 FA-MOSES	1.82 e	872.3 c
.50 Tr .50 FA-MOSES	1.95 a	434.9 a
.50 Tr .50 FA-BBSES	3.40 b	1034.1 b
.50 Sa .50 FA-MOSES	2.18 a	435.0 a
.50 Sa .50 FA-BBSES	4.00 b	888.6 b
.50 Sp .50 FA-MOSES	8.40 a	170.2 a
.50 Sp .50 FA-BBSES	10.75 b	351.4 b
1.00 Troup	3.53 a	108.2 ab
.75 Tr .25 Sp	4.90 b	103.2 ab
.50 Tr .50 Sp	7.47 c	115.0 b
.25 Tr .75 Sp	10.67 d	94.1 a
1.00 Spoil	13.48 e	100.6 ab

*Values in each group followed by the same letter are not significantly different at the 95% level of confidence.

loam texture, the materials which constitute it contribute little to the C.E.C.

The extremely low C.E.C. of fly ash-MOSES would indicate, therefore, practical limitations to heavy fly ash applications, particularly to coarse textured soils already having a low C.E.C. If heavy applications are deemed desirable for other reasons, another means of increasing C.E.C. may be necessary such as the incorporation of some type of organic matter.

In comparing the C.E.C. of fly ash-MOSES with that of fly ash-BBSES, it was clear that the fly ash from BBSES had a significantly higher C.E.C. In the 50%:50% mixtures of soil:fly ash, the mixtures with fly ash-BBSES consistently had a higher C.E.C. than the mixtures containing fly ash-MOSES (Table 8). The reasons for this difference were unclear from the work performed in this study but were most likely due to differences in the mineralogy and structure of the two fly ashes.

In the mixtures of Troup soil and mine spoil, a clear gradation in C.E.C. existed from 3.53 meq/100 g in 100% Troup soil to 13.84 meq/100 g in the mine spoil. Thus, as the texture changed from a sand to a sandy clay loam, there was a corresponding increase in C.E.C. This was the type of relationship which would normally be expected under these circumstandes.

Base Saturation

In the mixtures of Troup soil, Sacul soil, and mine spoil with fly ash-MOSES, a significant relationship developed between fly ash content of the mixtures and Percent Base Saturation (% B.S.). In all three soil materials, the % B.S. increased as the fly ash content of the mixtures increased (Table 8). This was due to the higher levels of soluble salts present as the fly ash content increased and to the concurrent decrease in C.E.C. Thus, while the total soluble salts were increasing with greater fly ash content, there were fewer exchange sites present. Consequently, % B.S. increased rapidly.

The % B.S. reached a high of 872.3% in 100% fly ash-MOSES. While this represented an extremely high level of soluble salts, it was considerably less than the 2375.6% base saturation of the fly ash-MOSES that was fresh and unweathered. Six months of leaching reduced the free salts in this fly ash considerably, although 873.3% base saturation must still be viewed as excessive for the normal growth of most species of plants. Nevertheless, % B.S. could be expected to continue decreasing if the fly ash were exposed to further leaching.

When fly ash from MOSES and BBSES were compared with regard to % B.S., it became clear that there was a significant difference between the two sources of ash. When mixed 50%:50% with the three types of soil, the mixtures containing fly ash-BBSES had a % B.S. which was at least twice as great as that of mixtures containing fly ash-MOSES (Table 8). This can be attributed to the higher levels of soluble salts, particularly those of calcium, present in fly ash-BBSES. Although fly ash-BBSES had a higher C.E.C. than fly ash-MOSES, this was more than offset by the much higher salt content.

In the mixtures of Troup soil and mine spoil, there was no apparent relationship between % B.S. and the various treatments. All mixtures were close to 100% base saturation. While C.E.C. increased significantly with increasing percentages of mine spoil in the mixtures, the quantities of base cations in the mixtures rose concurrently. Thus, the % B.S. remained fairly constant throughout the range of treatments.

Tissue Analysis

Live Seedlings--Needles

Nutrient levels in needles from live seedlings grown in mixtures of the three soil materials and fly ash-MOSES reflected very few significant differences with respect to treatment. As can be noted in Table 9, there was a significant difference in needle phosphorus levels between 100% Troup and Sacul soil controls and those treatments containing fly ash-MOSES. This undoubtedly reflected the effect of fly ash-MOSES on the availability of phosphorus in the soil. Nevertheless, this relationship was not apparent in the mixtures of mine spoil and fly ash-MOSES where needle phosphorus levels remained fairly constant in all treatments.

The only other significant difference noted in these mixtures was the higher level of sodium present in the needles of seedlings grown in 100% fly ash-MOSES with respect to that found in treatments containing a soil fraction. This was despite the fact that in two of the three soil materials, Sacul soil and mine spoil, the extractable sodium was greater than in 100% fly ash-MOSES. This may have been due to the low cation-exchange capacity of fly ash-MOSES in conjunction with its high percent base saturation. Unlike the soil materials where nearly all sodium would be held at exchange sites, the sodium in the fly ash was present as soluble salts which, due to the high solubility of sodium salts, would readily dissolve into solution in the presence of moisture.

Table 9. Mean Needle Nutrient Levels of Live Seedlings.*

	P	Ca	Mg	K	Na	Zn	Mn
	Percent					ppm	
1.00 Troup	0.11 a	0.11 a	0.11 a	0.60 a	0.32 ab	27 a	70 a
.75 Tr .25 FA-MOSES	0.09 b	0.11 a	0.16 b	0.65 ab	0.24 a	30 a	70 a
.50 Tr .50 FA-MOSES	0.09 b	0.11 a	0.15 b	0.67 ab	0.32 ab	33 a	60 a
.25 Tr .75 FA-MOSES	0.07 b	0.10 a	0.13 a	0.96 b	0.22 a	33 a	63 a
1.00 FA-MOSES	0.09 b	0.08 a	0.12 a	0.70 ab	0.44 b	30 a	63 a
1.00 Sacul	0.13 a	0.09 a	0.11 a	0.72 a	0.23 a	25 a	87 a
.75 Sa .25 FA-MOSES	0.09 b	0.12 bc	0.15 a	0.76 a	0.28 a	22 a	63 a
.50 Sa .50 FA-MOSES	0.09 b	0.14 c	0.15 a	0.66 a	0.28 a	28 a	67 a
.25 Sa .75 FA-MOSES	0.08 b	0.10 ab	0.13 a	0.68 a	0.28 a	22 a	50 a
1.00 FA-MOSES	0.09 b	0.08 a	0.12 a	0.70 a	0.44 b	30 a	63 a
1.00 Spoil	0.09 a	0.09 a	0.15 a	0.83 ab	0.15 a	45 a	143 a
.75 Sp .25 FA-MOSES	0.09 a	0.08 a	0.16 a	1.00 a	0.19 a	30 ab	47 c
.50 Sp .50 FA-MOSES	0.10 a	0.08 a	0.14 ab	1.05 a	0.20 a	32 ab	87 b
.25 Sp .75 FA-MOSES	0.10 a	0.08 a	0.11 c	0.90 ab	0.27 a	28 b	77 b
1.00 FA-MOSES	0.09 a	0.08 a	0.12 bc	0.70 b	0.44 b	30 ab	63 bc
.50 Tr .50 FA-MOSES	0.09 a	0.11 a	0.15 a	0.67 a	0.32 a	33 a	60 a
.50 Tr .50 FA-BBSES	0.08 a	0.08 a	0.14 b	0.94 a	2.44 b	58 b	70 a
.50 Sa .50 FA-MOSES	0.09 a	0.14 a	0.15 a	0.66 a	0.28 a	28 a	67 a
.50 Sa .50 FA-BBSES	0.08 a	0.07 b	0.12 a	0.90 b	2.45 b	65 b	97 a
.50 Sp .50 FA-MOSES	0.10 a	0.08 a	0.14 a	1.05 a	0.20 a	32 a	87 a
.50 Sp .50 FA-BBSES	0.08 a	0.09 a	0.12 a	1.16 a	1.71 a	58 b	67 a

Table 9, continued

	P	Ca	Mg	K	Na	Zn	Mn
	Percent					ppm	
1.00 Troup	0.11 a	0.11 a	0.11 a	0.60 a	0.32 a	27 a	70 a
.75 Tr .25 Sp	0.13 ab	0.06 a	0.11 a	0.80 b	0.15 b	35 ab	143 a
.50 Tr .50 Sp	0.17 b	0.06 a	0.11 a	1.00 c	0.14 b	42 b	117 a
.25 Tr .75 Sp	0.11 a	0.07 a	0.12 a	0.91 bc	0.18 b	37 ab	123 a
1.00 Spoil	0.09 a	0.09 a	0.15 b	0.83 b	0.15 b	45 b	143 a

*Values in each group followed by the same letter are not significantly different at the 95% level of confidence.

Consequently, higher levels of sodium would be present in soil solutions of 100% fly ash-MOSES. In this manner, greater quantities of sodium would be taken up by seedlings grown in 100% fly ash-MOSES.

The comparison of needle nutrient levels of seedlings grown in soil:fly ash-BBSES mixtures and soil:fly ash-MOSES mixtures revealed several significant differences. The most important of these were significantly higher levels of zinc and sodium present in needle tissue from seedlings grown in fly ash-BBSES amended soils (Table 9). Needles from fly ash-BBSES amended soils contained over seven times the amount of sodium found in needles from fly ash-MOSES amended soils. This would indicate higher levels of sodium in the soil solution of fly ash-BBSES amended soils although the extractable sodium was about equal in 50%:50% mixtures of soil: fly ash-MOSES and soil:fly ash-BBSES (Table 7). Zinc was present at roughly twice the concentration in needles from seedlings grown in fly ash-BBSES amended soils than in needles from seedlings grown in fly ash-MOSES amended soils. This difference was also not reflected in the soil analyses of the respective mixtures.

There were some minor fluctuations in needle nutrient levels of seedlings grown in various mixtures of Troup soil and mine spoil. Few of these differences were significant, however, and the quantities of nutrients in the needles tended to be fairly uniform in the various treatments.

Live Seedlings--Roots

Nutrient levels in the roots of live seedlings grown in mixtures of the three soil materials and fly ash-MOSES varied considerably with many significant differences between treatments. The amounts of phosphorus, potassium, zinc, and manganese in the seedling roots were significantly less in 100% fly ash-MOSES than in the control soils. On the other hand, calcium levels generally increased as fly ash-MOSES content of the mixtures increased (Table 10). The decreases in phosphorus, zinc, and manganese can be accounted for by the lesser availability of these nutrients at the higher pH levels which accompany increased fly ash content while the decrease in potassium may be due to the relatively small amounts present in fly ash-MOSES. The high calcium content of fly ash-MOSES was reflected dramatically in the amounts of calcium taken up by the seedling roots. Calcium levels in the root tissue increased significantly with the addition of 25% fly ash-MOSES and reached 2.22% calcium in the roots of seedlings grown in 100% fly ash-MOSES.

The roots of seedlings grown in 50%:50% mixtures of soil:fly ash-BBSES showed significantly higher levels of calcium and manganese than roots of seedlings grown in 50%:50% mixtures of soil:fly ash-MOSES. Higher levels of root manganese in the fly ash-BBSES amended treatments was difficult to account for inasmuch as these treatments had a higher pH than the fly ash-MOSES amended soils (Table 6). The significantly greater amounts of calcium present in seedling roots from fly ash-BBSES amended soils was undoubtedly a reflection of the

Table 10. Mean Root Nutrient Levels of Live Seedlings.*

	P	Ca	Mg	K	Na	Zn	Mn
	Percent					ppm	
1.00 Troup	0.18 a	0.56 a	0.11 a	0.30 a	0.75 a	45 a	110 a
.75 Tr .25 FA-MOSES	0.09 b	1.50 b	0.25 c	0.21 b	0.39 b	23 b	87 ab
.50 Tr .50 FA-MOSES	0.10 b	1.42 b	0.28 c	0.17 bc	0.33 b	20 bc	67 bc
.25 Tr .75 FA-MOSES	0.08 b	1.30 b	0.20 b	0.22 b	0.38 b	18 bc	37 c
1.00 FA-MOSES	0.09 b	2.22 c	0.22 b	0.11 c	0.41 b	15 c	53 bc
1.00 Sacul	0.16 a	0.28 a	0.11 a	0.34 a	0.51 a	48 a	67 a
.75 Sa .25 FA-MOSES	0.08 b	2.03 b	0.24 b	0.22 ab	0.35 a	20 b	60 a
.50 Sa .50 FA-MOSES	0.08 b	2.03 b	0.23 b	0.15 b	0.32 a	27 b	60 a
.25 Sa .75 FA-MOSES	0.11 b	2.53 b	0.26 b	0.25 ab	0.42 a	28 b	63 a
1.00 FA-MOSES	0.09 b	2.22 b	0.22 b	0.11 b	0.41 a	15 b	53 a
1.00 Spoil	0.10 a	0.08 a	0.11 a	0.36 a	0.46 a	32 a	137 a
.75 Sp .25 FA-MOSES	0.09 a	0.95 b	0.20 c	0.20 b	0.45 a	22 b	87 b
.50 Sp .50 FA-MOSES	0.09 a	1.05 b	0.14 b	0.22 b	0.35 a	18 b	47 c
.25 Sp .75 FA-MOSES	0.09 a	1.57 c	0.15 b	0.20 b	0.34 a	18 b	53 c
1.00 FA-MOSES	0.09 a	2.22 d	0.22 c	0.11 c	0.41 a	15 b	53 c
.50 Tr .50 FA-MOSES	0.10 a	1.42 a	0.28 a	0.17 a	0.33 a	20 a	67 a
.50 Tr .50 FA-BBSES	0.06 a	3.45 b	0.20 a	0.15 a	0.28 a	30 b	120 b
.50 Sa .50 FA-MOSES	0.08 a	2.03 a	0.23 a	0.15 a	0.32 a	27 a	60 a
.50 Sa .50 FA-BBSES	0.07 a	3.87 a	0.20 a	0.18 a	0.36 a	23 a	117 a
.50 Sp .50 FA-MOSES	0.09 a	1.05 a	0.14 a	0.22 a	0.35 a	18 a	47 a
.50 Sp .50 FA-BBSES	0.07 a	2.47 b	0.15 a	0.21 a	0.44 b	15 a	100 b

Table 10, continued

	P	Ca	Mg	K	Na	Zn	Mn
	Percent					ppm	
1.00 Troup	0.18 a	0.56 a	0.11 a	0.30 a	0.75 a	45 b	110 a
.75 Tr .25 Sp	0.12 bc	0.38 b	0.14 a	0.23 a	0.40 bc	43 b	93 a
.50 Tr .50 Sp	0.14 b	0.29 bc	0.13 a	0.28 a	0.39 bc	58 a	83 a
.25 Tr .75 Sp	0.11 bc	0.15 cd	0.13 a	0.32 a	0.34 c	45 b	107 a
1.00 Spoil	0.10 c	0.08 d	0.11 a	0.36 a	0.46 b	32 b	137 a

*Values in each group followed by the same letter are not significantly different at the 95% level of confidence.

significantly higher levels of calcium in fly ash-BBSES.

Root tissue of seedlings grown in mixtures of Troup soil and mine spoil showed significantly higher levels of calcium as the Troup soil fraction of the treatments increased (Table 10). This was difficult to account for inasmuch as the extractable soil calcium increased significantly as the mine spoil fraction of the mixtures increased (Tables 6 and 7).

Dead Seedlings

A comparison of the nutrient levels present in needles and roots of seedlings which died during the course of the growing season with nutrient levels of seedlings from corresponding treatments which survived failed to give any clear indication that a nutrient deficiency or toxicity was the direct cause of the mortality. In six of the seven treatments which experienced seedling mortality, needle phosphorus levels were significantly higher in dead seedlings than in live ones (Table 11). This was probably due to the fact that the seedlings which died did so fairly quickly and consequently retained their initial needle phosphorus content. Likewise, since these treatments were generally deficient in available phosphorus, seedlings which survived were unable to maintain their previous phosphorus levels.

In six of the seven treatments experiencing seedling mortality, sodium concentrations were significantly lower in needles of dead seedlings than in needles of live seedlings. As in the case of phosphorus, this was probably due to the dead seedlings having

Table 11. Comparison of Mean Needle and Root Nutrient Levels of Dead and Live Seedlings.

	P	Ca	Mg	K	Na	Zn	Mn
NEEDLES	---Percent---					---ppm---	
1.00 FA-MOSES							
LIVE	0.09*	0.08	0.12	0.70	0.44*	30	63
DEAD	0.27*	0.15	0.12	0.72	0.09*	36	140
.50 Tr .50 FA-MOSES							
LIVE	0.09*	0.11	0.15	0.67	0.32*	33*	60
DEAD	0.28*	0.16	0.14	0.94	0.10*	55*	150
.25 Sa .75 FA-MOSES							
LIVE	0.08	0.10	0.13	0.68	0.28*	22	50*
DEAD	0.21	0.10	0.10	0.69	0.06*	50	130*
.25 Sp .75 FA-MOSES							
LIVE	0.10*	0.08	0.11	0.90	0.27*	28	77*
DEAD	0.27*	0.21	0.13	0.85	0.10*	45	202*
.50 Tr .50 FA-BBSES							
LIVE	0.08*	0.08	0.14	0.94*	2.44*	58	70
DEAD	0.24*	0.13	0.12	0.75*	0.08*	44	221
.50 Sa .50 FA-BBSES							
LIVE	0.08*	0.07	0.12	0.90	2.45*	65	97
DEAD	0.26*	0.13	0.11	0.78	0.07*	45	218
.50 Sp .50 FA-BBSES							
LIVE	0.08*	0.09*	0.12	1.16*	1.71	58*	67*
DEAD	0.28*	0.17*	0.12	0.73*	0.08	42*	177*

Table 11, continued

	P	Ca	Mg	K	Na	Zn	Mn
ROOTS	----------Percent----------					----ppm----	
1.00 FA-MOSES							
LIVE	0.09	2.22	0.22*	0.11	0.41*	15	53
DEAD	0.11	2.47	0.09*	0.20	0.28*	20	64
.50 Tr .50 FA-MOSES							
LIVE	0.10	1.42	0.28*	0.17*	0.33*	20	67
DEAD	0.09	1.55	0.14*	0.04*	0.06*	15	60
.25 Sa .75 FA-MOSES							
LIVE	0.11	2.53	0.26	0.25	0.42	28	63
DEAD	0.10	1.66	0.10	0.22	0.20	18	88
.25 Sp .75 FA-MOSES							
LIVE	0.09	1.57	0.15*	0.20	0.34*	18	53
DEAD	0.09	1.63	0.09*	0.15	0.11*	21	60
.50 Tr .50 FA-BBSES							
LIVE	0.06	3.45	0.20	0.15	0.28	30	120
DEAD	0.09	2.91	0.13	0.15	0.24	32	77
.50 Sa .50 FA-BBSES							
LIVE	0.07	3.87	0.20*	0.18	0.36	23	117
DEAD	0.10	2.42	0.11*	0.20	0.28	22	70
.50 Sp .50 FA-BBSES							
LIVE	0.07*	2.47	0.15*	0.21	0.44*	15	100
DEAD	0.11*	2.17	0.10*	0.22	0.17*	31	78

*A pair of values followed by an asterisk (*) denotes that they are significantly different at the 95% level of confidence.

expired before excessive amounts of sodium could be absorbed from the soil solution and translocated to the needles. Seedlings which survived in these treatments, particularly those containing fly ash-BBSES, were exposed to high sodium levels in the soil solution and were able to absorb large quantities. This would, therefore, be another indication that the seedlings which died were never able to become fully established before death.

Consequently, the direct cause of the seedling mortality could not be narrowed to any particular nutrient deficiency or toxicity. Seedlings which died were most likely unable to adjust to the highly alkaline environment of the soil:fly ash mixtures. The very high levels of free salts indicated by the high percent base saturation probably created osmotic pressure problems. Although there were differences in tissue nutrient levels between live and dead seedlings, these were probably more symptomatic than causal.

CONCLUSIONS

The use of lignite fly ash as a soil amendment could be a valuable application for a waste material which is currently disposed of at a net cost of millions of dollars annually. The results of this study, however, clearly indicated that there are significant problems involved in such a use. Various application rates of lignite fly ash from the Monticello Steam Electric Station (MOSES) at Mt. Pleasant, Texas, and the Big Brown Steam Electric Station (BBSES) at Fairfield, Texas, to three different soil materials (sandy soil of the Troup series, sandy loam soil of the Sacul series, and a sandy clay loam mine spoil) resulted in mixtures which were generally hostile to the survival and growth of one-year-old loblolly pine (*Pinus taeda* L.) seedlings.

During the six months that the seedlings were exposed to the various treatments, survival was 87% in fly ash-MOSES amended soils, 34% in fly ash-BBSES amended soils, and 100% in controls containing no fly ash. Height growth of the seedlings was also adversely affected by fly ash, with fly ash-BBSES having the most detrimental effect. Nearly all seedlings grown in fly ash amended soils were declining at the end of the growing period and additional mortality could have been expected.

The characteristic of fly ash from both MOSES and BBSES which caused most of the adverse effects observed was the relatively large quantities of free salts, particularly those of calcium, which it contained. High salt concentrations in mixtures of soil and fly ash resulted in highly alkaline reactions and low levels of extractable phosphorus. Conditions such as these were not conducive to the survival or growth of loblolly pine.

Although nitrogen was quite deficient in pure fly ash, treatments containing 25% fly ash still had nitrogen levels which exceeded the minimums established by Fowells and Krauss (1959). Magnesium, potassium, and sodium were present in very low to moderate amounts in fly ash from both MOSES and BBSES. Sodium, however, appeared to be an important factor in the soil solution inasmuch as seedling needles accumulated much higher levels of it in fly ash amended treatments. The small but highly soluble sodium fraction must have also played a role in elevating pH levels above 9 in the pure fly ash and in many fly ash amended soils. Zinc and manganese were present in small amounts and did not appear to be important factors. The cation-exchange capacity of fly ash was found to be quite low and incorporations of fly ash into soils resulted in a decrease in C.E.C.

Fly ash-BBSES was shown to contain considerably greater quantities of soluble calcium and was significantly more alkaline than fly ash-MOSES. Both fly ashes had a silt loam texture and would theoretically improve both coarse and very fine textured soils. The cementitious properties of fly ash-BBSES in particular would undoubtedly preclude any such use, however.

The mine spoil used in this study was found to be an adequate soil for the growth of loblolly pine. Nearly all of the plant nutrients were present in greater quantities in the mine spoil than in either the Troup or Sacul soils.

It must be concluded that neither fly ash-MOSES nor fly ash-BBSES proved to be acceptable soil amendments for the growth of loblolly pine at the levels of applications used in this study. Growth and survival were reduced where seedlings grew in fly ash amended soils. Analysis of soil:fly ash-MOSES mixture containing as little as 25% fly ash revealed conditions not conducive to the perpetuation of loblolly pine. It is entirely possible that other plant species could perform adequately in soils amended with lignite fly ash or that smaller additions of fly ash than were used in this study would not have such adverse effects. Likewise, applications of lignite fly ash to soils considerably more acidic than those used in this study could prove more favorable to plant growth. In light of the findings of this research, however, it is clear that careful consideration must be given to the effects of lignite fly ash on the physical and chemical properties of soils. Indiscriminate use of lignite fly ash as a soil amendment could easily create more problems than it solves.

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APPENDIX A

SEEDLING GROWTH, SOILS AND TISSUE ANALYSES

Table 1. Total Seedling Height Growth of Loblolly Pine Seedlings Grown in Soil and Soil:Fly Ash Mixtures.

TREATMENT	POT NO.	SEEDLING NO.	BEGINNING HEIGHT (in)	END HEIGHT (in)
1.00 Troup	1	1	20.50	28.30
		2	12.25	17.00
		3	6.25	13.12
	2	1	7.88	14.00
		2	9.75	16.12
		3	19.50	24.88
	3	1	13.25	25.00
		2	6.88	11.25
		3	10.75	17.88
.75 Tr .25 FA-MOSES	1	1	13.00	17.75
		2	8.00	13.75
		3	15.88	19.12
	2	1	6.50	10.75
		2	11.75	15.12
		3	11.50	18.88
	3	1	6.62	11.38
		2	8.12	13.00
		3	13.00	19.25
.50 Tr .50 FA-MOSES	1	1	5.62	10.50
		2	11.62	17.38
		3	7.62	13.25
	2	1	10.50	18.25
		2	14.25	17.38
		3	9.38	12.88
	3	1	10.88	14.25
		2*	--	--
		3*	--	--
.25 Tr .75 FA-MOSES	1	1	10.50	16.00
		2	13.62	18.00
		3	10.62	14.00
	2	1	8.25	10.50
		2	12.50	13.25
		3	10.75	14.75

Table 1, continued

TREATMENT	POT NO.	SEEDLING NO.	BEGINNING HEIGHT (in)	END HEIGHT (in)
	3	1	6.00	9.50
		2	10.88	16.12
		3	9.38	15.50
1.00 Sacul	1	1	10.50	16.25
		2	14.75	21.88
		3	13.25	20.25
	2	1	15.12	23.50
		2	7.38	14.75
		3	14.62	21.00
	3	1	7.88	15.75
		2	6.50	13.00
		3	16.00	24.50
.75 Sa .25 FA-MOSES	1	1	11.88	15.88
		2	12.00	18.62
		3	10.38	13.50
	2	1	10.25	15.62
		2	13.00	19.12
		3	16.38	23.62
	3	1	15.00	20.50
		2	14.25	19.25
		3	6.75	10.38
.50 Sa .50 FA-MOSES	1	1	10.25	10.75
		2	9.75	13.75
		3	9.12	12.12
	2	1	13.25	12.88
		2	10.00	13.00
		3	11.25	13.38
	3	1	9.00	11.38
		2	12.50	17.75
		3	8.12	16.38

Table 1, continued

TREATMENT	POT NO.	SEEDLING NO.	BEGINNING HEIGHT (in)	END HEIGHT (in)
.25 Sa .75 FA-MOSES	1	1	20.12	22.12
		2	9.38	12.12
		3	10.25	14.88
	2	1	14.38	20.00
		2	7.75	13.12
		3	8.25	12.12
	3	1	12.38	16.00
		2	10.62	11.50
		3	13.50	18.38
1.00 Spoil	1	1	9.25	12.75
		2	12.00	12.88
		3	12.12	18.62
	2	1	19.75	23.12
		2	14.00	17.62
		3	6.38	10.38
	3	1	7.88	16.88
		2	10.50	21.12
		3	10.12	18.38
.75 Sp .25 FA-MOSES	1	1	16.62	20.50
		2	11.12	14.12
		3	6.00	9.25
	2	1	10.50	14.25
		2	7.12	14.12
		3	13.62	20.00
	3	1	6.38	8.75
		2	7.50	14.88
		3	13.38	21.25
.50 Sp .50 FA-MOSES	1	1	19.25	20.75
		2	9.25	13.75
		3	8.75	11.88

Table 1, continued

TREATMENT	POT NO.	SEEDLING NO.	BEGINNING HEIGHT (in)	END HEIGHT (in)
	2	1	13.25	16.12
		2	9.25	13.88
		3	7.00	12.12
	3	1	10.88	16.25
		2	13.38	19.00
		3	8.38	12.50
.25 Sp .75 FA-MOSES	1	1	14.75	17.38
		2	5.25	7.12
		3*	--	--
	2	1	11.12	14.00
		2	6.25	9.38
		3*	--	--
	3	1	6.25	11.12
		2	13.12	15.50
		3	9.00	12.12
1.00 FA-MOSES	1	1	11.25	12.75
		2	5.50	6.38
		3	14.25	17.62
	2	1	9.50	12.50
		2	5.25	9.50
		3*	--	--
	3	1	8.00	10.25
		2	10.00	13.62
		3	15.62	18.25
.50 Tr .50 FA-BBSES	1	1	12.75	13.75
		2	10.12	15.62
		3*	--	--
	2	1*	--	--
		2*	--	--
		3*	--	--
	3	1	6.50	8.38
		2	7.50	7.50
		3*	--	--

Table 1, continued

TREATMENT	POT NO.	SEEDLING NO.	BEGINNING HEIGHT (in)	END HEIGHT (in)
.50 Sa .50 FA-BBSES	1	1	8.12	9.12
		2*	--	--
		3*	--	--
	2	1	15.75	18.38
		2	8.88	12.50
		3*	--	--
	3	1	9.50	17.00
		2*	--	--
		3*	--	--
.50 Sp .50 FA-BBSES	1	1	8.38	11.25
		2*	--	--
		3*	--	--
	2	1*	--	--
		2	8.50	10.25
		3	17.12	19.12
	3	1	7.25	11.12
		2	19.75	19.50
		3	10.00	11.25
.75 Tr .25 Sp	1	1	7.50	15.00
		2	10.75	16.50
		3	10.62	19.75
	2	1	8.75	15.12
		2	10.00	15.88
		3	14.62	21.25
	3	1	9.00	14.75
		2	6.00	12.25
		3	14.12	23.25
.50 Tr .50 Sp	1	1	8.12	10.88
		2	13.38	18.00
		3	18.88	25.50
	2	1	14.25	21.38
		2	14.50	20.75
		3	7.50	14.25

Table 1, continued

TREATMENT	POT NO.	SEEDLING NO.	BEGINNING HEIGHT (in)	END HEIGHT (in)
	3	1	11.00	16.38
		2	11.00	16.25
		3	17.38	18.75
.25 Tr .75 Sp	1	1	8.50	15.25
		2	17.50	21.00
		3	8.62	17.00
	2	1	12.12	19.62
		2	8.62	17.50
		3	13.25	23.12
	3	1	12.88	18.00
		2	5.75	11.00
		3	20.25	24.88

*Asterisk denotes seedlings which did not survive.

Table 2. Analyses of Soils, Fly Ash, and Soils:Fly Ash Mixtures.

	POT NO.	pH	%N	P	Ca	Mg	K	Na	Zn	Mn	C.E.C.	% Base Sat.
							---------------ppm----------------				meq./100 g	
1.00 Troup	1	6.9	0.0376	24	638	22	19	44	2	5	3.15	114.6
	2	7.3	0.0376	29	728	22	18	39	1	5	3.45	117.1
	3	7.5	0.0376	21	652	20	21	52	2	5	4.00	92.8
.75 Tr .25 FA-MOSES	1	8.3	0.0293	1	1200	62	21	32	1	2	2.75	244.0
	2	8.3	0.0293	2	1200	68	20	28	2	2	2.65	254.3
	3	8.5	0.0237	1	1050	55	19	32	1	2	2.05	287.8
.50 Tr .50 FA-MOSES	1	8.9	0.0125	2	1500	80	24	36	1	5	1.85	453.5
	2	8.8	0.0181	1	1500	80	16	27	1	5	1.95	427.2
	3	8.8	0.0181	1	1575	80	18	21	1	2	2.05	423.9
.25 Tr .75 FA-MOSES	1	9.8	0.0098	1	2850	70	15	33	2	2	1.80	833.9
	2	8.9	0.0070	1	2025	68	16	45	2	2	1.60	683.1
	3	10.3	0.0098	1	3000	70	22	40	2	5	1.75	903.4
1.00 Sacul	1	7.1	0.0683	7	638	65	38	112	2	8	4.80	90.0
	2	7.1	0.0627	7	622	62	45	122	2	10	4.65	92.0
	3	7.2	0.0599	6	615	62	39	110	2	5	4.55	91.9
.75 Sa .25 FA-MOSES	1	8.2	0.0376	1	1200	75	21	30	1	2	3.25	209.2
	2	8.2	0.0404	1	1200	72	26	33	1	2	3.20	212.8
	3	8.3	0.0348	1	1275	70	30	40	2	2	3.00	240.3
.50 Sa .50 FA-MOSES	1	8.7	0.0237	1	1650	82	25	32	1	2	2.30	397.0
	2	8.7	0.0209	1	1650	85	19	32	1	2	2.15	425.6
	3	8.7	0.0237	1	1800	105	21	46	1	2	2.10	482.4

Table 2, continued

	POT NO.	pH	%N	P	Ca	Mg	K	Na	Zn	Mn	C.E.C.	% Base Sat.
				ppm							meq./100 g	
.25 Sa .75 FA-MOSES	1	10.0	0.0098	1	2625	105	28	58	1	2	1.80	795.6
	2	9.3	0.0139	1	2100	90	16	34	1	2	1.85	618.4
	3	10.3	0.0139	1	3000	92	22	32	1	2	2.10	760.5
1.00 Spoil	1	5.7	0.0432	100	1500	538	155	207	1	2	14.05	94.5
	2	5.6	0.0460	100	1500	562	160	195	2	2	13.20	101.8
	3	5.7	0.0460	100	1425	575	175	360	2	5	13.20	105.5
.75 Sp .25 FA-MOSES	1	8.3	0.0306	2	2700	325	110	138	1	2	12.00	142.4
	2	8.3	0.0362	1	2775	288	110	140	2	2	12.00	143.1
	3	8.3	0.0306	1	2700	300	115	138	1	1	11.40	148.2
.50 Sp .50 FA-MOSES	1	8.7	0.0237	1	2550	168	72	100	1	1	8.40	175.7
	2	8.6	0.0209	1	2575	162	67	84	1	2	8.40	169.9
	3	8.5	0.0195	1	2400	162	70	74	2	1	8.40	164.9
.25 Sp .75 FA-MOSES	1	9.0	0.0125	1	2475	122	36	57	1	2	4.95	277.6
	2	9.1	0.0125	1	2700	132	48	76	1	1	4.90	307.1
	3	8.9	0.0111	1	2550	140	42	62	2	1	4.95	288.9
1.00 FA-MOSES	1	10.9	0.0014	1	3975	90	17	32	1	2	1.95	1067.2
	2	10.5	0.0014	1	2625	95	14	30	1	2	1.80	782.2
	3	10.3	0.0014	1	2400	100	18	38	2	2	1.70	767.6
.50 Tr .50 FA-BBSES	1	10.7	0.0111	1	6000	218	19	39	1	2	3.35	956.4
	2	11.0	0.0139	2	7125	228	15	24	2	2	3.25	1158.8
	3	10.9	0.0139	2	6675	238	17	33	1	2	3.60	987.2

Table 2, continued

	POT NO.	pH	%N	P	Ca	Mg	K	Na	Zn	Mn	C.E.C.	% Base Sat.
				ppm							meq./100 g	
.50 Sa .50 FA-BBSES	1	10.6	0.0223	3	7125	255	16	30	1	5	3.90	972.1
	2	10.6	0.0223	3	5850	245	21	54	1	2	4.20	751.7
	3	10.5	0.0195	3	6900	240	24	42	1	5	3.90	942.1
.50 Sp .50 FA-BBSES	1	10.3	0.0195	2	7500	198	68	90	1	2	10.95	362.6
	2	10.3	0.0251	1	7050	192	64	84	1	2	10.55	354.3
	3	10.2	0.0223	1	6825	200	60	76	1	2	10.75	337.4
.75 Tr .25 Sp	1	7.1	0.0306	40	645	120	54	123	2	2	4.80	101.9
	2	7.5	0.0306	36	690	102	48	105	2	1	4.70	103.8
	3	7.5	0.0334	40	735	118	57	135	2	2	5.20	103.8
.50 Tr .50 Sp	1	6.7	0.0376	65	1125	275	87	136	2	2	7.80	111.8
	2	6.5	0.0362	70	1050	275	100	202	2	1	7.30	118.9
	3	6.6	0.0376	65	1012	262	102	195	1	2	7.30	114.4
.25 Tr .75 Sp	1	6.3	0.0432	90	1162	362	110	172	2	2	10.50	93.9
	2	6.3	0.0460	90	1238	375	120	195	2	2	10.80	96.9
	3	6.3	0.0418	90	1125	375	115	172	2	2	10.70	91.4
UNWEATHERED												
FLY ASH-MOSES		11.7	0.0014	2	3900	200	20	36	1	15	0.90	2375.6
FLY ASH-BBSES		12.3	0.0028	8	13050	462	22	86	1	32	1.60	4345.6

Table 3. Tissue Analysis--<u>Live</u> <u>Seedling</u> <u>Needles</u>

	POT NO.	P	Ca	Mg	K	Na	Zn	Mn
		-----------Percent--------					---ppm---	
1.00 Troup	1	0.11	0.09	0.10	0.58	0.32	30	40
	2	0.11	0.14	0.12	0.60	0.28	30	80
	3	0.12	0.09	0.11	0.63	0.35	20	90
.75 Tr .25 FA-MOSES	1	0.09	0.14	0.17	0.72	0.18	35	100
	2	0.09	0.08	0.15	0.66	0.27	25	30
	3	0.08	0.12	0.17	0.57	0.26	30	80
.50 Tr .50 FA-MOSES	1	0.08	0.10	0.15	0.59	0.32	30	70
	2	0.11	0.16	0.16	0.90	0.32	35	80
	3	0.09	0.08	0.15	0.51	0.32	35	30
.25 Tr .75 FA-MOSES	1	0.07	0.12	0.13	0.90	0.18	30	60
	2	0.08	0.09	0.13	1.08	0.24	35	60
	3	0.07	0.09	0.13	0.90	0.24	35	70
1.00 Sacul	1	0.12	0.10	0.11	0.69	0.22	25	90
	2	0.13	0.09	0.12	0.78	0.20	30	100
	3	0.13	0.08	0.09	0.69	0.26	20	70
.75 Sa .25 FA-MOSES	1	0.08	0.14	0.15	0.84	0.28	20	90
	2	0.09	0.11	0.15	0.75	0.27	20	50
	3	0.09	0.12	0.15	0.69	0.29	25	50
.50 Sa .50 FA-MOSES	1	0.09	0.13	0.14	0.60	0.29	30	90
	2	0.10	0.15	0.13	0.66	0.28	30	70
	3	0.09	0.15	0.19	0.72	0.28	25	40
.25 Sa .75 FA-MOSES	1	0.09	0.10	0.13	0.72	0.28	20	50
	2	0.08	0.11	0.13	0.66	0.27	25	60
	3	0.08	0.10	0.12	0.66	0.29	20	40
1.00 Spoil	1	0.09	0.06	0.16	0.90	0.18	50	140
	2	0.10	0.14	0.13	0.72	0.11	40	140
	3	0.08	0.06	0.16	0.87	0.16	45	150
.75 Sp .25 FA-MOSES	1	0.09	0.09	0.16	1.02	0.18	35	50
	2	0.10	0.07	0.15	0.87	0.19	30	40
	3	0.09	0.09	0.17	1.11	0.21	25	50

Table 3, continued

	POT NO.	P	Ca	Mg	K	Na	Zn	Mn
		-----------Percent----------					---ppm---	
.50 Sp .50 FA-MOSES	1	0.12	0.06	0.13	1.08	0.18	35	90
	2	0.08	0.10	0.14	0.99	0.18	30	100
	3	0.10	0.08	0.15	1.08	0.25	30	70
.25 Sp .75 FA-MOSES	1	0.13	0.09	0.12	0.84	0.28	35	70
	2	0.08	0.06	0.10	0.96	0.29	20	70
	3	0.10	0.09	0.11	0.90	0.24	30	90
1.00 FA-MOSES	1	0.09	0.06	0.10	0.78	0.52	25	50
	2	0.08	0.08	0.13	0.78	0.51	25	70
	3	0.09	0.10	0.13	0.54	0.28	40	70
.50 Tr .50 FA-BBSES	1	0.06	0.07	0.13	0.99	2.43	50	50
	2*	--	--	--	--	--	--	--
	3	0.10	0.08	0.14	0.90	2.46	65	90
.50 Sa .50 FA-BBSES	1	0.10	0.09	0.14	0.81	2.37	80	180
	2	0.07	0.08	0.12	0.96	2.46	60	70
	3	0.06	0.04	0.10	0.93	2.52	55	40
.50 Sp .50 FA-BBSES	1	0.07	0.08	0.10	1.29	2.34	50	40
	2	0.07	0.10	0.13	0.99	2.34	65	80
	3	0.10	0.08	0.13	1.20	0.46	60	80
.75 Tr .25 Sp	1	0.13	0.06	0.12	0.78	0.14	30	130
	2	0.13	0.06	0.11	0.75	0.16	45	190
	3	0.13	0.06	0.11	0.87	0.16	30	110
.50 Tr .50 Sp	1	0.15	0.07	0.12	0.96	0.14	45	70
	2	0.13	0.06	0.11	1.02	0.14	40	120
	3	0.22	0.05	0.10	1.02	0.14	40	160
.25 Tr .75 Sp	1	0.11	0.08	0.11	0.84	0.15	30	140
	2	0.11	0.06	0.15	0.87	0.16	40	110
	3	0.11	0.06	0.11	1.02	0.22	40	120

*No surviving seedlings.

Table 4. Tissue Analysis--<u>Live</u> <u>Seedling</u> <u>Roots</u>

	POT NO.	P	Ca	Mg	K	Na	Zn	Mn
		----------Percent-----------					---ppm---	
1.00 Troup	1	0.16	0.58	0.11	0.35	0.81	50	120
	2	0.18	0.59	0.12	0.24	0.72	40	110
	3	0.19	0.52	0.10	0.32	0.72	45	100
.75 Tr .25 FA-MOSES	1	0.09	1.45	0.26	0.22	0.50	25	70
	2	0.09	1.85	0.24	0.22	0.33	25	120
	3	0.10	1.20	0.26	0.20	0.34	20	70
.50 Tr .50 FA-MOSES	1	0.08	1.10	0.26	0.19	0.34	20	60
	2	0.08	1.25	0.26	0.17	0.33	20	60
	3	0.13	1.90	0.32	0.14	0.33	20	80
.25 Tr .75 FA-MOSES	1	0.07	1.10	0.22	0.23	0.34	20	30
	2	0.08	1.45	0.19	0.20	0.40	15	30
	3	0.08	1.35	0.20	0.23	0.39	20	50
1.00 Sacul	1	0.16	0.24	0.11	0.35	0.51	45	70
	2	0.16	0.29	0.11	0.39	0.52	50	70
	3	0.15	0.32	0.11	0.28	0.50	50	60
.75 Sa .25 FA-MOSES	1	0.08	1.70	0.24	0.29	0.38	20	50
	2	0.08	2.30	0.25	0.16	0.33	20	50
	3	0.08	2.10	0.23	0.20	0.33	20	80
.50 Sa .50 FA-MOSES	1	0.08	1.40	0.21	0.13	0.33	30	60
	2	0.09	2.50	0.22	0.16	0.30	20	60
	3	0.07	2.20	0.26	0.17	0.32	30	60
.25 Sa .75 FA-MOSES	1	0.08	1.50	0.20	0.16	0.26	15	30
	2	0.16	4.20	0.37	0.40	0.62	50	110
	3	0.08	1.90	0.21	0.19	0.39	20	50
1.00 Spoil	1	0.10	0.13	0.12	0.37	0.46	35	160
	2	0.10	0.05	0.09	0.37	0.45	30	130
	3	0.09	0.06	0.11	0.35	0.48	30	120
.75 Sp .25 FA-MOSES	1	0.09	0.90	0.19	0.17	0.50	15	80
	2	0.10	0.96	0.20	0.15	0.50	20	100
	3	0.08	1.00	0.21	0.29	0.34	30	80

Table 4, continued

	POT NO.	P	Ca	Mg	K	Na	Zn	Mn
		----------Percent-----------					---ppm---	
.50 Sp .50 FA-MOSES	1	0.09	1.05	0.13	0.19	0.36	20	40
	2	0.09	1.10	0.15	0.23	0.36	15	50
	3	0.08	1.00	0.13	0.25	0.34	20	50
.25 Sp .75 FA-MOSES	1	0.09	1.30	0.13	0.19	0.36	15	50
	2	0.08	1.85	0.15	0.21	0.33	20	60
	3	0.09	1.55	0.16	0.19	0.33	20	50
1.00 FA-MOSES	1	0.10	1.75	0.20	0.13	0.45	15	50
	2	0.08	2.80	0.22	0.10	0.36	15	60
	3	0.09	2.10	0.23	0.11	0.42	15	50
.50 Tr .50 FA-BBSES	1	0.05	3.70	0.20	0.14	0.30	30	120
	2*	--	--	--	--	--	--	--
	3	0.07	3.20	0.20	0.16	0.25	30	120
.50 Sa .50 FA-BBSES	1	0.08	6.00	0.17	0.10	0.22	20	100
	2	0.06	4.00	0.21	0.20	0.28	30	160
	3	0.06	1.60	0.21	0.24	0.58	20	90
.50 Sp .50 FA-BBSES	1	0.06	2.50	0.14	0.20	0.45	15	90
	2	0.07	3.10	0.18	0.20	0.42	20	120
	3	0.09	1.80	0.14	0.23	0.44	10	90
.75 Tr .25 Sp	1	0.14	0.22	0.13	0.32	0.45	50	120
	2	0.11	0.45	0.14	0.17	0.36	35	80
	3	0.12	0.47	0.15	0.21	0.38	45	80
.50 Tr .50 Sp	1	0.15	0.29	0.12	0.23	0.39	65	80
	2	0.12	0.21	0.12	0.28	0.34	50	100
	3	0.14	0.38	0.15	0.33	0.44	60	70
.25 Tr .75 Sp	1	0.12	0.14	0.12	0.32	0.36	50	90
	2	0.09	0.18	0.14	0.28	0.34	45	140
	3	0.11	0.14	0.13	0.35	0.32	40	90

*No surviving seedlings.

Table 5. Tissue Analysis--Dead Seedling Needles

	SEEDLING NO.	P	Ca	Mg	K	Na	Zn	Mn
		----------Percent----------					---ppm---	
.50 Tr .50 FA-MOSES	1	0.22	0.13	0.11	0.84	0.08	50	110
	2	0.33	0.20	0.18	1.05	0.12	60	190
.25 Sa .75 FA-MOSES	1	0.15	0.12	0.11	0.63	0.06	35	120
	2	0.27	0.08	0.09	0.75	0.07	65	140
.25 Sp .75 FA-MOSES	1	0.14	0.38	0.15	0.69	0.08	35	170
	2	0.27	0.21	0.11	0.99	0.08	30	170
	3	0.40	0.16	0.13	0.99	0.10	50	140
	4	0.25	0.16	0.13	0.84	0.06	40	290
	5	0.27	0.15	0.14	0.75	0.19	70	240
1.00 FA-MOSES	1	0.22	0.21	0.10	0.75	0.08	30	100
	2	0.25	0.13	0.12	0.81	0.08	40	140
	3	0.30	0.10	0.14	0.53	0.08	40	240
	4	0.30	0.15	0.12	0.81	0.11	35	80
.50 Tr .50 FA-BBSES	1	0.22	0.24	0.13	0.78	0.04	40	160
	2	0.23	0.12	0.11	0.72	0.06	50	180
	3	0.26	0.14	0.10	0.75	0.07	40	130
	4	0.24	0.17	0.12	0.69	0.06	40	150
	5	0.27	0.09	0.12	0.87	0.08	40	100
	6	0.22	0.12	0.11	0.66	0.07	50	360
	7	0.16	0.10	0.12	0.72	0.07	35	370
	8	0.29	0.08	0.13	0.87	0.07	35	320
	9	0.28	0.14	0.16	0.72	0.16	65	220
.50 Sa .50 FA-BBSES	1	0.14	0.11	0.10	0.63	0.05	40	210
	2	0.21	0.25	0.14	0.84	0.05	30	100
	3	0.23	0.11	0.10	0.58	0.06	35	120
	4	0.29	0.21	0.09	0.90	0.04	30	110
	5	0.27	0.11	0.14	0.81	0.08	40	140
	6	0.26	0.08	0.09	0.78	0.07	75	230
	7	0.24	0.09	0.10	0.72	0.11	55	370
	8	0.28	0.12	0.10	0.78	0.07	45	500
	9	0.28	0.12	0.10	0.90	0.05	40	120
	10	0.35	0.10	0.13	0.87	0.10	65	300
	11	0.35	0.10	0.08	0.81	0.06	40	200

Table 5, continued

	SEEDLING NO.	P	Ca	Mg	K	Na	Zn	Mn
		---------Percent-----------					---ppm---	
.50 Sp .50 FA-BBSES	1	0.24	0.21	0.11	0.72	0.06	35	170
	2	0.27	0.10	0.11	0.75	0.06	35	110
	3	0.28	0.14	0.15	0.75	0.10	60	180
	4	0.25	0.16	0.11	0.72	0.08	40	190
	5	0.27	0.11	0.11	0.75	0.14	45	230
	6	0.34	0.24	0.12	0.87	0.07	40	160
	7	0.32	0.25	0.13	0.56	0.08	40	200

Table 6. Tissue Analysis--Dead Seedling Roots

	SEEDLING NO.	P	Ca	Mg	K	Na	Zn	Mn
		----------Percent----------					---ppm---	
.50 Tr .50 FA-MOSES	1	0.10	1.65	0.11	0.05	0.06	15	40
	2	0.08	1.45	0.18	0.03	0.06	15	80
.25 Sa .75 FA-MOSES	1	0.11	1.97	0.12	0.27	0.22	20	125
	2	0.10	1.35	0.09	0.16	0.19	15	50
.25 Sp .75 FA-MOSES	1	0.12	1.88	0.11	0.20	0.17	30	85
	2	0.09	1.25	0.09	0.22	0.10	25	90
	3	0.12	1.45	0.09	0.30	0.15	20	40
	4	0.06	1.65	0.06	0.04	0.06	15	40
	5	0.05	1.91	0.09	0.03	0.06	15	45
1.00 FA-MOSES	1	0.12	2.61	0.13	0.22	0.28	20	95
	2	0.13	2.49	0.08	0.23	0.36	25	80
	3	0.08	2.79	0.09	0.11	0.21	15	50
	4	0.11	2.00	0.07	0.22	0.28	20	30
.50 Tr .50 FA-BBSES	1	0.13	2.30	0.20	0.22	0.29	20	90
	2	0.14	2.65	0.18	0.22	0.27	25	120
	3	0.09	3.30	0.09	0.20	0.33	20	80
	4	0.08	1.65	0.10	0.17	0.24	35	60
	5	0.08	3.90	0.10	0.08	0.22	20	80
	6	0.06	4.00	0.10	0.14	0.25	95	60
	7	0.07	1.40	0.09	0.17	0.21	25	45
	8	0.08	1.63	0.11	0.12	0.27	25	45
	9	0.08	5.40	0.21	0.03	0.06	25	110
.50 Sa .50 FA-BBSES	1	0.10	2.90	0.13	0.33	0.36	15	100
	2	0.15	2.91	0.18	0.22	0.41	30	100
	3	0.09	1.70	0.10	0.23	0.24	20	70
	4	0.09	1.35	0.12	0.15	0.20	20	70
	5	0.09	2.44	0.10	0.16	0.25	20	70
	6	0.10	1.70	0.08	0.29	0.27	20	60
	7	0.06	2.70	0.09	0.08	0.22	30	60
	8	0.08	3.52	0.10	0.09	0.28	20	55
	9	0.16	2.45	0.09	0.26	0.34	20	50
	10	0.08	3.00	0.11	0.11	0.24	35	70
	11	0.09	1.95	0.09	0.23	0.25	15	70

Table 6, continued

	SEEDLING NO.	P	Ca	Mg	K	Na	Zn	Mn
		----------Percent-----------					---ppm---	
.50 Sp .50 FA-BBSES	1	0.11	1.45	0.12	0.28	0.17	30	65
	2	0.11	1.20	0.10	0.26	0.16	20	60
	3	0.14	2.60	0.12	0.26	0.18	25	85
	4	0.12	2.46	0.09	0.28	0.18	25	95
	5	0.10	4.29	0.11	0.07	0.08	70	120
	6	0.14	1.30	0.10	0.28	0.27	20	50
	7	0.08	1.90	0.09	0.09	0.18	25	70

APPENDIX B

ANALYTICAL PROCEDURES

Kjeldahl Determination of Total Nitrogen

Reagents

Digestion mixture - 3 parts copper sulfate and 1 part selenium metal mixed with anhydrous sodium sulfate in ratio of 5:1

Concentrated sulfuric acid

Saturated (40%) sodium hydroxide

Saturated (4%) boric acid

Indicator - 1.0 g brom cresol green and 0.2 g methyl red dissolved in 100 ml of 95% alcohol. Titrate to brown midpoint with 0.1 N sodium hydroxide.

Approx. 0.1 N hydrochloric acid - dilute 8.1 ml concentrated (36-38%) HCl to 1000 ml with distilled water. Titrate with 0.1 N sodium hydroxide.

Procedure

1. Weigh out on filter paper: 5 g soil sample or 0.5 g tissue sample.
2. Wrap sample in filter paper (low N content) and slide down neck of Kjeldahl flask. Do not spill sample on sides of flask.
3. Add a level teaspoonful of digestion mix and 20 ml of H_2SO_4.
4. Mix gently and digest under hood with low flame for 20 to 30 min.
5. After 30 min. the flame may be increased until the solution boils.
6. With an asbestos glove the flask is shaken at intervals for about 2 hours or until a light gray or straw color appears to indicate the complete destruction of organic matter.
7. Remove from flame and cool
8. While flask is cooling, add about 50 ml of boric acid and 3 drops of indicator solution to a 300 ml Erlenmeyer flask and place flask under the distillation rack with delivery tube extending below the surface of boric acid.

9. Add 300 ml distilled water to Kjeldahl flask.

10. CAREFULLY add 100 ml sodium hydroxide - Make sure NaOH is layering below acid; DO NOT MIX. Add a piece of Mossy zinc; this prevents bumping.

11. Connect flask to distillation rack and place on support over a low flame. Swirl flask to mix solutions.

12. Heat flask slowly until the original volume in the Erlenmeyer flask has approximately doubled.

13. Remove Erlenmeyer flask, shut off distillation rack, and titrate distillate to gray midpoint between red and blue with 0.1 N HCl.

Calculations

$$\%N = \frac{(\text{Volume HCl})\ (\text{Normality})\ (\text{Equivalent weight of N})\ (100)}{(\text{Oven-dry weight of sample})\ (1000)}$$

Note:

A blank should be run with each determination to keep a check on the amount of N in the solutions. This blank is subtracted from the test sample after titration.

The problem of organic N in the Kjeldahl determination can be alleviated somewhat because reducing sugars in soil may convert up to 80 percent of the NO_3 to NH_4. Here is a better procedure for determining total N:

(1) Soil + 10 ml H_2O

(2) 20 ml 5% $KMnO_4$ $NO_2 \longrightarrow NO_3$

(3) 10 ml 50% H_2SO_4

(4) 5 g reduced Fe $NO_3 \longrightarrow NH_4$

(5) Reflux 45 minutes

(6) Proceed with regular Kjeldahl procedure

Determination of Available Phosphorus

Reagents

Extracting solution - Prepare a stock solution of 0.1 N H_2SO_4 by titrating against standard alkali. Dilute convenient volume to 0.002 N (1 ml H_2SO_4 per 18 liters H_2O = 0.002 N) and buffer with 3 g $(NH_4)_2SO_4$ per liter.

Sulfomolybdic acid - Dissolve 25 g ammomium molybdate in 200 ml H_2O at 60°C. Dilute 275 ml concentrated H_2SO_4 to 800 ml. When cool mix both solutions and cool again. Dilute mixture to 1000 ml.

Stannous chloride solution - Dissolve 25 g $SnCl_2$ in 100 ml concentrated HCl. Dilute to 1000 ml. Store in brown bottle and protect from air with a layer of mineral oil.

Standard solution - Dissolve 0.2195 g KH_2PO_4 and dilute to 1000 ml. This contains 50 ppm P. Dilute 50 ml ppm P to 500 ml. This final solution contains 5 ppm.

Procedure

1. Soil - (a) Place 1.0 g soil in 250 ml "E" flask
   (b) Add 100 ml of 0.002 N H_2SO_4.
   (c) Shake 1/2 hour and filter. Do not rinse or add any more solution.

   Tissue - (a) Ash 1-2 g at 480°C. Dissolve in 4 drops of 6 N HCl.
   (b) Dilute to 100 ml volume with H_2O

2. Take 50 ml aliquot.

3. Add 2 ml of sulfomolybdic acid.

4. Add 3 drops of $SnCl_2$.

5. Pour some of the colored solution into a test tube or colorimeter tube

6. Determine intensity of color on colorimeter at 660 mμ.
   The conentration of P in the test solution is determined from a standard curve made up with solutions containing a known amount of P.

Table for Preparing P ppm-standards

Using appropriately labeled 100 ml volumetric flasks, pipette the following amounts of 5-ppm standard solution into each flask and bring the volume to the 100 ml mark with extracting solution. This will give the concentration in the ppm indicated:

add (ml)-	4	8	12	16	32	48	64
to get (ppm)-	0.2	0.4	0.6	0.8	1.6	2.4	3.2

When using 500 ml volumetric flasks, the table becomes:

add (ml)-	20	40	60	80	160	240	320
to get (ppm)-	0.2	0.4	0.6	0.8	1.6	2.4	3.2

Follow parts 2-6 in the procedure section. Plot the values of percent transmission obtained on the colorimeter (660 mμ) with the corresponding concentrations of P in ppm on semi-log graph paper. Plot the values obtained with percent transmission on the log scale and ppm P on the linear scale. The test solutions are compared to the graph.

Determination of Exchangeable Cations Using Ammonium Acetate as Extractant

Reagents

Stock solution - Dilute 114 ml glacial acetic acid with 500 ml water. Slowly add 135 ml of concentrated ammonium hydroxide. Cool and adjust to pH 6.9 with ammonium hydroxide and dilute to 1 liter. This is a 2 N solution.

Extracting solution - Dilute stock solution with equal volume water.

Standard solutions - Na - Dissolve 2.542 g of oven-dried (110°C) NaCl in H_2O. Dilute to 1 liter (1000 ppm); dilute 50 ml of this solution to 500 ml. This is a 100 ppm solution.

K - Dissolve 1.907 g KCl in water and dilute to 1 liter (1000 ppm); dilute 100 ml of this solution to 500 ml. This is a 200 ppm solution.

Ca - Place 2.497 g $CaCO_3$ in a 250 ml beaker, add approximately 30 ml water, and slowly add dilute (1:10) HCl until effervescence ceases and solution becomes clear. Evaporate to approximately 10 ml and dilute to 1 liter with water (1000 ppm); dilute 250 ml of this solution to 500 ml. This is a 500 ppm solution.

or

Dissolve 2.775 g $CaCl_2$ in water and dilute to 1 liter (1000 ppm); dilute 250 ml of this solution to 500 ml. This is a 500 ppm solution.

Mg - Place 1.000 g pure magnesium in a 250 ml beaker; add approximately 30 ml water, and slowly add dilute (1:10) HCl until solution becomes clear. Evaporate to approximately 10 ml and dilute to 1 liter with water (1000 ppm); dilute 250 ml of this solution to 500 ml. This is a 500 ppm solution.

Procedure

1. Soil - (a) Place 10 g of soil in a 500 ml flask.
   - (b) Add 50 ml of extracting solution.
   - (c) Shake 1/2 hour and filter until filtrate is clear. Rinse several times with extracting solution (about 30-40 ml).
   - (d) Dilute filtrate to 100 ml with extracting solution.

   Tissue - (a) Ammonium acetate isnot used for tissue analysis.
   - (b) The HCl solution is run directly on the flame spectrophotometer.
   - (c) In this case the calibrating solutions are made up with HCl.

2. 2 ml of the test solutions are run through the flame spectrophotometer and the percent transmissions are compared to the graphs constructed for the standard solutions in order to determine concentrations in ppm.

Table for Preparing
Na, K, Ca, and Mg ppm Standards

Using appropriately labeled 500 ml volumetric flasks, pipette the following amounts of standard solutions to the appropriate flask and bring the volume in the flasks to the 500 ml mark with extracting solution. This will give the concentration in the ppm indicated:

add <u>100 ppm</u> Na (ml)	0	10	25	50	75
to get (ppm)	0	2	5	10	15
add 200 ppm K (ml)	0	10	25	50	75
to get (ppm)	0	4	10	20	30
add 500 ppm Ca (ml)	0	10	25	50	75
to get (ppm)	0	10	25	50	75
add 500 ppm Mg (ml)	0	10	25	50	75
to get (ppm)	0	10	25	50	75

Determine the percent transmission of the cation standards on the flame spectrophotometer. Plot the obtained percent transmission values with corresponding concentrations in ppm on linear graph paper. Log or semi-log graph paper is not used for these graphs. The procedure is similar to the plotting for phosphorus; percent transmission is plotted over ppm.

MECHANICAL ANALYSIS (BOUYOUCOS METHOD) FOR THE DETERMINATION OF THE PERCENT SAND, SILT, AND CLAY

Reagent

Sodium metaphosphate - saturated solution

Special Apparatus

1. Stirring machine
2. Boyoucos cylinder
3. Hydrometer
4. Fahrenheit thermometer
5. Textural triangle
6. Stop watch

Procedure

1. Weigh 50 g (oven dry) soil (100 g of coarse textured soil). Add to mixing cup and fill 1/2 with water. Add 20 ml of sodium metaphosphate. The Na replaces the cations on the surface of the clay and promotes an increase in the net negative charge, causing the particles to disperse by repelling each other.

2. Stir on stirrer until soft aggregates are broken down (10-15 minutes). This enables the soil fractions to become separated and free in suspension.

3. Transfer to Bouyoucos cylinder and fill to lower mark (upper mark if 100 g are used). Keep hydrometer in solution while filling.

4. Remove hydrometer, place stopper in top of cylinder, and shake cylinder. Place cylinder on desk and record time. At 20 seconds insert hydrometer and take reading at 40 seconds. Sand size fraction (larger than 0.05 mm) settles out in 40 seconds. Silt and clay fraction remain in suspension.

5. Remove hydrometer and record temperature. For each degree above that on hydrometer (67^{o} or 68^{o}F) add 0.2 to the reading, subtract 0.2 for each degree less than is listed.
6. Calculate percent sand (Wt. of sample - corrected hydrometer reading = wt. of sand. Wt. of sand/wt. of sample x 100 = percent sand). The hydrometer is calibrated to read in grams of soil particles in suspension. Thus, the 40 second reading gives the grams of silt and clay in suspension.
7. Repeat hydrometer reading, temperature reading and correction at 2 hours to give the weight of the clay fraction remaining in suspension.
8. Calculate percent clay (percent clay = corr. hyd. reading/wt. of sample x 100)
9. Calculate percent silt 100 - (percent sand + percent clay) = percent silt.
10. Determine class name or texture from textural triangle.

CATION-EXCHANGE CAPACITY*

NH_4OAc, pH 7.0

Reagents

Ammonium acetate (NH_4OAc), 1N, pH 7.0. Mix 68 ml ammonium hydroxide (NH_4OH), specific gravity .090, and 57 ml 99.5-percent acetic acid (CH_3COOH) per liter of solution desired. Cool, dilute to volume with water, and adjust to pH 7.0 with CH_3COOH or NH_4OH.

Optionally, prepare from NH_4OAc reagent salt and adjust pH.
Ethanol (CH_3CH_2OH), 95-percent, U.S.P.
Nessler's reagent (optional). Prepare according to Yuen and Pollard.

Procedure

Weigh 25 g airdry 2-mm soil into a 250 ml Erlenmeyer flask and add 35 to 50 ml NH_4OAc solution. Stopper, shake the flask for several minutes, and allow to stand overnight. Transfer contents of the flask to a Büchner funnel (Coors No. 1) fitted with moist Whatman No. 42 filter paper. Filter, using gentle suction if needed. Leach with 200 ml NH_4OAc, adding small amounts at a time so that leaching requires no less than 1 hour. Transfer leachate from suction flask to volumetric flask and retain for analysis of NH_4OAc-extractable cations.

Add 95 percent ethanol in small amounts to the ammonium-saturated soil remaining on the Büchner funnel until the leachate gives a negative test for ammonia with Nessler's reagent or leach with 100 ml. ethanol.

Direct distillation of adsorbed ammonia, Kjeldahl.

Reagents

Sodium chloride (NaCl).
Antifoam mixture. Mix equal parts of mineral oil and n-octyl alcohol.
Sodium hydroxide (NaOH), 1N.

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*From U.S.D.A., 1972

Hydrochloric acid (HCl), 0.2N, standardized.
Boric acid (H_3BO_3), 4 percent.
Mixed indicator. 1.250 g methyl red and 0.825 g methylene blue in 1 liter 95 percent ethanol.
Brom cresol green, 0.1 percent, aqueous solution.

Procedure

Transfer the soil plus filter paper to a Kjeldahl flask. Add 400 ml water and about 10 g NaCl, 5 drops antifoam mixture, a gram or two or granular zinc, and 40 ml NaOH. Connect the flask with the condenser and distill 200 ml into 50 ml 4 percent H_3BO_3 solution. Titrate the distillate to the first tinge of purple with 0.2N HCl, using 10 drops mixed indicator and 2 drops brom cresol green,

Calculations

$$\text{CEC (meq/100 g)} = \frac{\text{ml HCl}}{\text{g sample}} \times \underline{N} \text{ of acid} \times 100$$

Report on ovendry basis.

USE OF LIGNITE FLY ASH AS A SOIL AMENDMENT

An Abstract of a Thesis

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1923

USE OF LIGNITE FLY ASH AS A SOIL AMENDMENT

by

Thomas Victor Brown, B.A.

AN ABSTRACT OF A THESIS
Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
of the Requirements

For the Degree of
Master of Forestry

STEPHEN F. AUSTIN STATE UNIVERSITY
December 1977

ABSTRACT

One-year-old loblolly pine (Pinus taeda L.) seedlings were grown in a greenhouse in potted mixtures of two Texas lignite fly ashes and a Troup sand, Sacul sandy loam, and a sandy clay loam strip-mine spoil. Mixtures contained 0, 25, 50, 75 and 100 percent fly ash. After six months, soil:fly ash mixtures were analyzed for N, P, Ca, Mg, K, Na, Mn, Zn, pH, cation-exchange capacity, percent base saturation, and texture. Needle and root tissue analyses were performed on both live and dead seedlings.

Survival and height growth were both adversely affected by fly ash amendments. Nearly all seedlings grown in fly ash amended soils were exhibiting needle die-back at the end of the six-month growing period.

Soil analyses revealed the effects of fly ash amendments to include: 1) elevated pH, 2) excessive free salts, particularly calcium, and extremely high levels of percent base saturation, 3) reduced cation-exchange capacity, 4) reduction of available phosphorus to extremely low levels. Conditions such as these were not conducive to the survival or growth of loblolly pine.

VITA

Thomas Victor Brown was born in Elmhurst, Illinois, on November 20, 1948, the son of Frances and Victor Brown. He completed his high school education at York Community High School, Elmhurst, Illinois, in 1966. He thereupon entered Rice University, Houston, Texas where he received the Bachelor of Arts degree in May, 1971. From 1971 to 1972 he was employed in Houston as a painter and from 1972 until 1974 he was self-employed as a truck driver. In August, 1974, he entered the Graduate School at Stephen F. Austin State University. He was married to the former Cheryl Delores Peterson in June, 1972; they have no children.

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