Mixtures of Bottom Ash and Soil as a Growth Medium for Three Range Species

DAVID B. WESTER AND M. J. TRLICA

Highlight: Bottom ash from a coal-fired power plant was mixed with soil in varying proportions to determine its effects on germination, growth, and survival of blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), western wheatgrass (*Agropyron smithii* Rydb.), and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.). Five ash-soil growth mediums were developed, ranging from 100% ash-0% soil to 0% ash-100% soil (control). Bottom ash had no significant effect on the percentage germination of western wheatgrass and fourwing saltbush, but germination of blue grama seeds was reduced by the 100% ash-0% soil treatment. Percentage survival of all three species was not significantly affected by any of the ash-soil treatments. The treatments did, however, exert a significant effect on height growth of all three species. Plant height usually increased as the proportion of soil in the mixtures was increased. In addition, control plants produced significantly more biomass than did plants growing in any of the ash-soil treatments. Some of the physical and chemical properties of the bottom ash may account for its deleterious effects on the growth of these three species. High pH, lack of adequate plant nutrients such as nitrates and potassium, and unfavorable structural characteristics of the bottom ash may have caused reductions in plant growth.

Coal ash is a general term used to describe the waste material which is produced after the combustion of pulverized coal. There are two main types of coal ash: (1) fly ash, the lighter, less massive waste which flies up the smoke stack, and (2) bottom ash, the more massive, conglomerate waste which must be removed from the furnace. Coal ash is the ninth most abundant solid mineral being produced in the U.S. today. It has been estimated that by 1980 over 50 million tons of ash will be produced annually (Covey and Faber 1972), of which 16 million tons will be bottom ash and 36 million tons will be fly ash (Brackett 1970). Only about 10% of the ash being produced today is utilized for industrial purposes such as construction fill, road bases, concrete, and concrete products. The rest of this ash is being disposed of at considerable cost (Martens et al. 1970). With new coal-fired power plants being constructed to utilize the vast western coal deposits, ash disposal might become an important problem in the future. At present, various means of ash disposal include dumping the material directly on some rangelands or burying it and subsequently seeding the area with range species.

Fly ash and bottom ash may pose several severe problems for plant growth, such as (1) lack of adequate nutrients (for example, nitrogen), (2) high concentrations of certain elements (for example, aluminum, boron, manganese, and selenium), (3) unfavorable textural and structural characteristics, and (4) high pH. Rees and Sidrak (1956) found that natural plant colonization of ash deposits in Warwickshire, England, was markedly different from the earlier stages of colonization of other waste areas. Specifically, they found that *Atriplex hastata* var. *deltoidea* often formed a nearly pure stand on ash deposits, excluding other common weeds usually prevalent in colonization. Hodgson and Townsend (1973) found that within 5 or 6 years a number of species successfully established themselves on ash deposits in England, beginning with a moss (*Funaria hygrometrica*), and succeeeding to woody species such as *Ulex* sp. and *Betula* sp. These latter species came in after much of the toxicity had been reduced by natural weathering.

Gutenmann et al. (1976) found that fly ash from 21 states contained total selenium contents ranging from 1.2 to 16.5 parts per million (ppm). Cabbage (*Brassica oleracea* var. green winter) grown on soil containing 10% of this fly ash absorbed selenium in direct proportion to the selenium concentrations in the ash. Rees and Sidrak (1956) investigated the nutritional value of fly ash for plant growth and found it to be low in nitrogen. They also indicated that manganese and aluminum appeared to be present in toxic amounts. Other investigators have found that boron, rather than manganese and aluminum, was the dominant toxic element in fly ash (Holliday et al. 1958; Hodgson and Townsend 1973). Capp and Spencer (1970) discussed this apparent contradiction. They reported that other studies had shown that aluminum and manganese were present in toxic amounts in coal ash from the United States, whereas boron was found to be the principal offender in restricting plant growth in coal ash from Britain. It should be noted, however, that the solubility and availability of manganese and aluminum is largely dependent on soil pH. These elements are more likely to become soluble under acidic conditions (Gilbert and Pember 1935; Gotoh and Patrick 1972).

Plant growth and crop yield can be increased when fly ash is mixed with infertile loam soils and acidic mine spoils, if fertilizers are also added (Capp and Engle 1967; Adams et al. 1972). In these cases, the ash increased the pH and altered soil texture which improved growth characteristics.

The purpose of the present study was to determine if bottom ash could be incorporated into a rangeland soil and still support native shortgrass species. If this were feasible, it might provide an economical alternative means for ash disposal.

Methods and Materials

The unweathered bottom ash used in this experiment was obtained from a coal-fired power plant in central Wyoming. Sub-bituminous

Authors are student and associate professor, Colorado State University, Fort Collins. The senior author is currently a graduate research assistant in the Department of Range and Wildlife Management, Texas Tech University, Lubbock. This work was conducted as an undergraduate research project, Range Science Department, Colorado State University, Fort Collins. The authors wish to acknowledge the assistance of Ned Fetcher in data analysis and interpretation for this study.

Manuscript received September 22, 1976.

Table 1. Analyses for bottom ash and soil used in the experiment.

Analysis	Bottom ash	Soil	Procedures
Organic matter (%)	0.5	2.2	Wet oxidation-colorimetric
Nitrate-nitrogen (ppm)	1.8	17.5	Silver sulfate-nitrate electrode
Phosphorus (ppm)	33.3	8.0	Olsen bicarbonate-colorimetric
Potassium (ppm)	62.0	301.0	Ammonium acetate-flame emission
Iron (ppm)	17.8	6.4	DTPA-atomic absorption
Manganese (pm)	2.2	4.2	DTPA-atomic absorption
Boron (ppm)	1.2	0.3	Hot water-colorimetric
CEC (m.e./100 g)	5.9	38.9	Sodium acetate-flame emission
EC (mmhos/cm)	1.0	0.4	Saturated paste-conductivity bridge
pH	11.8	7.4	Saturated paste-pH electrode

coal for this electrical power generating plant comes from a strip mine near the plant. The coal is taken from the Fort Union formation and has approximately 21% ash and 0.7% sulfur content (Radian Corp. 1975). The soil was obtained from a shortgrass prairie site on the Foothills Campus of Colorado State University. Analyses of these two growth mediums are presented in Table 1.

The bottom ash was passed through a 0.635-mm screen and mixed with soil on a volume basis in the following proportions:

Treatment No.	Bottom Ash (%)	Soil (%)
1	100	0
2	75	25
3	50	50
4	25	75
5	0	100

The ash-soil mixtures as growth mediums were tested by growing blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), western wheatgrass (*Agropyron smithii* Rydb.), and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) in a greenhouse experiment using a completely randomized design with six replications for each species. Twenty seeds of blue grama and western wheatgrass and 10 seeds of fourwing saltbush were planted at a depth of 1 cm in separate 3.8-liter containers as each replication. Treatments were randomly assigned to bench space in the greenhouse. The greenhouse was maintained at 30°C day and 20°C night temperatures. Artificial lighting was not used as a supplement or to extend the photoperiod.

All ash-soil treatments were watered regularly to restore the growth mediums to field capacity. Blue grama and western wheatgrass were allowed to grow for about 14 weeks (May 15, 1975 to August 21, 1975) and fourwing saltbush was allowed to grow for about 10 weeks (July 2, 1975 to September 10, 1975). A nutrient solution (Hoagland's solution) was used to water blue grama and western wheatgrass for several weeks in June; thereafter, this was discontinued.

The following data were taken for each species: percentage germination, percentage survival, height at 2-week intervals, and aboveground biomass production. All data were analyzed using standard statistical procedures (Steel and Torrie 1960). Significant differences were accepted at the 0.05 level of probability and Tukey's test was used to distinguish significant treatment effects.

Results

Percentage germination and survival of blue grama, western wheatgrass and fourwing saltbush as influenced by ash-soil treatments is shown in Table 2. Percentage germination for the three species ranged from 25 to 77%. Germination of blue grama was significantly lower in the 100% ash-0% soil treatment than in the control. However, the ash-soil treatments had little effect on germination of western wheatgrass and fourwing saltbush.

The survival of the plants which germinated was high, ranging from 76 to 100% (Table 2). Western wheatgrass and fourwing saltbush had the highest percentage survival, whereas blue grama had the lowest percentage survival. There were no

Table 2. Average percentage germination and survival for blue grama, western wheatgrass, and fourwing saltbush in the ash-soil treatments.

Species	Ash-soil treatment (%)	Germination (%)	Survival (%)
Blue grama	100-0	35 a[1]	76 a
	75-25	46 ab	87 a
	50-50	58 ab	88 a
	25-75	57 ab	94 a
	0-100	62 b	93 a
Western wheatgrass	100-0	50 a[1]	99 a
	75-25	77 a	99 a
	50-50	76 a	98 a
	25-75	76 a	99 a
	0-100	77 a	100 a
Fourwing saltbush	100-0	38 a[1]	100 a
	75-25	35 a	100 a
	50-50	27 a	100 a
	25-75	37 a	100 a
	0-100	25 a	100 a

[1] Means for a species in a column with a similar letter are not significantly different at $p = 0.05$.

significant treatment effects on the survival of these three species. In addition, there were no significant interactions between ash-soil treatments and species for either percentage germination or percentage survival.

The average heights of blue grama, western wheatgrass, and fourwing saltbush in each ash-soil treatment are shown as a function of time in Figures 1, 2, and 3, respectively. The ash-soil treatments exerted a significant influence on the heights of each of the three species. In general, plant heights increased as the proportion of soil in the mixtures was increased, with the largest difference in height occurring between the control and all the other ash-soil treatments. Final heights of blue grama ranged from 3.2 cm in the 75% ash-25% soil treatment to 54.5 cm in the 0% ash-100% soil treatment (control) (Fig. 1). Final heights of

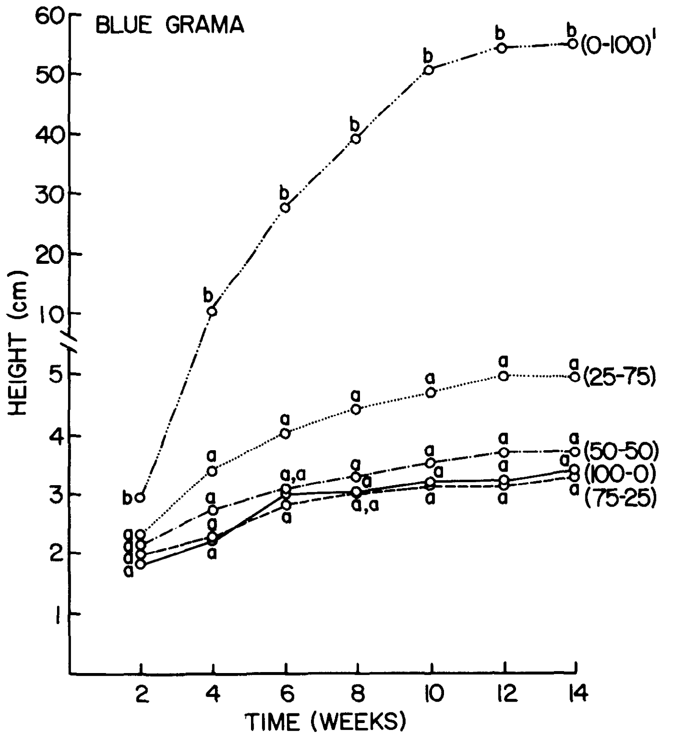

Fig. 1. *Mean height of blue grama as affected by ash-soil treatments. Means for the treatments at a given time with a similar letter are not significantly different at p = 0.05.*
[1]*Ash-soil treatment (%).*

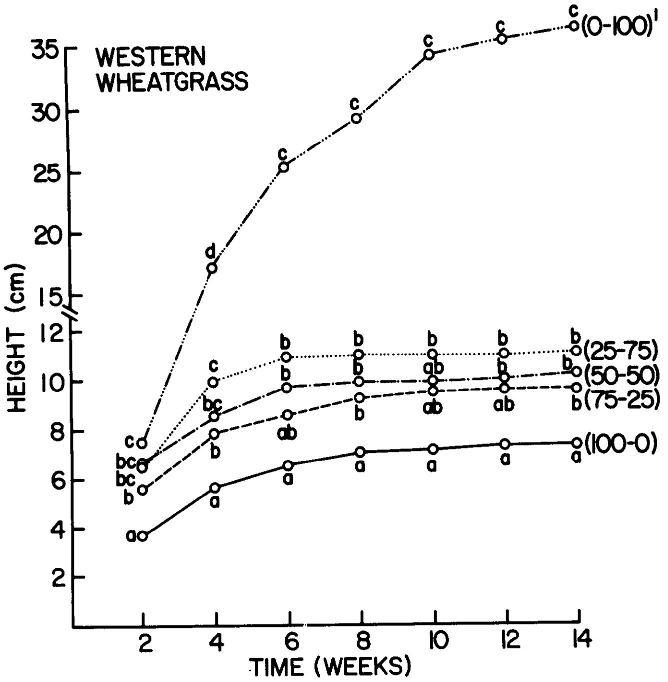

Fig. 2. *Mean height of western wheatgrass as affected by ash-soil treatments. Means for the treatments at a given time with a similar letter are not significantly different at* $p = 0.05$.
[1]*Ash-soil treatment (%).*

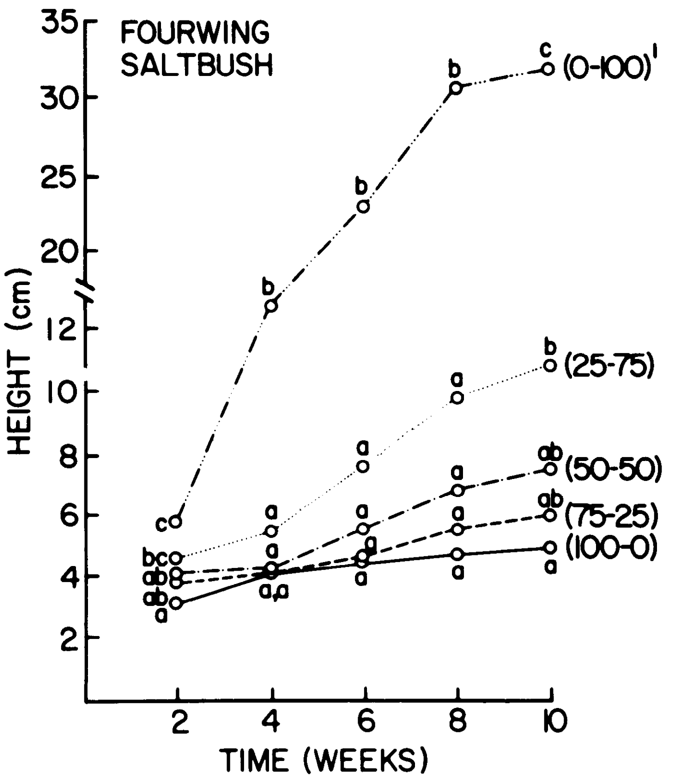

Fig. 3. *Mean height of fourwing saltbush as affected by ash-soil treatments. Means for the treatments at a given time with a similar letter are not significantly different at* $p = 0.05$.
[1]*Ash-soil treatment (%).*

western wheatgrass ranged from 7.4 cm in the 100% ash-0% soil treatment to 36.6 cm in the control (Fig. 2). Final heights of fourwing saltbush ranged from 4.9 cm in the 100% ash-0% soil treatment to 32.1 cm in the control (Fig. 3). In general, both the growth rate and the period of rapid height growth increased for all three species as the proportion of soil in the mixtures was increased. This is particularly evident when the controls are compared with the other ash-soil treatments. Plants in the 100% ash-0% soil treatment usually attained maximum height after only a few weeks of growth, whereas plants in the 0% ash-100% soil treatment (control) continued growing for 8 to 14 weeks.

There were significant interactions between species and ash-soil treatment with regard to height growth (Figs. 1, 2, and 3). In all ash-soil treatments other than the control, western wheatgrass was usually the tallest of the three species, while blue grama was the shortest. In addition, more variability was noted in the height growth of western wheatgrass than for the other two species in the various ash-soil mixtures.

Very early in the growing period (until about 2 weeks of age), plant height of all species responded similarly to the ash-soil treatments (Figs. 1, 2, and 3). Both blue grama and fourwing saltbush usually reacted in a similar manner to the ash-soil treatments during the middle portion of the growing period (from about 2 weeks through about 6 weeks of age), while western wheatgrass tended to be taller than these two species. Toward the end of the growing period (from about 6 weeks through 10 weeks of age), blue grama tended to be shorter than western wheatgrass in the various ash-soil treatments.

In an effort to determine if the major problems in early growth exhibited by blue grama and western wheatgrass were being caused by a nutrient deficiency, or alternatively by toxicity posed by the bottom ash, a nutrient solution (Hoagland's solution) was added to the growth mediums of these two species three times a week for 3 weeks in June. Because seedlings of these two species in all of the ash-soil treatments except the control were very small and stunted at this time (2–6 cm tall), any positive effects of the nutrient solution additions should have been noted within a few days. However, because there were no evident changes in growth following these additions, nutrient solution additions were discontinued.

A multiple step-wise regression analysis was used to study the predictability of height growth (dependent variable) of the three species as affected by the five following variables: (1) time (weeks), (2) time squared, (3) soil percentage in the ash-soil treatment, (4) soil percentage squared, and (5) soil percentage × time. The multiple r^2 values for each of the three species were relatively high, indicating the strength of the relationship between the percentage of soil in the ash-soil mixture and time as they affected height growth of these species. The multiple r^2 values for height growth of blue grama, western wheatgrass, and fourwing saltbush were 0.78, 0.81, and 0.80, respectively. For all three species, a large portion of the variability in height was accounted for by the single variable of soil percentage squared. Using only this variable, r^2 values of 0.50, 0.58, and 0.50 were obtained for height growth of blue grama, western wheatgrass, and fourwing saltbush, respectively.

Aboveground biomass production for blue grama, western wheatgrass, and fourwing saltbush as affected by ash-soil treatments is shown in Table 3. Aboveground biomass production of all three species was significantly reduced by all combinations of ash and soil. Although no significant differences in production for any of the three species were noted among the various ash-soil mixtures, production usually increased with an increase in the proportion of soil in the mixtures. In addition, it should be noted that the largest difference in aboveground biomass production occurred between the control and the 25% ash-75% soil treatment. These results indicate that when there

Table 3. Aboveground biomass production (g/m²) of blue grama, western wheatgrass, and fourwing saltbush in the ash-soil treatments.

Ash-soil treatment (%)	Production		
	Blue grama	Western wheatgrass	Fourwing saltbush
100-0	0.54 a[1]	3.24 a	4.32 a
75-25	0.54 a	5.40 a	8.64 a
50-50	0.54 a	5.94 a	7.56 a
25-75	1.08 a	6.48 a	24.84 a
0-100	471.96 b	214.92 b	164.70 b

[1] Means in a column followed by a similar letter are not significantly different at $p = 0.05$.

was at least 25% bottom ash in the treatment, aboveground biomass production was severely reduced.

Discussion and Conclusions

Results of this study indicated that growth responses, as determined by plant height and aboveground biomass production of blue grama, western wheatgrass, and fourwing saltbush, were significantly influenced when plants were grown in ash-soil mixtures containing at least 25% bottom ash. Plants growing in the ash-soil mixtures were severely stunted, even after 14 weeks of growth under greenhouse conditions with adequate soil water. Because of strong pozzolanic (cementing) activity in the 100% ash-0% soil treatment, root development of western wheatgrass was restricted to the seminal root stage with the stunted plants being maintained only by the seminal roots. Limited water and nutrient uptake imposed by this situation were compounded by the fact that the seminal roots could not adequately anchor the plants and in some cases rendered them easily uprooted during watering.

The plants growing in the ash-soil mixtures exhibited severe leaf chlorosis and tip die-back, indicative of nutrient deficiencies or toxicities. In some cases, all the leaves of the blue grama growing in the 100% ash-0% soil treatment showed die-back, leaving only the lower portion of the culm green.

Other than the percentage germination of blue grama being reduced by the ash-soil treatments, there were no significant treatment effects on either the percentage germination or survival of blue grama, western wheatgrass, and fourwing saltbush. Apparently, any toxicity problems posed by the bottom ash were not experienced by the germinating seeds of these species. Because of the stunting and retarded root development of plants in the mixtures containing bottom ash, it is doubtful whether these plants would have survived a period of dormancy and renewed growth activity. Survival undoubtedly would be reduced by bottom ash under harsh growth conditions generally present on the shortgrass plains.

Some of the physical and chemical properties of bottom ash may account for its deleterious effects on the growth of these three species. Although it was not the objective of this study to identify specific deficiency or toxicity mechanisms (and it may be difficult to attribute the poor growth of these species to any one problem posed by the ash), chemical analyses of the bottom ash indicated that there may be a host of nutritional imbalances confounded by an extremely high pH. The bottom ash used in this experiment was low in organic matter, nitrate, and potassium. In addition, the cation exchange capacity (CEC) was marginally low. These unfavorable properties, along with the structural properties previously discussed, must be amended in order for blue grama, western wheatgrass, and fourwing saltbush to attain adequate growth in bottom ash-soil mixtures.

Hodgson and Townsend (1973) found that by incorporating 5.1 to 7.6 cm layers of colloidal material such as sewage or clay into raw ash, structural stability was improved. Surface particle coalescence, which inhibits seed emergence of some small-seed species, may be decreased by using sewage. In addition, they found that pozzolanic activity was inhibited by adding small amounts of sewage, peat, or ground straw.

It is difficult to reduce the high pH of the ashes, although weathering and normal leaching will reduce alkalinity (Hodgson and Townsend 1973). Townsend and Hodgson (1973) found that natural weathering would reduce pH values only slightly, but that the soluble salt content was reduced to tolerable levels in 2 to 3 years. In order to obtain complete neutralization of a 23- to 25-cm layer of ash, as much as 112 metric tons per hectare of concentrated sulfuric acid would need to be added (Hodgson and Townseld 1973).

Because bottom ash and fly ash are usually low in such essential nutrients as nitrogen, the addition of fertilizer may be necessary for normal plant growth. Rees and Sidrak (1956) found that fertilizing with nitrogen, phosphorus, and potassium increased plant yields in fly ash-soil mixtures. Capp and Engle (1967) and Adams et al. (1972) also added nitrogen, phosphorus, and potassium fertilizers to their experimental plots when they mixed fly ash with acidic mine spoils.

Results of this study indicate that incorporation of bottom ash into shortgrass prairie soil may not be a desirable means of ash disposal. Other methods, such as ash burial within the mine and commercial uses, should be investigated.

Literature Cited

Adams, L. M., J. P. Capp, and D. W. Gillmore. 1972. Coal mine spoil and refuse bank reclamation with power plant fly ash, p. 105-111. *In:* M. A. Schwartz (ed.). Proc. Third Mineral Waste Util. Symp., Chicago, March 14-16, 1972.

Brackett, C. E. 1970. Production and utilization of ash in the United States, p. 11-16. *In:* Ash Utilization, Proc. 2nd Ash Utilization Symp., U.S. Bur. Mines Inform. Circ. No. 8488.

Capp, John P., and Carl F. Engle. 1967. Fly ash in agriculture, p. 210-220. *In:* Fly Ash Utilization Proc., Edison Electrical Institute-Nat. Coal Ass.-Bur. Mines Symp., U.S. Bur. Mines Inform. Circ. No. 8348.

Capp, John P., and John D. Spencer. 1970. Fly ash utilization—A summary of application and technology. U.S. Bur. Mines Inform. Circ. No. 8483. p. 44-51.

Covey, James N., and John H. Faber. 1972. Ash utilization—Views on a growth industry, p. 27-34. *In:* M. A. Schwartz (ed.). Proc. Third Mineral Waste Util. Symp., Chicago, March 14-16, 1972.

Gilbert, E., and F. R. Pember. 1935. Tolerance of certain weeds and grasses to toxic aluminum. Soil Sci. 39:425-428.

Gotoh, S., and W. H. Patrick, Jr. 1972. Transformation of manganese in a water-logged soil as affected by redox potential and pH. Soil Sci. Soc. Amer. Proc. 36:738-742.

Gutemann, W. H., C. A. Bache, W. D. Youngs, and D. J. Lisk. 1976. Selenium in fly ash. Science 191:966-967.

Hodgson, D. R., and W. N. Townsend. 1973. The amelioration and revegetation of pulverized fuel ash, p. 247-271. *In:* R. J. Hutnik and G. Davis (eds.). Ecology and Reclamation of Devastated Land. Vol. II. Gordon and Breach, New York.

Holliday, R., D. R. Hodgson, W. N. Townsend, and J. W. Wood. 1958. Plant growth on 'fly ash.' Nature 181:1079-1080.

Martens, D. C., M. G. Schnappinger, Jr., J. W. Doran, and F. R. Mulford. 1970. Fly ash as a fertilizer, p. 310-326. *In:* Ash Utilization, Proc. 2nd Ash Utilization Symp., U.S. Bur. Mines Inform. Circ. No. 8488.

Radian Corp. 1975. Coal fired power plant trace element study. Vol. I. A three station comparison. Prepared for Environmental Protection Agency Region VIII. Denver, Colo. 51 p.

Rees, W. J., and G. H. Sidrak. 1956. Plant nutrition on fly-ash. Plant and Soil 8:141-159.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York. 481 p.

Townsend, W. N., and D. R. Hodgson. 1973. Edaphological problems associated with deposits of pulverized fuel ash, p. 45-56. *In:* R. J. Hutnik and G. Davis (eds.) Ecology and Reclamation of Devasted Land. Vol. I. Gordon and Breach, New York.