# DIRECT REVEGETATION OF ANTHRACITE REFUSE USING COAL FLY ASH AS A MAJOR SOIL AMENDMENT[1]

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Abstract.--The Pennsylvania Power and Light Company (PP&L) used fly ash as a major soil amendment to prepare a 10-acre anthracite refuse site for direct (soil-less) revegetation. The site is located at Harwood, near Hazleton, PA. In the laboratory, experimental mixtures of fly ash and anthracite refuse were used to estimate the chemical and physical suitability of various rates of fly ash amendment for establishment of vegetation. Based on laboratory studies, fly ash was applied to the anthracite refuse at a rate of 200 dry tons/acre, and was plowed, in combination with agricultural limestone and fertilizers, into the refuse to a depth of 10 inches. For comparison, a soil-covered "control plot" was established at the site. The site was seeded in September 1984. Fly ash amendment improved the physical and chemical characteristics of the anthracite refuse by increasing the plant available water-holding capacity, shifting the USDA textural class of the refuse from sandy loam to silt loam and improving the pH and fertility of the coal refuse materials. Vegetation response has been vigorous in fly ash-amended coal refuse areas and is comparable to that in the soil-covered control plot. Excellent erosion control and partial release of the revegetation performance bond was achieved in the establishment year. Plant tissue analyses conducted recently indicate normal uptake of nutrients and trace elements from fly ash-amended coal refuse materials, with the exception that molybdenum and selenium uptake was high. Surface water quality improved as a result of the reclamation program.

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## INTRODUCTION

At the Harwood site, anthracite refuse materials were directly vegetated without using soil and using Class F fly ash as a major soil amendment. Direct (soil-less) revegetation of the site was considered to avoid the economic cost of obtaining borrow soil from a location off site and to avoid the environmental costs (reduction in borrow site productivity) of removing soil from a borrow site. Direct revegetation concepts and examples at four contrasting sites, including the Harwood site, are described by Buck and Houston, 1987.

Fly ash was considered as a soil amendment to neutralize part of the coal refuse acidity, to provide major and trace nutrients, and, most importantly, to improve soil texture and water retention by addition of fines to the coarse-textured refuse. Addition of the light-colored ash to the dark refuse was also expected to reduce heat absorption and thus reduce water losses.

### Site Background

Harwood, located near Hazleton in northeastern Pennsylvania, is an abandoned mine-mouth anthracite coal-fired electric generating station owned by the Pennsylvania Power and Light Company (PP&L). The Harwood reclamation site is just west of the south-bound lane of Interstate 81 at a point 0.6 miles south of the PA-924/I-81 interchange.

The 10-acre reclamation site was once used in a coal cleaning process to store anthracite coal fines. The refuse coal discharged from the coal breaker/processing plant had filled a sedimentation pond with fine anthracite coal particles typical of those discarded in the early 1900's. In 1984 the anthracite fines were excavated, cleaned, and burned at electric generating stations. After reprocessing in 1984, PP&L was required under provisions of a surface mining permit to regrade and revegetate the disturbed area.

The Class F fly ash used in the reclamation program came from PP&L's Montour Electric Generating Station, 40 miles to the west. The bituminous coal from which the fly ash was derived originated from the Greenwich Mines in north-central Pennsylvania. Thus, the utility company used its reclamation site to demonstrate constructive use of its own fly ash as a soil amendment.

## METHODS

### General Approach

The goal of this project was to demonstrate the beneficial use of fly ash in reclamation of coal-mined land. Fly ash applications had to be: 1) cost effective; 2) practical to apply and mix into the coal refuse; and, 3) not detrimental to plant growth or water quality, or to animals consuming forage grown on ash-amended refuse.

An empirical soil chemistry approach was used to evaluate the chemistry of fly ash-amended coal refuse before any ash was placed in the field. It consisted of:

1) identifying and sampling each major type of coal refuse;

2) making laboratory mixtures of fly ash and coal refuse, then allowing the mixtures to approach equilibrium by wetting and air-drying;

3) analyzing the fly ash, coal refuse materials, experimental ash/refuse mixtures, and (control plot) borrow soil using appropriate soil tests;

4) designing/implementing a soil amendment and seeding plan;

5) monitoring vegetation success and soil and water quality for 5 years;

6) analyzing plant tissue to determine potential impacts to wildlife using the site; and,

7) developing protocols for design of ash utilization projects elsewhere.

### Special Design Concerns Associated with Fly Ash Use

Research has shown that soluble salt and soluble boron (B) concentrations associated with fly ash may be toxic to some plants and thus may limit the usefulness of fly ash as a growing medium or soil amendment (Adriano et al. 1980). Where soluble salts and boron are not toxic to plants (phytotoxic), excessive plant uptake and accumulation of certain elements, especially molybdenum (Mo) and selenium (Se), can pose a danger to animals grazing on plants grown in fly ash or fly ash-amended soils (Adriano et al. 1980).

If the fly ash has self-hardening properties, it may cause excessive soil crusting if used as an amendment. Because Type F fly ash (the type used at Harwood) is not typically self-hardening, this was not a concern.

## Sampling and Analysis

### Sampling

A field survey was done in July 1984 after grading was complete. Based on the results of the field survey and preliminary laboratory analyses, the site was divided into three distinct coal refuse zones and a 0.5-acre control plot, covered with borrow soil to a 10-inch depth, was established to compare revegetation success with and without borrow soil. Composite samples (made from at least 10 subsamples) were collected from the surface 10-inch depth of each coal refuse zone and the borrow soil plot.

Plant tissue samples were collected in June, 1987 from 10 evenly spaced locations in each coal refuse zone and the control plot. Samples were dried at 60°C then ground in a stainless steel mill to pass a 20-mesh sieve prior to analysis. Live plant biomass was determined by shearing the grass/legume sward along 0.1 x 1.0 meter transects at 10 locations in each zone, drying at 80°C, and weighing each subsample.

### Physical Analyses

Particle size analyses were done in accordance with ASTM Method D-422. Plant-available water holding capacity was determined using a pressure membrane apparatus and was calculated as the difference in moisture content at -0.33 bar (field capacity) and -15 bar (permanent wilting point) moisture tension (Klute, 1986).

### Laboratory Mixtures

Mixtures of Greenwich fly ash and coal refuse were made in the laboratory to estimate the field reaction of 200- and 300-ton/acre applications (dry weight basis) of fly ash to the coal refuse. The 200-ton/acre (2.0 inches deep) application rates correspond to field ash:coal refuse ratios of 1:4, 1:6, and 1:8 when ash is mixed with the refuse to a depth of 7, 10 and 12 inches, respectively. A 300-ton/acre (3.0-inch-deep) ash application rate corresponds to a field ash:refuse ratio of 1:4 when ash is mixed with the refuse to a depth of 10 inches.

Most of the agronomically significant physical and chemical properties of soils (e.g. water holding capacity, compactability, cation and anion exchange capacity) are attributed to the "fine-earth" (<2.0-mm) size fraction of soils. For this reason bulk (field) fly-ash:coal-refuse ratios of 1:4, 1:6, and 1:8 were represented in the laboratory by mixtures of the fine-earth fraction of the fly ash and coal refuse materials. Fine-earth-sized fly ash and coal refuse materials were mixed in ratios which were adjusted for the relatively inert coarse fractions of the coal refuse and fly ash components.

The ratios of fly ash and coal refuse most appropriate for creation of acceptable growing media were determined experimentally by: 1) mixing the components; 2) moistening the mixtures to 50% moisture (dry weight basis) to allow the constituents to approach chemical equilibrium, air-drying the mixtures; and 3) analyzing each mixture using conventional soil chemical assays.

### Chemical Analyses

The coal refuse materials, fly ash, partially-equilibrated mixtures, and borrow soil samples were assayed at the Pennsylvania State University Soil and Environmental Chemistry Laboratory for pH (1:1 water:soil) and lime requirement (SMP-buffer) (McLean, 1982), soluble salts (electrical conductivity of a 2:1 water: soil extract) (Rhodes, 1982), Bray-1 P (Olsen and Sommers, 1982), neutral, normal ammonium acetate extractable Ca, Mg, and K (Thomas, 1982), and, using the Baker-method, for plant-available Ca, Mg, K, Mn, Fe, Cu, Zn, Na, Al, Pb, Ni, and Cd (Baker and Amacher 1981). Concentrations of hot water soluble B (Bingham 1982), oxalic acid (Tamms) extractable Mo (Reisnauer 1965), and total Se (Fine 1965) were also determined. Beginning in 1986, saturation extracts were assayed for soluble salts (Rhodes, 1982) and B (Bingham, 1982).

## PRE-APPLICATION RESULTS AND DISCUSSION

When soluble salt levels measured by electrical conductivitity exceed 2.0 mmhos/cm, yields of very salt sensitive plants are reduced (Rhodes, 1982). Boron becomes toxic to most agricultural species when hot water soluble B exceeds 20 mg/kg soil (Hodgson and Townsend, 1969) and was adopted as a B phytotoxicity threshold. Soluble salt and B levels of the fly ash were high, but laboratory mixtures indicated that mixing the ash with the coal refuse reduced B and soluble salt concentrations to acceptable levels (Table 1). It is important to note that soluble B in fly ash is not always "diluted" upon mixture with low B materials. We have observed at fly ash disposal sites that soil/ash interactions sometimes increase B solubility to levels above that of either component. This underscores the need for testing of equilibrated or partially-equilibrated experimental mixtures.

Table 1.--Results of pH, soluble salts, boron, phosphorus, molybdenum, and selenium soil analyses, Harwood anthracite refuse site.

| Sampling Date | Sample | pH | Bray P-1 Phosphorus (mg/kg) | 2:1 Water:Soil Extract Soluble Salts (EC, mmhos/cm) | Saturation Extract Soluble Salts (EC, mmhos/cm) | Hot Water Soluble Boron (mg/kg) | Saturation Extract Boron (mg/L) | Oxalate Extractable Molybdenum (mg/kg) | Total Selenium (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| 8/18/84 | Greenwich Fly Ash | 6.0 | 95 | 2.60 | - | 18.2 | - | 35.4 | 6.10 |
| 8/18/84* | Stockpiled Borrow Soil | 4.7 | 4 | 0.10 | - | - | - | - | - |
| 9/4/84** | Control Plot Soil | 7.6 | 179 | 2.20 | - | 1.2 | - | <0.5 | <5.0 |
| 11/1/84 | Control Plot Soil | 6.3 | 84 | 1.90 | - | - | - | - | - |
| 7/8/85 | Control Plot Soil | 5.5 | 32 | 0.16 | - | 1.3 | - | - | - |
| 6/27/86 | Control Plot Soil | 6.0 | 14 | 0.10 | 0.66 | 1.3 | 0.15 | - | - |
| 6/2/87 | Control Plot Soil | 5.6 | 26 | 0.10 | 0.50 | 1.0 | <0.05 | 0.73 | 0.53 |
| 8/18/84* | Zone 1 Refuse | 3.9 | 8 | 0.40 | - | 0.8 | - | 0.4 | 6.4 |
| Lab Mix# | Zone 1 AACR | 5.0 | 57 | 1.20 | - | 4.4 | - | - | - |
| 9/4/84** | Zone 1 AACR | 7.0 | 18 | 0.16 | - | 5.7 | - | 7.3 | <5.0 |
| 11/1/84 | Zone 1 AACR | 7.1 | 76 | 2.20 | - | 11.2 | - | - | - |
| 7/8/85 | Zone 1 AACR | 7.0 | 89 | 1.30 | - | 6.4 | - | - | - |
| 6/27/86 | Zone 1 AACR | 7.1 | 89 | 0.76 | 2.10 | 2.6 | 0.63 | - | - |
| 6/2/87 | Zone 1 AACR | 6.5 | 89 | 0.67 | 2.40 | 2.2 | 0.61 | 8.40 | 6.67 |
| 8/18/84* | Zone 2 Refuse | 4.0 | 6 | 0.32 | - | 1.2 | - | 0.2 | 3.14 |
| Lab Mix# | Zone 2 AACR | 4.9 | 84 | 1.08 | - | 3.7 | - | - | - |
| 9/4/84** | Zone 2 AACR | 7.1 | 73 | 2.20 | - | 9.4 | - | 5.3 | <5.0 |
| 11/1/84 | Zone 2 AACR | 6.9 | 89 | 2.00 | - | 6.8 | - | - | - |
| 7/8/85 | Zone 2 AACR | 7.1 | 78 | 1.80 | - | 7.2 | - | - | - |
| 6/27/86 | Zone 2 AACR | 6.7 | 89 | 1.62 | 2.80 | 3.7 | 1.33 | - | - |
| 6/2/87 | Zone 2 AACR | 6.9 | 114 | 1.31 | 2.50 | 2.5 | 0.86 | 13.1 | 4.64 |
| 8/18/84* | Zone 3 Refuse | 3.9 | 3 | 0.14 | - | 0.6 | - | 0.2 | 9.2 |
| Lab Mix# | Zone 3 AACR | 6.1 | 82 | 1.70 | - | 6.2 | - | - | - |
| 9/4/84** | Zone 3 AACR | 6.7 | 82 | 2.00 | - | 5.5 | - | 7.0 | <5.0 |
| 11/1/84 | Zone 3 AACR | 6.3 | 54 | 0.40 | - | 8.6 | - | - | - |
| 7/8/85 | Zone 3 AACR | 7.2 | 95 | 1.20 | - | 4.0 | - | - | - |
| 6/27/86 | Zone 3 AACR | 7.4 | 105 | 0.32 | 1.25 | 2.9 | 0.49 | - | - |
| 6/2/87 | Zone 3 AACR | 7.5 | 132 | 0.45 | 1.70 | 2.5 | 0.52 | 8.78 | 6.65 |
| 6/21/85 | Zone 1 0-10" | 6.8 | 87 | 0.80 | - | 1.8 | - | - | - |
| 6/21/85 | Zone 1 10-20" | 4.0 | 15 | 0.50 | - | 0.8 | - | - | - |
| Soil Criteria for Concern Regarding Plant Toxicity in Sensitive Species: | | | | >2.0 | >2.0-4.0 | >20.0 | >1.0 | | |

*Before Amendment with fly ash (Zones 1-3 only), limestone and fertilizers. AACR = Fly Ash Amended Coal Refuse
**Day of seeding, after amendment with fly ash (none in control plot), limestone, and fertilizers.
#The 1:6 ash:refuse mixtures made in laboratory are reported here. Mixtures of ash and refuse were also made in 1:4 and 1:8 ratios. These experimental mixtures did not contain added limestone or fertilizers.

The available nutrient and trace element status (by Baker test) of the experimental mixtures was better than that of the components. Mixing fly ash into the coal refuse increased the pH, decreased potentially phytotoxic aluminum solubility, and increased the concentrations of major nutrients and essential trace elements, especially phosphorus (Table 1). The inherent fertility of the fly ash-amended refuse materials was higher than that of the control plot borrow soil (with the probable exception of nitrogen, which was not assayed for). Availability of potentially toxic heavy metals (Pb, Ni, Cd) tested low-to-normal for the experimental mixtures assayed by the Baker method.

Molybdenum and selenium assays were used to compare trace element concentrations with soils (Table 1). Although these elements are not typically toxic to plants, Mo and Se can accumulate in forage and potentially become toxic to livestock intensively grazed on high (5-20 mg/kg) Mo and/or high (4-5 mg/kg) Se feed (Adriano, et al. 1980). Because Mo and Se tested higher for the unweathered experimental mixtures than soils, and reliable soil Mo and Se availability indices are not available (Adriano, 1986), it was recommended that fly ash-amended coal refuse areas at Harwood not be used for intensive (confined) livestock grazing unless future testing of the soil and forages indicated this was a safe practice. Follow-up soil and forage analyses are discussed later.

## Revegetation Plan

### Fly Ash, Limestone, and Fertilizer Requirements

Although our analyses of experimental mixtures indicated that Greenwich fly ash applications of up to 300 dry tons/acre could be used as a soil amendment at the Harwood site, an application rate of 200 dry tons fly ash/acre, incorporated to a 10-inch depth was chosen (This application rate is represented by the 1:6 ash:coal refuse laboratory mixtures).

Based on soil tests on the experimental mixtures, fertilizer and limestone requirements of the ash-amended refuse materials were less than required for the soil-covered control plot. Commercial N-P-K fertilizers and high-magnesium limestone were used to balance the nutrient and lime requirements of the fly ash-amended refuse and the control plot soil. Soil amendments used are given in Table 2.

### Seeding Mixture

A fall seed mixture was designed to provide quick cover and establish permanent species tolerant of wet or dry conditions and low pH. Although the pH of the coal refuse could be increased to pH 7, acid-tolerant species were chosen because: 1) they could survive a decline in soil pH; 2) some areas might not be sufficiently neutralized by lime and fly ash; and, 3) acid-tolerant species could also exploit water and nutrients in the unamended, acidic subsoil. To quickly provide temporary cover and erosion control, winter rye (Secales cereale) and annual ryegrass (Lolium multiflorum) were used. Redtop (Agrostis alba), reed canarygrass (Phlaris arundinacea), deertongue grass (Panicum clandestinum), and birdsfoot trefoil (Lotus corniculatus) were the perennial species chosen.

### Construction Methods

A soil-covered control plot was established at the center of the site. Soil amendments (Table 2) were incorporated into the top 10 inches of the fly ash/refuse mixtures with a chisel plow. The site was hydraulically seeded. Straw mulch was spread at a rate of 3 tons/acre and tacked in place using cellulose-fiber mulch hydraulically applied at the rate of 800 pounds/acre. All of this work was completed within 2 1/2 days in early September 1984.

## RESULTS: POST-RECLAMATION MONITORING

Soil chemistry, soil physical properties, surface water quality, soil pore (lysimeter) water quality, and vegetation success have been monitored since the site was reclaimed in September of 1984. Vegetation yield and elemental composition was monitored in 1987 to determine nutrient and trace/potentially toxic element content. Monitoring will continue on at least an annual basis through 1988.

## Vegetation Monitoring

Erosion control was excellent in all areas of the site. Erosion control was enhanced by chisel-plowing along contours which left 4- to 6-inch furrows to catch rainfall and seed. Initial fall growth was confined mainly to winter rye, which grew uniformly throughout fly ash-amended coal refuse areas and the soil-covered control plot. Redtop also took hold that fall, but was too small to contribute much to erosion control. Where fly ash or soil was not used, growth was weak. First-year vegetation was stronger and more uniform within the soil-covered control plot.

In the summer following seeding, winter rye, reed canarygrass and redtop matured and set seed. In descending order of predominance, reed canarygrass, birdsfoot trefoil, annual ryegrass, and

Table 2.--Soil Amendments used at the Harwood Anthracite Refuse Site (incorporated to a 10-inch depth).

| Test Plots | Soil Amendments: Fly Ash (dry tons/acre) | Fertilizer* (lb $N-P_2O_5-K_2O$/acre) | Limestone** (tons $CaCO_3$ equiv./acre) |
|---|---|---|---|
| Zone 1 refuse/ash | 200 | 200-50-200 | 4.5 |
| Zone 2 refuse/ash | 200 | 200-50-200 | 6.5 |
| Zone 3 refuse/ash | 200 | 200-50-200 | 5.0 |
| Soil-covered control | 0 | 200-200-200 | 7.0 |

*80 of 200 lb n/acre were applied in a slow-release form.
**Limestone containing at least 9 percent MgO equivalent was used to supply at least 240 lb/Ac Mg.

deertongue grass became established as secondary species the first summer (1985). Vegetal cover exceeded 70 percent in all areas by visual estimate.

In the second summer after seeding, winter rye and annual ryegrass had vanished from the sward while redtop, reed canarygrass, and birdsfoot trefoil (in descending order) took predominance. Third-year vegetation shifted toward a reed canarygrass/birdsfoot trefoil-dominated sward. Vegetal cover on fly ash-amended coal refuse areas was strong and indistinguishable from that on the soil-covered control plot.

Examinations of peripheral areas suggested that even where coarse-textured refuse materials are supplied with adequate water (as in unamended areas near swales), refuse amended with fly ash support a more uniform and diverse stand of vegetation. This may be due, in part, to improved soil water retention and fertility, as well as to textural changes which result in better seed/soil contact.

## Physical Changes in Growing Media from Fly Ash Amendment

As expected, fly ash amendment increased the "fine earth" (<2.0 mm) fraction of the anthracite refuse, with a notable increase in silt content (Table 3). Fly ash amendment shifted the coal refuse textural classes of the refuse materials from sandy loam to silt loam in all zones of the site. As expected, fly ash-amended coal refuse materials have increased plant available water holding capacity (Table 3). The fly ash-amended coal refuse tested had the highest plant available water holding capacity--greater than the fly ash alone, the unamended refuse, and the borrow soil, in descending order.

## Chemical Monitoring of Ash-Amended Coal Refuse Materials and Soil

The surface 10 inches ("plow zone") of the soil-covered control plot and each of the three fly ash-amended coal refuse areas were sampled on the day of seeding and during each of our annual monitoring visits.

All samples were analyzed for the same chemical parameters described earlier. Results of pH, P, soluble salts (conductivity), B, Mo, and Se tests on unamended refuse, experimental mixtures, control plot soils, and actual field mixtures are summarized in Table 1.

The experimental mixtures adequately predicted the chemistry of the ash/coal refuse mixtures produced in the field. Over time, mixtures of ash and coal refuse have remained within an optimal pH range. From the beginning of the program, hot water soluble B concentrations remained below the guideline for phytotoxicity (20.0 mg/kg) and have since weathered to levels more typical of Pennsylvania soils. Levels of soluble salts were acceptable, with a decreasing trend over time. Contrary to expectation, the pH of the soil-covered control plot dropped considerably after seeding.

Analyses of soil saturation extracts were begun in 1986 for B phytotoxicity evaluation and estimation of the potential for soluble salt phytotoxicity. The saturation extracts more closely simulate the ionic composition of the soil solution from which plants absorb nutrients (and toxic substances). Recent literature (Keren and Bingham 1975) indicates that the saturation extract method is better for evaluation of B phytotoxicity potential than the hot water method. (The hot water soluble B assay is still best for diagnosing B deficiency.) Very boron-sensitive crops can tolerate soils with saturation extract concentrations up to 1.0 mg B/L. Tolerant species (e.g., alfalfa) can tolerate up to 15 mg B/L (Sprague 1972). By these methods and

Table 3.--Results of soil texture and plant available water holding capacity assays, Harwood Anthracite Refuse Site.

| Sample | % Fine Earth** (<2.0 mm) | Particle Size Distribution of Fine Earth Fraction* | | | USDA Textural Class | Plant-Available Water Holding Capacity** (%, dry wt.) |
|---|---|---|---|---|---|---|
| | | % Sand | % Silt | % Clay | | |
| Greenwich Fly Ash | 100.0 | 19.0 | 71.0 | 10.0 | silt loam | 10.45 |
| Control Plot Borrow Soil | 70.9 | 14.0 | 72.0 | 14.0 | silt loam | 6.12 |
| Zone 1 Coal Refuse | 50.2 | 69.0 | 23.0 | 8.0 | sandy loam | 9.53 |
| Zone 1 Fly Ash Amended Coal Refuse | 69.7 | 22.0 | 68.0 | 10.0 | silt loam | ---- |
| Zone 2 Coal Refuse | 64.0 | 59.0 | 31.0 | 10.0 | sandy loam | --- |
| Zone 2 Fly Ash Coal Amended Refuse | 68.4 | 15.0 | 73.0 | 12.0 | silt loam | 17.59 |
| Zone 3 Coal Refuse Refuse | 26.0 | 72.0 | 21.0 | 7.0 | sandy loam | --- |
| Zone 3 Fly Ash Amended Coal Refuse | 49.2 | 19.0 | 71.0 | 10.0 | silt loam | --- |

*Sieve and hydrometer analyses were conducted in accordance with ASTM Method D-422.
**Determined as the difference in moisture content at field capacity (-1/3 bar moisture tension) and the permanent wilting point (-15 bar moisture tension).

criteria, the samples collected in 1986 and 1987 are not phytotoxic, although B and soluble salt concentrations are higher in the fly ash-amended coal refuse zones than in borrow soil.

Soil assays for Mo and Se were high and suggested that the fly ash-amended coal refuse could potentially produce forage containing excessive concentrations of those elements (if that forage is the sole food source). Soil in the control plot contained very little Mo and Se. Plant analyses done in June 1987 support concerns arising from soil analysis (discussed below).

The nutrient and trace element availability assays by the Baker method (not reported) indicated that nutrient and trace element availability have remained nearly ideal for the ash-amended coal refuse zones and for the soil-covered control plot. Availability of non-essential/potentially toxic elements [sodium (Na), aluminum (Al), lead (Pb), nickel (Ni), and cadmium (Cd)] consistently tested low-to-normal by the Baker method for all fly ash-amended coal refuse and soil samples analyzed.

## Water Quality Monitoring

Pennsylvania Power and Light's Environmental Management Division has conducted a soil pore water and surface water quality monitoring program at the site Results are summarized in detail elsewhere (Buck and Houston 1987; Buck 1987).

Except for pH increases following a companion reclamation project adjacent to the offsite pond, reclamation activities apparently caused no significant changes in the water quality of the onsite spring, the offsite pond, or the water in the creek at the property line (downstream of the swale drainage). Runoff water quality in the drainage swale at the center of the site improved as a result of reclamation activities (pH increased and Al, Cu, Mn, Zn, As and Se decreased).

## Biomass Yield Comparison

Live plant biomass yields were highly variable within each coal refuse zone and within the control plot when sampled in June 1987. This variability is explained by the sampling method--short (1.0 m) transects through birdsfoot trefoil yielded much more than areas covered with grasses. Average dry weight yields were higher in the coal refuse plots (range: 393.7 to 1134.3 lb/Ac) than in the soil-covered control plot (278.1 lb/Ac), but are of dubious comparative value because of excessive sample variance (C.V. range = 90.7 to 116.3 percent).

### Plant Tissue Analyses

Birdsfoot trefoil and reed canarygrass composite samples were collected in June 1987. At the time of sampling, less than 5 percent of the birdsfoot trefoil had gone to flower and less than 10 percent of the reed canarygrass was at the "boot" stage or older. Only established plants (over 1 year old) were sampled. Dry spring weather and moderate soluble salt concentrations may have put the plants under some stress.

Results of analyses plus expected values (Penn State) and chronic animal feed toxicity guidelines (National Research Council 1980) are presented in Tables 4A and 4B. As expected, concentrations of Mo, Se, B, and As were elevated where plants were grown using fly ash as a soil amendment. Arsenic and B concentrations in plant samples were all low and of no toxicological concern. Molybdenum in birdsfoot trefoil and Se in both species exceeded National Research Council (NRC) guidelines for chronic toxicity in animals (NRC, 1980). Molybdenum data suggest that animals should not be exclusively grazed on the fly ash-amended portions of the Harwood site. Molybdenum toxicity to wildlife is unlikely because animals using the site (particularly deer) have large home ranges and do not exclusively feed on Mo-rich birdsfoot trefoil. If the site were to be used by confined ruminant animals (e.g. cattle, sheep), Mo toxicity could be a problem especially if dietary intake of Cu were low. Selenium concentrations exceeded recommended forage concentrations, but are not extremely high. Unconfined wildlife should not be affected adversely because adjacent lands, like most of the northeast, produce low-Se forage. Thus livestock should not be exclusively grazed on or fed from Harwood fly ash-amended coal refuse materials unless testing of forage for Se, Mo, and other elements indicates that the forage is safe. There are no plans to convert any part of the Harwood site to agricultural use.

### Relationship Between Plant Tissue Analyses and Soil Analyses

Plant analyses done to date affirm the validity of the soil tests used to predict the potential for plant toxicity or food web contamination. Based on experience to date, it is believed that the saturation extract assay for soluble salts (Rhodes 1982) and B (Bingham 1982), Bray-1 P (Olsen and Sommers 1982), and the Baker method of soil testing (Baker and Amacher 1981) are appropriate for pre- and post-reclamation analyses of fly ash-amended coal refuse materials. Soil Se and Mo soil assays are not adequate predictors of Se and Mo uptake, especially for unconventional soils (Adriano 1986). More predictive Se and Mo soil assays need to be developed. In the interim, forage nutrient content, including Se and Mo, should be done prior to feeding the forages to livestock.

### Cost Comparison

The revegetation of the Harwood site cost $4,053/acre. This figure includes a trucking cost of $4.19/ton for fly ash from the Montour Station, which is approximately 45 miles from the site. Cost estimates for placing 6 inches of soil on the control area at the site and treating as required were $5,272/acre. Cover soil was not available on site, but suitable soil was available on PP&L property approximately 1 mile from the site. For the 10-acre project, PP&L estimated the savings due to using fly ash instead of a 6-inch soil cover to be $12,000.

These cost comparisons are conservative. If soil was not available from the owners' property or if thicker soil cover were used, costs of the conventional soil cover treatment would be much higher. Fly ash trucking costs were higher than for a site more convenient to the fly ash source. Fly ash disposal costs to the utility were also saved, but these costs were not included in the analysis described above.

## CONCLUSIONS AND RECOMMENDATIONS

Fly ash was successfully used as a soil amendment to prepare anthracite refuse for direct revegetation. The growth of vegetation on fly ash amended coal refuse was comparable to growth on borrow soil. Impacts to water quality were acceptable. Forage quality was acceptable for use by wildlife with large home ranges. Soil chemistry was stable and at nearly ideal pH and nutrient levels. Reclamation costs were less when fly ash was used in mixture with anthracite refuse instead of cover soil.

It is important to note that not all fly ash is appropriate for use as a mine-soil amendment. Unique chemical interactions between fly ash and coal refuse should be taken into account by evaluating experimental fly ash/refuse mixtures as well as the separate components. Pyritic, acid-generating coal refuse and spoils should be carefully evaluated with regard to potential acidity problems. The potential for plant toxicity, degradation of water quality,

Table 4A.--Concentrations of major nutrients in composite samples of plant tissue, Harwood anthracite refuse site, June 1987.

| Sample I.D. | Sample Description | N | P | K | Ca | Mg | S |
|---|---|---|---|---|---|---|---|
| | | (------------ | ------------ | percent, dry | weight basis | ------------ | ------------) |
| Z1RC687 | Zone 1 Reed Canarygrass | 2.46 | 0.41 | 2.71 | 0.34 | 0.20 | 0.53 |
| Z2RC687 | Zone 2 Reed Canarygrass | 2.43 | 0.43 | 2.75 | 0.37 | 0.21 | 0.55 |
| Z3RC687 | Zone 3 Reed Canarygrass | 2.26 | 0.41 | 2.64 | 0.30 | 0.19 | 0.43 |
| CP4C687 | Control Plot Reed Canarygrass | 2.17 | 0.35 | 2.62 | 0.21 | 0.28 | 0.36 |
| Expected Range for Grasses (PSU)* | | 1.57-2.94 | 0.16-0.30 | 1.07-2.31 | 0.29-0.69 | 0.10-0.22 | 0.13-0.27 |
| Z1TB687 | Zone 1 Birdsfoot Trefoil | 3.54 | 0.33 | 2.90 | 1.28 | 0.26 | 0.44 |
| Z2BT687 | Zone 2 Birdsfoot Trefoil | 3.16 | 0.34 | 3.26 | 1.26 | 0.26 | 0.43 |
| Z3BT687 | Zone 3 Birdsfoot Trefoil | 3.24 | 0.34 | 2.90 | 1.15 | 0.24 | 0.33 |
| CPBT687 | Control Plot Birdsfoot Trefoil | 3.71 | 0.35 | 2.52 | 0.84 | 0.38 | 0.28 |
| Expected Range for Legumes (PSU)* | | 2.75-4.16 | 0.26-0.36 | 1.94-3.18 | 0.89-1.43 | 0.16-0.30 | 0.19-0.33 |

*Source: The Pennsylvania State University Merkle Laboratory.

Table 4B.--Plant tissue concentrations of trace/potentially toxic elements in composite samples of plant tissue, Harwood anthracite refuse site, June 1987.

| Sample I.D. | Sample Description | Mn | Fe | Cu | Zn | Al | Pb | Ni | Sr | B | Mo | Se | As |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (------ | ------ | ------ | ------ | ------ | mg/kg, | dry | weight basis | ------ | ------ | ------ | ------) |
| Z1RC687 | Zone 1 Reed Canarygrass | 91 | 50 | 4 | 30 | 27 | 4 | 4.45 | 16.0 | 9.0 | 1.50 | 2.02 | 0.33 |
| Z2RC687 | Zone 2 Reed Canarygrass | 96 | 44 | 3 | 28 | 24 | 5 | 2.55 | 18.0 | 11.0 | 2.38 | 2.20 | 0.50 |
| Z3RC687 | Zone 3 Reed Canarygrass | 38 | 52 | 3 | 23 | 34 | 3 | 2.75 | 14.0 | 8.0 | 2.86 | 2.86 | 0.48 |
| CP4C687 | Control Plot Reed Canarygrass | 159 | 58 | 5 | 26 | 37 | 3 | 2.65 | 6.0 | 6.0 | 0.61 | <0.05 | <0.05 |
| Expected Range for Grasses(PSU)* | | 19-<br>131 | 44-<br>310 | 3-<br>19 | 15-<br>41 | 27-<br>186 | | | | | | | |
| Z1TB687 | Zone 1 Birdsfoot Trefoil | 81 | 114 | 11 | 50 | 41 | 8 | 7.35 | 60.0 | 48.0 | 43.0 | 3.16 | 0.48 |
| Z2BT687 | Zone 2 Birdsfoot Trefoil | 74 | 85 | 11 | 40 | 41 | 8 | 6.35 | 54.0 | 49.0 | 93.0 | 3.26 | 0.47 |
| Z3BT687 | Zone 3 Birdsfoot Trefoil | 38 | 98 | 10 | 29 | 56 | 6 | 5.30 | 53.0 | 44.0 | 43.0 | 5.54 | 0.30 |
| CPBT687 | Control Plot Birdsfoot Trefoil | 55 | 95 | 9 | 29 | 55 | 6 | 4.00 | 12.0 | 11.0 | 1.67 | <0.05 | <0.05 |
| Expected Range for Legumes (PSU)* | | 11-<br>75 | 91-<br>345 | 5-<br>19 | 10-<br>46 | 32-<br>234 | | | | | | | |
| Maximum Feed Concentrations Chronically Tolerated by Domestic Animals (NRC)** | | 400-<br>2000 | 500-<br>3000 | 25-<br>1000 | 300-<br>1000 | 200-<br>1000 | 30 | 50-<br>1000 | 2000-<br>30000 | 150 | 6.2-<br>1000 | 2 | 50-<br>100 |

*Source: The Pennsylvania State University Merkle Laboratory.
**Source: National Research Council, 1980. Mineral Tolerance of Domestic Animals. Nat. Acad. Sci., Washington, DC. 577 pp.

and food web contamination by fly ash-borne elements must be addressed in any fly ash amendment program.


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