EXPERIMENTAL VEGETATION OF BOTTOM ASH AND SCRUBBER SLUDGE AT KANSAS CITY POWER & LIGHT COMPANY'S LACYGNE GENERATING STATION

by

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INTRODUCTION

As an alternative to petroleum and natural gas, coal is becoming increasingly important as a source of fuel for the generation of electrical power in this country. Powerplants which burn coal to produce steam for generating turbines represent more than 50% of the total installed generating capacity in the U. S. (Nesbit, 1982). During the coal combustion process ash is produced as a residual waste product, along with gases and particulate matter, varying in quantity and characteristics depending on coal source, burning techniques, and cleaning and disposal methods. Over half of all man-made SO_2 emissions originate from electric utilities sources (Nesbit, 1982).

The U.S. Environmental Protection Agency (EPA), under authority of the Clean Air Act, has established National Ambient Air Quality Standards (NAAQS) for six "criteria pollutants": sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), total suspended particulates (TSP), photochemical oxidants (O_x), and lead (Pb) (Environmental Research and Technology, Inc., 1983). In areas meeting these NAAQS, major facilities are subject to Prevention of Significant Deterioration (PSD) requirements. New fossil-fuel steam electric plants are required to apply for a PSD permit if expected emissions of any of the regulated pollutants will exceed 90.7 tonnes/year (100 T/yr). For modifications to existing plants, a PSD permit is required if net emissions increase will exceed any value on an established "de minimis" emissions list (Table 1).

Solid ash produced from the burning of coal is typically in two forms: fly ash and bottom ash. Fly ash consists of finer particles, less than 0.08 mm (Woodward-Clyde Consultants, 1981b), which are removed from the smoke and flue gas before it is emitted from the stack, while bottom ash is

Table 1. "Deminimis" emissions limits, beyond which the Clean Air Act requires Prevention of Significant Deterioration (PSD) permits of electric plant modifications.

Pollutant	Emission Rates (t/yr)
Carbon monozide	90.7
Nitrogen oxides	36.3
Sulfur dioxide	36.3
Particulate matter	22.7
Ozone (volatile organic compounds)	36.3
Lead	0.5
Asbestos	0.006
Beryllium	0.00036
Mercury	0.09
Vinyl chloride	0.9
Fluorides	2.7
Sulfuric acid mist	6.3
Hydrogen sulfide (H_2S)	9.1
Total reduced sulfur (including H_2S)	9.1
Reduced sulfur compounds (including H_2S)	9.1

heavier and more coarse grained, 0.3-4.8 mm in size, removed from the floor of the boiler furnaces. The NAAQS established for SO_2 concentrations specify 80 $\mu g/m^3$ (0.03 ppm) as an annual arithmetic mean, and 365 $\mu g/m^3$ (0.14 ppm) as a maximum 24-hour concentration, not to be exceeded more than once per year (General Services Administration, 1983). New generating stations which burn high-sulfur coal as fuel are required to install flue gas desulfurization (FGD) systems for SO_2 removal.

Nesbit (1982) describes one of the more common conventional FGD systems in use today, the wet scrubber system. An alkaline reagent, lime or limestone, is mixed with water and then sprayed into the flue gas produced during coal combustion. The SO_2 in the gas is absorbed in the slurry, and calcium sulfite ($CaSO_3$) and/or calcium sulfate ($CaSO_4$) precipitates out for disposal. The wet slurry is approximately 90% water and 10% solids. Once the sulfur is absorbed, the slurry is pumped to a thickener where solids settle out of suspension before going on to a filter for further dewatering. This material, FGD sludge or scrubber sludge, may at some point be mixed with fly ash and/or lime before being pumped to settling ponds for disposal. Cleaned flue gas flows upward past the slurry nozzles into a demister which removes any large slurry droplets still in the gas. Gas may then be reheated to provide it the buoyancy to rise up the stack for release.

While scrubber systems may account for as much as 25% of the capital and operating expenses of a new generating station, once in operation a wet scrubber typically uses 3-5% of total plant energy (Nesbit, 1982). VanNess et al. (1981) estimated that lime or limestone wet scrubbers will account for most S or SO_2 removal at powerplants in the U. S. for the next 10-15 years.

Solid waste disposal at coal-fired generating plants is a problem well documented. In 1977 coal ash ranked among the 10 most abundant solid minerals produced in the U. S. (Wester and Trlica, 1977), with the increasing volume creating a tremendous problem of recycling or disposal. Twelve years ago this country's utilities were reportedly producing over 27 million tonnes (t) of fly ash annually, yet less than 15% was being recycled for some commercial use (Adams et al., 1972). In 1974, the U. S. consumed 363 million t of coal for the generation of electricity, and produced nearly 55 million t of bottom ash, fly ash, and other boiler refuse (Elseewi et al., 1980). Adriano et al. (1980) have determined that only 20% of the total waste residues from coal combustion is commercially utilized, requiring disposal of the remaining 80%. In 1981 alone, U. S. powerplants larger than 100 megawatt (MW) capacity burned 513 million t of coal and produced 44 million t of fly ash, 16 million t of bottom ash, and just under 3 million t of scrubber sludge and other by-products (Utility Data Institute, 1983). Of this quantity, commercial utilization recycled 8.0, 18.0, and 0.1%, respectively, for a total of 6.4 million t, leaving over 56 million t for disposal.

The LaCygne Generating Station, owned jointly by Kansas City Power & Light Company (KCP&L) and Kansas Gas & Electric Company (KG&E), is a coal-fired powerplant located in eastern Kansas south of Kansas City (Fig. 1). The station consists of two boiler-turbine units: No. 1 is an 800-MW capacity unit, with a maximum burning rate of 526 t/hr, which began operation in 1973; No. 2 is a 650-MW capacity unit, with a maximum burning rate of 363 t/hr, operating since 1977 (Woodward-Clyde Consultants, 1981b; Utilities Division, K.C.C., 1977; KCP&L-KG&E, undated). Coal used for fuel in Unit No. 1 is mined locally in eastern Kansas and western Missouri and contains 24-25% ash and approximately 5% S, while Unit No. 2 burns coal

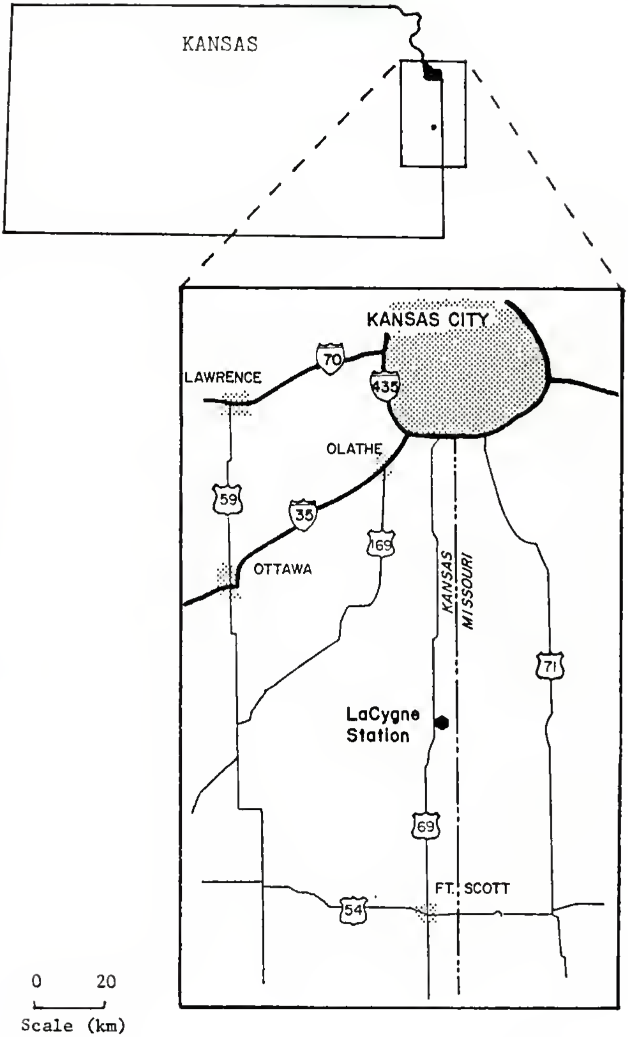


Figure 1. Location of the LaCygne Generating Station in eastern Kansas, south of Kansas City.

mined in eastern Wyoming, containing 5% ash and less than 0.5% S (McPhee, 1974; Woodward-Clyde Consultants, 1981b).

Because of the high-sulfur fuel source, Unit No. 1 is equipped with a wet scrubber system consisting of eight two-stage venturi absorber scrubbers, using limestone slurry. Fly ash is removed from the gas in the first stage and S compounds removed in the second, and the scrubber sludge is discharged to storage ponds. LaCygne/Unit No. 2 is not equipped with an FGD system since it burns low-sulfur coal. Fly ash removal from Unit No. 2 is accomplished by means of an electrostatic precipitator which causes particles in the flue gas to become electrically charged and cling to metal plates within the system (KCP&L-KG&E, undated. The dry ash is then deposited into hoppers for removal to storage areas. Bottom ash removal, or cleaning of the furnace floor, is similar for both units.

Descriptions of all LaCygne waste products, as well as annual production rates, were outlined by Woodward-Clyde Consultants (1981b). Unit No. 1 bottom ash is a black, glassy material resembling coarse sand, ranging in size from 0.3 to 4.76 mm. It is high in silica (SiO_2), ferric oxide (Fe_2O_3), alumina (Al_2O_3), lime (CaO), and sulfite (SO_3). Unit No. 1 scrubber sludge consists of $CaSO_3$ and $CaSO_4$, unreacted limestone, fly ash and water. If kept wet, this material is thixotropic, or very difficult to stabilize, but dewatering improves handling capabilities. Unit No. 2 bottom ash is brown, granular, and slightly finer-grained than Unit No. 1 ash. It is also high in SiO_2, CaO, Al_2O_3, and Fe_2O_3. Unit No. 2 fly ash is very fine-textured, less than 0.03 mm diameter, dry and powdery, high in SiO_2, CaO, and Al_2O_3. It is sometimes used as a cement substitute. Breaker rejects are 8-25 cm diameter rocks, acidic and high in pyrites, which are rejected from the coal crushing equipment of Unit No. 1. They have no known commercial use at this time.

Annual estimated production rate figures for all these materials (Table 2) indicate that the LaCygne station generates 926,055 t of waste each year, with only 240,355 t (25%) recycled. Just over half (51.5%) the Unit No. 1 bottom ash is recycled annually for use as foundation stabilizing material, railroad bed ballast, concrete block aggregate, sand-blasting grit, asphalt pavement additive, and in roofing shingle fabrication. Half (50.5%) the Unit No. 2 fly ash is commercially recycled as structural fill material and as a concrete additive. Recycling of scrubber sludge, produced at a rate of 1,270 t per day of operation, has been attempted by means of either gypsum production, return to the mine site, or by application to agricultural land, but is uneconomical atthis time.

It has been estimated (Woodward-Clyde Consultants, 1981a) that at agricultural application rates of 22 t/ha (20 T/acre) per year, somewhat less than 3,644 ha (9,000 acres) of farmland would be needed to dispose of all the Unit No. 2 bottom and fly ash produced at LaCygne in one year. Although all materials have been determined non-hazardous, no other recycline alternatives existed at this time.

Storage piles for bottom ash are approximately 10 m high, segregating No. 1 from No. 2 ash (Woodward-Clyde Consultants, 1981b). The breaker rejects are disposed adjacent to the bottom ash storage and are buried in a pile of No. 2 bottom ash to cover them and fill all void spaces, to safeguard against acid runoff and possible combustion of the material (Woodward-Clyde Consultants, 1981a).

The thixotropic nature of Unit No. 1 scrubber sludge makes this material difficult to stabilize in a disposal pond without adequate drying. Leaching of some trace elements such as Ca, SO_4, and Cl into surrounding soils may also be a problem, yet addition of alkaline material to slude has been shown to increase particle strength and reduce permeability (VanNess

Table 2. Annual estimated dry-weight production and recycling rates of LaCygne Generating Station waste materials.

MATERIAL	ANNUAL PRODUCTION (t)	ANNUAL RECYCLING (t)
Unit No. 1 bottom ash	370,056	190,470
Unit No. 1 scrubber sludge	463,477	none
Unit No. 1 breaker rejects	4,898	none
Unit No. 2 bottom ash	24,761	none
Unit No. 2 fly ash	98,863	49,885
	962,055	240,355

et al., 1981). It was further determined that 30-40% moisture is optimum for maximum compaction and stability of sludge solids.

Waste dumps of various types in Kansas and other states typically incorporate into their management schedules plans for final closure, usually involving soil as a cover material. Within 30 days of closure of a construction and/or demolition waste dump, the site must be covered with at least 60 cm (2 ft) of compacted earth material, before seeding to vegetation as soon as is practical within normal growing seasons (Kansas Department of Health and Environment, undated). A solid waste site closure plan must include plans for the final type and depth of cover material, with odors and particulates controlled by daily covering or other acceptable means (Kansas Department of Health & Environment, 1982). Regulations concerning sanitary landfills are identical for both Kansas and Missouri, each requiring a compacted cover layer of at least 15 cm (6 inches) at the end of each 24-hour working period, with a final cover of at least 60 cm in addition to this dialy requirement (Kansas Department of Health & Enironment, 1983; Missouri Department of Natural Resources, 1977).

Disposal of powerplant waste materials also involves the outlining of closure procedures for specific disposal areas once these are no longer in active use. Typically, such procedures call for the area to be covered with approximately 60 cm (2 ft) of soil and then planted to vegetation (Woodward-Clyde Consultants, 1981b; Cutright, 1982). This poses another problem in that it would be very costly to acquire and relocate the necessary volume of soil. Furthermore, large areas may have to be stripped of topsoil, leaving them in an unproductive state and in need of additional reclamation.

Powerplants in Kansas are not bound by a single set of regulations concerning type or depth of coverage to be used for each disposal area.

A disposal plan unique to each facility must be prepared for review by the Kansas Department of Health & Environment (KDHE) before an operating permit is issued (Joseph E. Cronin, Engineering & Sanitation Section, KDHE, personal communication). A depth of 30 cm (1 ft) has been shown to be effective in fulfilling the primary objectives of a soil cover: supporting vegetation, restricting infiltration of precipitation, and resisting erosion (Knight and Rothfuss, 1983). Woodward-Clyde Consultants (1981b) have recommended establishing a maximum 46-cm (18-inch) cover, to be used as a tentative procedure depending upon the outcome of the revegetation study described in this report.

Woodward-Clyde Consultants (1981b) estimate it would require 252,000 m^3 (9 million ft^3) of soil to place a 46 cm cover over the retired ash and sludge areas at LaCygne, totaling 54 ha (134 acres). If topsoil were a uniform 1 m depth this would require stripping 27 ha (67 acres) of land. This computes to approximately 4,667 m^3/ha (67,467 ft^3/acre) covered, or a requirement of 0.5 ha (1.2 acre) of farmland per ha of disposal area. The Riley County Extension Council quoted an April 1984 average selling price for topsoil of \$65-\$78/m^3 (\$50-\$60/yd^3), for a total cost of approximately \$326,690/ha of reclamation.

The Federal Lank Bank in Ottawa, Kansas, quoted average selling prices of Linn County pasture land at \$741/ha (\$300/acre), cropland at \$1,279/ha (\$525/acre). If 0.5 ha of farmland were needed per ha of disposal area, costs would be at least \$370/ha and as much as \$650/ha to purchase this land. It is probably unrealistic to consider that pasture land or even any but the better cropland would yield 1 m of topsoil, so the upper range of this cost should be assumed.

Based on these figures, if plant operators wished to reclaim the 54 ha of retired disposal area using the recommended 252,000 m^3 of soil, the cost of simply purchasing the soil would be over $17.6 million. Assuming labor and transportation costs for placing this volume of soil were 50% of material cost, this would add $8.8 million for a total cost of $26.4 million. There are presently an additional 213 ha of disposal areas in active use, which will be considered for closure within the next 12-15 years (Woodward-Clyde Consultants, 1981b). At today's figures, the estimated cost of covering these areas with purchased topsoil would be $104.5 million, added to the previous figure yields a total cost of $130.9 million.

If the operators wished instead to purchase farmland outright from which to remove topsoil, the cost for enough land to provide a cover for 54 ha would be $35,100. Labor costs would be higher, since topsoil has to be stripped from the surface for removal to the powerplant. Assuming these costs at least equal to the land price itself, total cost rises to $70,200. If one estimates the cost of relcaiming the denuded farmland at equal its original price, the price triples to $105,300. To cover the remaining 213 ha of active disposal area, another $415,350 is added to the cost, producing a total of $520,650.

The price for this type of disposal method by KCP&L and KG&E, and ultimately by their customers and shareholders, is obviously quite restrictive. Yet the waste areas must be reclaimed to prevent or reduce wind and water erosion, and to restore the aesthetics of the region. Vegetation planted into the soil cover provides the most suitable closure technique for these areas, and this has generated an interest in growing plants on the surface of the ash and/or scrubber sludge itself.

The objective of this research, therefore, was to investigate the potential for vegetating the waste disposal areas at the LaCygne plant without using topsoil. This alternative could provide the same beneficial effects as topsoil but at a much lower total cost. The primary research was split into two segments. Phase I, extending from 1 April 1982 to 31 March 1983, was exploratory in nature, evaluating potential plant species and determining the nature of the ash substrates as well as characterizing invading vegetation. Phase II, 1 April 1983 to 31 March 1984, utilized 1982 experimental results as the basis for expanded field tests to further refine the methodology and to evaluate second-year growth on the disposal areas.

LITERATURE REVIEW

Nature and Properties of Coal Ash

Throughout this review, each initial reference to a plant species will include its scientific name. Where none was given by the citation indicated, names were supplied by referring to one of the following: Stephens (1973), Bailey (1976), Barkley (1983), or Great Plains Flora Association (1977).

The interest in waste ash and the question of what to do with it have generated a great deal of research in the past. Ash has been analyzed to reveal its content and been tested to determine its potential use as a soil additive and plant growth stimulator. Most vegetative and planting studies documented for coal ash refuse have dealt primarily with fly ash or scrubber sludge. Therefore, characteristics and properties of these are more widely reported than those of bottom ash. One study which did test bottom ash as a growth medium (Wester and Trlica, 1977) noted a strong "pozzolanic" or cementing effect of the ash when watered, which severely restricted root development in potted western wheatgrass (*Agropyron smithii* L.). The plants exhibited severe leaf chlorosis and dying of the growing tips.

The textural quality and particle size of fly ash from various sources tends toward a primarily silty characteristic. Fly ash particle size distribution has been estimated to be 80% silt and 20% sand (Nebgen et al., 1978), such that addition to fine clays and coarse sandy soils would shift them toward medium-textured loamy soils. Based on these determinations, fly ash application of 224 t/ha (100 T/acre) would add 1-2 cm to the topsoil. Jacobs et al. (1982) reported three fly ashes as being 63-80% silt, with a capacity to hold 30-50% available water. Pulverized fuel ash

(PFA) in England was reported to be 60% fine sand (0.2-0.02 mm) and 40% silt (0.02-0.002 mm), and that approximately 1% of the particles floated on the disposal lagoon surfaces, causing problems from the blowing dust (Brown, 1982).

Virtually all trace elements are present in some quantity in fly ash, generally found high in calcium (Ca), magnesium (Mg), and potassium (K) (Adriano et al., 1980), and it is described as an "amorphous ferro-alumino silicate", indicating its content of specific metals. It has been determined that as fly ash particle size decreases, some elements increase in concentration, notably lead (Pb), thallium (Tl), antimony (Sb), cadmium (Cd), selenium (Se), arsenic (As), zinc (Zn), nickel (Ni), chromium (Cr), and sulfur (S) (Davison et al., 1974). In sampling fly ash from a number of locations, levels of boron (B), phosphorus (P), and Zn were found to be higher than normal surrounding soils (Martens, 1971). However, it was also further determined that adding alkaline fly ash to zinc-deficient soils would further decrease levels of available Zn (Plank and Martens, 1973).

Although PFA is seen as characteristically similar to British mineral soils, it is completely sterile and virtually devoid of all nitrogen (N) due to its combustion process (Brown, 1982). Graham (1981) typifies PFA as being deficient in N, with a lack of bacteria, and high in pH and soluble salts. High aluminum (Al) content may inhibit or reduce P-availability, and ash-applied B in soil may cause toxicity problems for non-tolerant species, especially in the first growing season. Phosphorus and K found in scrubber sludge were in forms probably not immediately available to plants, and relatively heavy applications were suggested to provide long-term sources of nutrients (Nebgen et al., 1978). Barium (Ba) here was seen as a potential problem, but evidence suggests that a Ba-Se complex may be formed which reduces the toxic potential of each. Chloride (Cl) likewise may pose salinity problems, but these will likely be insignificant (Nebgen et al., 1978).

Acidic New York fly ash was found to contain 32 of 42 elements tested in higher concentrations than a slightly less acidic soil (Furr et al., 1976), including iron (Fe), molybdenum (Mo), B, K, and Mg. The soluble salt content of fly ash is usually 1-3% except where excess salts are injected into the precipitator during cleaning (Kussow et al., 1980). This research suggests very rapid leaching of sodium (Na), B, and sulfate-sulfur (SO_4-S) from fly ash-amended soils. Kussow and Schulte (1981) suggest that the rate of fly ash leaching is influenced by soluble salt content, with the major leachates consisting of Na, S, B, Al, K, and P. These materials were seen to dissolve large quantities of organic matter from soils, raising pH considerably.

The pH of fly ash varies, but seems to remain relatively constant for the same fly ash whether fresh or old and weathered, with N being the only macronutrient always at low levels (Hodgson and Holliday, 1966). Fly ash added to acidic soils such as mined areas can provide some trace and major nutrients, as well as neutralizing acidity (Capp and Gillmore, 1974). Fly ash from a Nevada powerplant contained 0.4% S, which was as available as gypsum-S to certain crops (Elseewi et al., 1978). In England, the available water capacity (AWC) of coarse soils was elevated by addition of fly ash to the top 30 cm, making these soils potentially more suitable for plant growth (Salter and Williams, 1967).

Of the elements found in coal ash, B seems to have attracted the most research attention from the viewpoint of plant toxicity. As the AWC of soils increased with fly ash applications, higher ash concentrations simultaneously resulted in reduced root development, which was hypothesized to be due to "toxic quantities" of B (Salter and Williams, 1967). A normal soil concentration is suggested as 10 ppm, with a range of 2-100 ppm (Allaway, 1968). It has been concluded that for unweathered fresh fly ash, B was the dominant toxic element present (Holliday et al., 1958). Levels have been seen to be considerably reduced in lagooned ash compared with precipitator ash, even when weathered as much as 10 years (Rippon and Wood, 1973).

Analysis of fly ashes from 15 U. S. powerplants revealed a B content ranging 234-618 ppm, with higher levels associated with elevated pH and concurrent decline in Zn, to possible deficiency levels (Mulford and Martens, 1971). Zinc content of fly ash ranges 12.9-378.2 ppm total Zn, and 1.5-93.0 ppm acid-extractable Zn, with pH determining availability to corn (Zea mays L.) (Schnappinger et al., 1975). More recently, both B and Se were found at elevated levels in tissues of fly ash-grown apple trees (Furr et al., 1979). Allaway (1968) suggests normal soil levels of Se to be approximately 0.5 ppm, with the element being non-essential for plant growth.

A variety of plants grown in fly ash/soil mixtures and in water from an ash settling pond all had elevated B levels (Romney et al., 1977). These levels were not considered toxic but it was believed they could be raised even higher with greater ash concentrations, possibly to toxic levels. On the other hand, fly ash added to B-deficient soils improved plant production by making the element more available (Plank and Martens, 1974). But it is believed that too much fly ash may cause soluble salt damage to plants. In studies with ash-grown barley (Hordeum vulgare L.), B was the only element reported at toxic concentrations in plant tissues (Hodgson and Holliday, 1966).

Greenhouse Tests of Ash and Plant Growth

There have been a number of studies conducted in recent years to record the effect of growing plants in ash in greenhouse pots. Bottom ash from a Wyoming power plant (pH 11.8) was mixed with Colorado prairie soil (pH 7.4) to grow a variety of plant species (Wester and Trlica, 1977). Neither survival nor germination were affected by the ash, but plant height and biomass production were significantly restricted with higher ash concentrations. From this it was concluded that ash limitations seemed not to affect germinating seeds but produced stunting and deficiency symptoms in later plants which could eventually make them unfit in a natural environment. Furr et al. (1976) determined that 13 of 42 elements tested were higher in the edible plant tissues of bush bean (*Phaseolus vulgaris* L.), cabbage (*Brassica oleracea* var. *capitata*), carrot (*Daucus carota* var. *sativa*), onion (*Illium copa*), potato (*Solonum tuberosum*), tomato (*Lycopersicon esculentum*), and Japanese millet (*Echinochloa crusgalli* var. *frumentacea*) grown in ash-amended soils than in untreated soil. Increases occurred in levels of As, B, Ca, Cu, Fe, K, Mg, Mo, Ni, Se, Sb, mercury (Hg), and iodine (I). Uptake of Se was directly proportional to fly ash application rate.

Coal mine refuse, or "gob" (pH 3.5), amended with alkaline fly ash was inferior to refuse mixed with either soil or lime for growing tall fescue (*Festuca arundinacea* Schreb.) and smooth bromegrass (*Bromus inermis* Leyss) (Hastrow et al., 1981). Increased levels of Cd, Co, Fe, Mn, vanadium (V), and Zn were found in fly ash mixes, with some levels near toxic. A variety of crops, including apples and vegetables, were grown in mixtures of soil and acidic (pH 4.5) New York fly ash (Furr et al., 1979). Tissue accumulations of Co, Fe, Mn, Cu, Mg, Zn, and Mo were higher in most plants on the higher ash concentrations.

Greenhouse applications of 22 t/ha (10 T/acre) fly ash to soil were reported to contain all the B, Ca, Mn, Mo, and S required by 13 kl/ha (150 bu/acre) corn, and 15-30% of the required Mg and Zn (Schulte and Kussow, 1982). Heavy metals were reportedly quite similar to normal soil conditions. Soybeans (Glycine max) in this study responded more favorably to fly ash than did corn or oats (Avena sativa L.), probably due to a higher tolerance for B. Stunting of alfalfa (Medicago sativa L.) was attributed to soluble salt damage at the highest fly ash applications. Adriano et al. (1978) found yields of corn and bush beans grown in soil amended with fly ash (pH 6.3) were equal to those on a soil control, but less than those on an N-P-K fertilizer treatment. Phosphorus was deficient in both crops, Cu, Mn, and Zn were somewhat below normal, while Fe was normal. Boron toxicity symptoms occurred in beans only. Salinity, B-toxicity, and P-deficiency were suggested as limitations to the use of ash as a soil treatment.

Shoot weights of brittlebrush (Encina farinosa) and yields of barley were significantly increased by application of fly ash to two western soils, with incrased pH and levels of salts, Ca, Mg, Na, B, and SO_4-S (Elseewi et al., 1980). Boron and SO_4-S had little initial release but tended to increase with cropping. Ash additions decreased the availability of P, Zn, Fe, and Mn. A positive plant response was seen to both S and Mo, but a lowered Cu:Mn ratio in tissues could pose problems of toxicity for grazers. Applications of fly ash high enough to provide more than 0.2 mg B/21 g soil decreased the yield of alfalfa, believed due to Zn deficiency from an elevated pH (Mulford and Martens, 1971). Uptake of B increased as pH increased.

Various fly ashes mixed with soil increased K uptake by corn plants, but were not equal to lesser applications of potassium-chloride (KCl), with somewhat better yields even at the same rate of uptake (Martens et al., 1970). Tissue analysis suggested that too much B was responsible for decreased yield in ash-grown plants. Some of the ashes used increased uptake of Mg, probably reducing K uptake. Calcium was not available enough to significantly affect K uptake. Elseewi et al. (1978) reported that fly ash containing 0.4% S produced improved yields and S-content of turnip (Brassica rapa L.) and white clover (Trifolium repens L.) equal to that of gypsum application.

Fly ash applications of up to 20% by weight in sand increased water retention while still maintaining the necessary 10% air-filled porosity for plant growth (Jacobs et al., 1982). An unusual finding of this study was that soybeans were more sensitive to B and soluble salts in general than corn, with reductions occurring at lower levels. The acid neutralizing ability of three fly ashes tested was further determined to be minimal and not a good substitute for aglime. This was suggested partially the result of the low residual lime content of the eastern coals which produced these ashes. Levels of Mo were significantly increased, but no plant toxicity was observed although danger to grazers was suggested. This study concluded by stating that application rates to supply some nutrients to soil would have to be so high that B and salts could be problems, while addition of fly ash to fine-textured soils would make them worse, increasing surface crusting.

Use of Ash in Mined Land Reclamation

In attempts to reclaim disturbed mine areas, a 4-5 cm layer of fly ash has achieved comparable results to a much deeper layer of topsoil (Babcock, 1973). Tall fescue and other hay species grew well on acidic West Virginia mine spoils treated with fly ash (Adams et al., 1972), comparing favorably with native pastures. Addition of fly ash to acidic (pH 4-6) Alabama mine spoils proved an effective neutralizer and improved growth of soybeans (Fail and Wochok, 1977). These fly ash areas did not produce as well as nearby farmland, but were superior to mine refuse which received no fly ash treatment.

Application of up to 336 t/ha of fly ash to strip mine spoils reportedly neutralized acidity, increased P availability to plants, and lowered the substrate density, which increased water percolation leading to increased subsurface water reserves (Plass and Capp, 1974). Further benefits noted were textural changes to allow root penetration and growth, reduction of erosion due to germination of a quick cover of grasses and legumes, the beneficial disposal of large quantities of waste ash (Adams et al., 1972), as well as addition of some trace and major nutrients to the substrate (Capp and Gillmore, 1974). The soil levels of not only B but also P and Zn were able to be elevated by adding fly ash to soils deficient in these elements (Martens, 1971).

In some areas, the natural colonization of ash deposits and mine spoils is significantly different from that of other waste ares (Rees and Sidrak, 1956), and these colonizing invaders tend to be mostly short-lived species. Two major problems cited for waste areas have been wind exposure and surface temperatures (Bramble, 1952). Wind is a concern not only because of erosion but also for its role in influencing evapotranspiration and in increased drying of surface lands. Extreme surface temperatures, especially on dark-colored lands, can restrict the vegetation process. Common spoil bank temperatures of 130° F (54.5° C), reportedly may be lethal to tree seedlings which have not developed a corky bark.

Application of 1,344 t/ha (600 T/acre) of fly ash neutralized highly acidic mine spoils and created a mixture more suitable for germination of seeds and subsequent plant growth (Adams et al., 1971). A variety of grasses and legumes, including K-31 tall fescue, ryegrass (Lolium sp.), and birdsfoot trefoil (Lotus corniculatus L.) flourished on the ash-amended spoils, producing good yields. Voles fed forage from the ash areas and from normal soils produced significantly equal weight gains. Addition of fly ash to these spoils increased the AWC, at the same time improving the microbiological climate in the rooting zone. Kovacic (1972) estimated that for situations where transport costs could be reduced, such as at mine-mouth powerplants, fly ash can be successfully and economically used to modify acid mine spoils in Kansas. Test plots demonstrated that fly ash improved the soil for agricultural purposes, particularly for planting fescue for cattle grazing.

Effects of Ash and Soil Mixtures

Research into use of ash an an agricultural soil amendment is important as a disposal alternative. It has been estimated that approximately 45-60 cm (1½-2 ft) of topsoil is needed to sustain adequate growth on coal refuse piles (Babcock, 1973). This is similar to guidelines suggested for sanitary landfill reclamation (Gilman et al., 1983), recommending a 60 cm soil cover for grass establishment, 90 cm for trees, with a quick grass cover recommended for stabilization on sloping areas. A fly ash pond in England yielded reasonable success in producing cover with the addition of 15 cm of topsoil from a sugar beet refinery prior to seeding (Gillett, 1974). Red beets (Beta vulgaris) were grown on a series of test plots in a range of ash/soil mixture ratios, the ash being introduced into the top 30 cm of the soil (Salter and Williams, 1967). The highest ash concentration resulted in a 9% reduction in root development, believed due to toxic levels of B.

Fly ash added to soil deficient in certain elements, notably B, increased plant growth by making these elements more available (Plank and Martens, 1974). But alkaline fly ash tended to decrease the amount of Zn available to plants, and so was not recommended for soils already deficient in this element (Schnappinger et al., 1974; Plank and Martens, 1973). Levels of available B and Mn responded oppositely to fly ash applications on agricultural soils, Mn decreasing with an elevated pH while B increased (Walker et al., 1979), sometimes high enough to adversely affect crop yields. No other elements were significantly affected in this study. This same situation was attributed to be responsible for improved yields of alfalfa under test conditions, the crop reportedly responding more favorable to B on fly ash-amended soils than on aglimed soils, and a positive response to significant reductions in uptake of Mn (Kussow et al., 1980). Alfalfa was therefore suggested as a good candidate crop for fly ash applications, with a recommended pH of 6.6. Alfalfa was also chosen for vegetating soil-covered ash dumps in Wisconsin, partially because of its tolerance to B (Curtight, 1982).

Schulte and Walker (1977) have reported that higher rates of fly ash application were necessary to reduce alfalfa yields on the second and third cutting than on the first. Boron symptoms were observed in corn which followed the alfalfa, and it was hypothesized that B would reduce oat yields at levels which would not harm alfalfa. However, when all plots of all species were irrigated, no reductions were observed in any crops, due to dissipation of the B. It was later recommended that fall applications of fly ash allow time for soluble salts to dissipate and B to become fixed with soil particles (Schulte et al., 1981), after which light applications every four to five years could help maintain a desired pH and provide a ready source of available S. Alfalfa protein content increased significantly due to higher N-fixation stimulated by a higher pH.

Molybdenum present in fly ashes tested by Doran and Martens (1972) was equally available as that found in some commercial fertilizers, with soil pH change similar for each. They did however warn that too much ash could present problems of molybdenosis poisoning for grazing livestock on ash-grown forage. When used on less acidic soils, pH 5.8 or above, lower ash rates which reduce toxic potentials have been highly recommended as a soil additive, reportedly neutralizing acidity quicker and more effectively than aglime (Kussow et al., 1978), possibly as a result of its finer particle size (Schulte and Kussow, 1982). Less than one-quarter of the Ca and only one-third of the B present in ash was seen in forms available to plants, with S present as SO_4 subject to leaching. Because of a more favorable root environment created by fly ash application, N, P, K, and Mg all increased in corn tissue, as did S and B. Reductions in both Mn and Zn were observed. Field corn increased yield with one 22 t/ha (10 T/acre) application of fly ash, but repeated doses had a negative effect, while B-tolerant sunflowers (*Helianthus annuus* L.) grew equally well on soil and on soil/ash mixtures.

Elevated tissue levels of Cd, Pb, and Se were observed in ash-grown plants, but growth was not affected (Graham, 1981). Arsenic was present in ash more than was Se, but Se was seen to be taken up more readily in grasses. This study determined that while total Se declines with time, that available to plants actually increases, which was concluded to indicate an association with soil humus content. Patterson and Capp (1970) applied sintered (pelleted) fly ash into the top 15 cm of intensively-used turf areas, characterized by poor drainage, and reported modification of the substrate to allow water infiltration. Grass yields observed were significantly higher on ash-treated areas than on untreated controls receiving no fly ash. Furr et al. (1979) reported that apple trees from soil/fly ash mixes showed elevated concentrations of some elements over soil-only plants, but no toxicity symptoms were observed.

Nebgen et al. (1978) suggested that application of 1,120 t/ha fly ash to soil could effect a 10% yield increase in corn, soybeans, oats, and smooth bromegrass, with little effect on wheat (*Triticum aestivum* L.). They concluded that agricultural application was a better method of disposal than storage in unlined ponds, asserting that soil depth is not great enough to contain all the trace elements. At pH above 5 or 6, reductions in availability of Al, Be, Cd, and Zn can be expected, with increases in Se and Mo. High levels of Ba may tend to occupy exchange sites to the exclusion of necessary elements, while Co is seen as a soil benefit of ash application. They found B to be the primary plant inhibitor present, but observed it to weather and become less available after one or two years. Adriano et al. (1980) cautions that several factors should be explored before fly ash is widely used as a soil amendment for improved conditions: 1) loss of N in soil due to increased pH; 2) fixing of P and other nutrients; 3) accumulation of some elements by plants at "dangerous levels"; 4) decreased microbial activity; and 5) use of ash in conjunction with high-carbon materials such as sewage sludge, peat, or manure.

Vegetation of Ash Disposal Areas

In comparing ash of various sources, nearly a three-fold increase in yields of barley plants grown in lagooned ash was recorded over those plants in ash fresh from the precipitator (Rippon and Wood, 1974). The pH was reduced more with lagooned ash, N content and was 12 times higher, while P and B were much less. High amounts of rainfall resulted in a drop uptake of B by ryegrass plants on fly ash, increasing forage yields. Rippon and Wood (1974) concluded that the lagooning process removes many soluble salts and may add small quantities of nutrients.

Ash dumps in Pennsylvania were observed to naturally revegetate quite slowly, with 5-year-old areas still supporting little vegetation (Ghiselin and Shaw, 1977). Invasion of these areas appeared to originate at the edges, where it was theorized the ash was thinner and plants could more readily begin growth. Reclamation attempts at a KCP&L generating station in western Missouri have met with some success in stabilizing mixtures of fly and bottom ash (Brown and Vassar, 1983). Both cool and warm season species have been utilized, with salt cedar (*Tamarix* sp.) and kochia (*Kochia scoparia* (L.) Schrad.) the dominant invaders.

Furr et al. (1975) observed yellow sweetclover (*Melilotus officinalis* (L.) Lam.) naturally invading a 5-m deep fly ash pond in New York, producing a thick stand 1-1½ m tall. When this clover was harvested and processed into commercial pet rations and fed to a group of guinea pigs, they observed 28 of 35 elements higher in ash-grown clover than soil clover, with 19 of these occurring in higher concentrations in test animals than controls. Rubidium and Se were always three times higher in tissues of test animals, but no toxicity symptoms were observed. Further effects of ash-grown forage plants on the animals that eat them were tested when wild white sweetclover (*Melilotus alba* Medic.) was fed to lambs and pregnant goats (Furr et al., 1978). Elevated levels of Se, Mo, Sr, Br, and Rb were detected in various animals, such that dietary levels were above normal recommendations. No toxic symptoms developed in any animals, but it was believed this was because the feeding time (173 days) was not long enough for these to manifest themselves. The conclusion was that fly ash could be used as a soil amendment but should not be a primary base upon which to produce food-chain crops.

Several tree and shrub species were tested for growth directly on fly ash, with half the plants grown utilizing a 10 cm soil cover (Scanlon and Duggan, 1979). Nitrogen-fixers (*Elaeagnus* and *Alnus*) did well and were recommended for fly ash plantings. Boron accumulations were high but no toxic symptoms were observed. The topsoil addition helped reduce erosion but did not significantly affect tree growth or survival. On a 12-year-old abandoned Georgia bottom ash basin, 1-year-old loblolly pine (*Pinus taeda* L.), longleaf pine (P. *palustris* Mill.), sweetgum (*Liquidambar styraciflua* L.), and American sycamore(*Platanus occidentalis* L.) were planted in test blocks (McMinn et al., 1982). Survival after four years was significantly better on ash than on soil control plots for all species. Height, basal diameter, and "plot volume index" were all higher on ash-grown hardwoods, while pine was better on soil. Even though higher elemental concentrations were observed in ash, soil-grown trees had elevated levels in their tissues possibly due to higher ash pH which reduced availability to plants on this substrate.

Plant Species Used for Reclamation

Various species of plants have been tested to determine their usefulness in reclamation of disturbed sites such as disposal areas or mined lands, and other species have been documented as natural invaders of such areas. Acidic West Virginia mine spoils treated with alkaline fly ash were successfully planted to a variety of forage crops including sirecea lespedeza (*Lespedeza cuneata* (Dumont) G. Don), weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), ryegrass, birdsfoot trefoil, and alfalfa, while K-31 tall fescue was consistently a superior grower (Adams et al., 1972). Eight forage species which were used for planting of mined lands in Kentucky also included tall fescue, two varieties of sirecea lespedeza, two species of bluestem (*Andropogon* spp.), indiangrass (*Sorghastrum nutans* (L.) Nash), switchgrass (*Panicum virgatum* L.), and crownvetch (*Coronilla varia* L.) (Henry et al., 1981).

Species naturally invading Pennsylvania ash dumps included not only "opportunistic" plants such as ragweed (*Ambrosia* sp.) and brambles (*Rubus* sp.), but also milkweed (*Asclepias* sp.) and horsetail (*Equisetum arvense*), with the greatest number and variety of species found on older (25-30-year-old) dumps (Ghiselin and Shaw, 1977). Woody invaders included aspen (*Populus* sp.), willow (*Salix* sp.), white ash (*Fraxinus americana*), and silver maple (*Acer saccharinum*). In the wooded areas the beginnings of a soil profile were observed, with humus extending approximately 8 cm deep. Brown and Vassar (1983) tested several species for growth on mixtures of fly and bottom ash in Missouri. Western wheatgrass, K-31 tall fescue, bromegrass, alfalfa, and yellow sweetclover were successful cool season plants, while little bluestem (*Andropogon scoparius* L.) and switchgrass were recommended warm season plants.

At a powerplant in Tennessee, a slurry pond surface was planted to tall fescue and white sweetclover, partially fertilized and mulched with municipal sewage (Duggan and Scanlon, 1974), and seedlings of Virginia pine (*Pinus virginiana* Mill) and European black alder (*Alnus glutinosa* L.) were planted successfully. Pioneer woody species recorded as successfully invading Pennsylvania strip-mined lands (Bramble, 1952) included two aspens (*Populus tremuloides* and *P. grandidentata*), fire cherry (*Prunus pennsylvanicum*), and red maple (*Acer rubrum*), all described as relatively short-lived species. Sycamore, sweetgum, black walnut (*Juglans nigra* L.), cottonwood (*Populus deltoides* Marsh.), red maple, silver maple, and black locust (Robinia pseudoacacia) were woody species which survived 10 or more years on spoil banks in Indiana (DenUyl, 1962).

Of 13 tree species planted on mined lands in Kansas, five exhibited the best survival and growth over a 20 year period: black locust, but oak (Quercus macrocarpa Michx.), sycamore, loblolly pine, and shortleaf pine (Pinus echinata Mill) (Geyer and Rogers, 1972). Survival was best for black locust, but growth of loblolly pine suggested it as a "promising commercial species". Changes which were noted in these spoils after 20 years of tree growth included an increase in soil-sized particles (2 mm) as spoils broke down with exposure, increased pH from 5.6 to 6.1, but a decrease in available P. Neither K nor organic matter concentrations changed significantly. Another study evaluating trees for successful reclamation of strip mine spoils in Kansas recommended cottonwood, black locust, loblolly pine, pin oak (Quercus palustris L.), but oak, autumn olive (Elaeagnus umbellata), and European black alder (Gallagher and Naughton, 1980).

Thirty years after planting, trees which exhibited at least 30% or higher survival on mined lands in Kansas, Missouri, and Oklahoma included bur oak, black locust, and green ash (Fraxinus pennsylvanica Marsh.) (Vogel, 1977), with volunteers primarily consisting of black locust, various elms (Ulmus spp.), dogwood (Cornus sp.), and black cherry (Prunus serotina Ehrh.). Black locust also ranked among the better surviving species in similar plantings in Illinois and Indiana, with moderate success in Ohio, and was considered "the most commonly used tree species" for mined land relcamation. Eastern red cedar (Juniperus virginiana L.), black locust, cottonwood, and European alder are tree species whose described habitat preferences and desirable characteristics (U.S. Environmental Protection Agency, 1976) indicate them as likely candidates for disposal area vegetation, while non-woody species include annual ryegrass (*Lolium multiflorum* Lam.), tall wheatgrass (*Agropyron elongatum* (Host) Beauv.), yellow sweetclover, and tall fescue.

Enhancement of Vegetative Growth by Mulching

The use of mulches is an important aspect in the process of reclaiming or restoring disturbed areas. Increased water availability, decreased surface temperature, erosion control, and addition of organic matter are all benefits derived from mulch. On similar soil plots, average annual moisture was higher with applied mulches of either straw or "trash" (plant material pulled from other areas) than on unmulched areas (Stephenson and Schuster, 1945). Straw mulch also aided by the increase of both nitrate and potassium concentrations, with a significant increase in organic material. Studies of naturally occurring dead plant material on grassland soil cite an increase in water infiltration, a stabilization of the ground-level microclimate by reduction of surface temperatures, and an increase in available soil moisture, even on hot dry days (Hopkins, 1954).

Compared with unmulched areas, an organic mulch can result in higher levels of soluble N, P, K, Ca, Mg, and B (Gourley, 1943), before any other type of fertilizer is added. Five disturbed sites in West Virginia were seeded making use of three mulches: hardwood bark, straw, and wood fiber. Contrary to previous expectations, the wood bark was not toxic to the plants but actually enhanced seedling growth and survival and aided in establishing a quick cover (Sarles and Emanuel, 1977). Straw tended not to stick well, and both straw and wood fiber tended to disintegrate through the winter, while bark continued to give protection. Several forage species were tested in Kentucky using five methods of establishment: 1) broadcast with bark mulch; 2) broadcast with straw mulch; 3) drilled with straw; 4) drilled without mulch; and 5) broadcast without mulch (Henry et al., 1981). After two seasons, cover was greatest on the bark mulch treatment, but by the third year there was no significant difference between treatments.

In testing the effectiveness of cattle manure as a source of plant nutrients, Adriano et al. (1973) found barley and sudangrass (Sorghum sudanense) more tolerant of the salts and ammonia than were spinach (Spinacia sp.) or radish (Raphanus sativus). Germination injury from these materials was observed to be reduced by allowing several days between manure application and planting, to permit volatilization of significant amounts of ammonia; or to irrigate the area before planting to increase leaching. Dried manure was also observed to be more effective than fresh. Further studies on the effectiveness of manuring well in advance of planting (Adriano et al., 1974) reported that higher soil moisture and temperature resulted in higher N losses from applied manure, stating that possibly 50% of the N from dairy manure on uncropped farmland may be lost within a few weeks, mainly as ammonium gas.

When several organic mulches were applied to a fly ash disposal site, most tended to reduce phosphate (PO_4) levels, but increased available N, with poultry manure and sewage sludge stimulating the best yields in barley and perennial ryegrass (Lolium perenne) (Rippon and Wood, 1973; 1974). Reductions in PO_4 may have been due to utilization by microorganisms stimulated by the organic additives. The addition of a PO_4-releasing bacterium further increased the yield and the N and P concentrations of both substrate and crops, as well as improving the activity of N-fixing Azotobacter. Regardless of additive, weathered ash was superior to fresh ash for use as a growth substrate.

Fly ash plots in Tennessee were planted to tall fescue and white sweetclover, partially fertilized and partially mulched with unscreened municipal compost (5% sewage sludge). The best cover was obtained on plots treated with 224 t/ha (200 T/acre) of compost, with control plots of untreated fly ash resulting in only scattered cover (Duggan and Scanlon, 1974). Seeding of trees here was a complete failure, but established seedlings of Virginia pine and European alder were succcessful on all plots.

Summary Statements

Much of the available literature on ash reclamation deals with mined land spoils, with ash as a soil amendment, or with ash in conjunction with a topsoil cover. All of these topics are somewhat irrelevant to the study which will be described here. However, they are valuable from the standpoint of determining what others have done facing similar, though different, conditions, and in reviewing actual techniques used in this expanding field. Another value of this literature review is to highlight the importance of this particular type of research as an alternative to more commonly used disposal schemes, and to show some of the discrepancies between documented studies.

Each situation is unique, depending on the materials dealt with, such that no single documented plan of action can generally fit all or most conditions. With an increasing demand for energy in this country, the problem of coal ash disposal will continue and no doubt even increase for many years to come. Gaining insights and ideas into how to deal with the questions of ash disposal is therefore essential in order to prevent a stockpiling effect, resulting in much more of a problem than can be dealt with effectively.

PHASE I

1 April 1982 - 31 March 1983

METHODS AND MATERIALS

Study Area

The LaCygne Generating Station is located 80 km south of Kansas City, and 8 km east of LaCygne, Kansas. The station consists of the two previously discussed coal-fired units and associated fuel storage and handling facilities, and ash disposal areas (Fig. 2). The total site occupies 3,036 ha and contains a 1,065-ha cooling reservoir, LaCygne Lake. Ash and sludge disposal areas account for 266.8 ha of the land surface, with the "original" sludge pond covering 52.6 ha, the "current" pond covering 149.8 ha, bottom ash storage covering 10.1 ha, and a total of 54.3 ha covered by older scrubber sludge ponds to the north of the bottom ash storage (Fig. 2) (Woodward-Clyde Consultants, 1981b).

Both the original and the current scrubber sludge and fly ash disposal ponds are presently in use and are expected to continue for at least the next 12-15 years. The smaller sludge ponds were previously used as settling ponds and later received material dredged from the original pond. Since construction of the current disposal pond in 1979, these areas have not been used for further disposal, and so the test site for this vegetation study was located in the southeast corner of this area (Fig. 2). Since the bottom ash storage is in continuous use, a separate Unit No. 1 bottom ash worksite for this study was prepared and leveled immediately adjacent to the sludge pond.

Information on the environment of the area overlying the Mulberry coal reserves, 777 km^2 of eastern Kansas which includes the LaCygne station, has been compiled by Kenny et al. (1982). The region is composed of broad

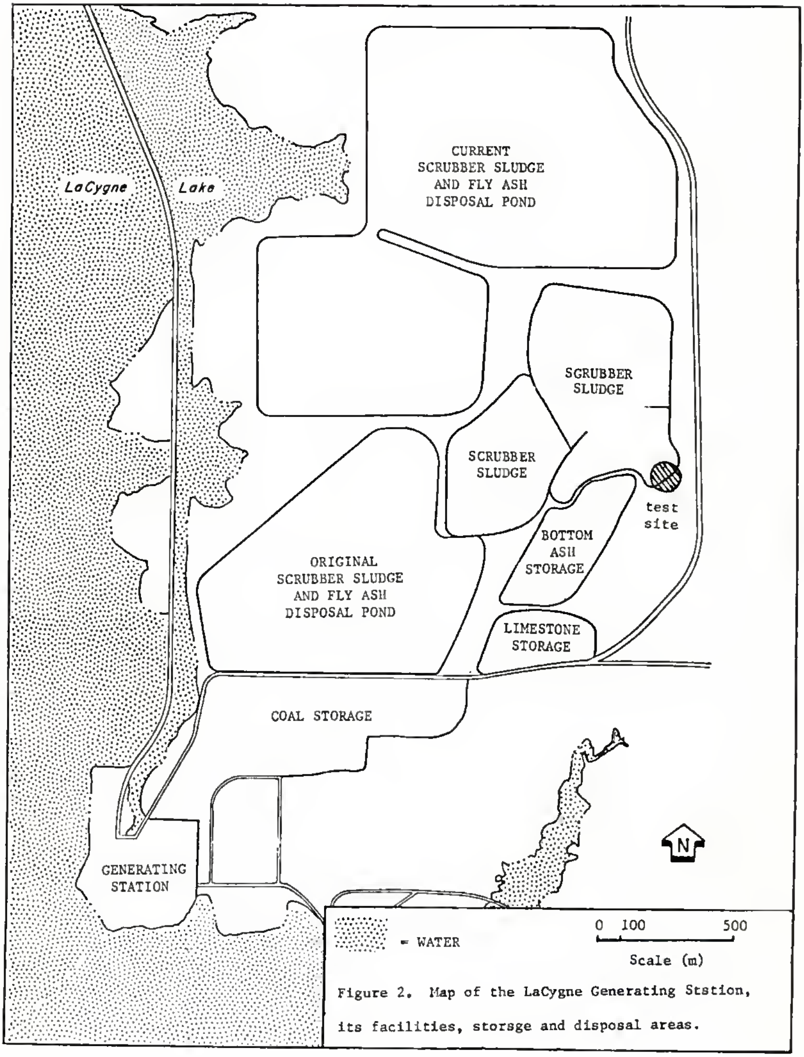


Figure 2. Map of the LaCygne Generating Station, its facilities, storage and disposal areas.

level floodplains and rolling hilly uplands, local relief ranging 30-100 m. Approximately 30 different soil types are identified in this area, primarily silt and clay loams with moderate to very low permeabilities and infiltration rates. Upland type soils, originating from underlying bedrock, cover approximately 87% of the area, with 1.5% from weathered bedrock outcrops, and 11.5% from alluvial deposits located near stream channels.

The primary land use is agricultural, with roughly equal portions of cropland (corn, wheat, oats, soybeans, sorghum, and alfalfa) and pasture. Forests comprise the second largest land category. Oak (*Quercus*) and hickory (*Carya*) are dominant on the uplands and valley sides, with hackberry (*Celtis*), cottonwood (*Populus*), willow (*Salix*), and elm (*Ulmus*) occurring in bottom-land woods.

Surface water bodies and wetlands are numerous in the area and are generally small. The Marais des Cygnes River, with seven major tributaries, and the Little Osage River, with four major tributaries, are the principle drainages of the region. Ground water discharge, responsible for "base streamflow", is negligible due to lack of adequate aquifers in the area. Four general classifications of wildlife habitat have been identified: open areas (originally native tallgrass but now primarily cropland or pasture), woodlands, riparian areas, and water.

The average annual temperature for the region is 14.5° C, ranging from -0.2° in January to 27.1° in August. The average growing season, April to October, is 181 days. Prevailing winds are from the south except for January, February, and March when they are northerly. Windspeed averages 16.7 km/hr, greatest in march and April. Average annual precipitation, recorded at Mound City, 28 km southwest of LaCygne, is 101.6 cm. December, January, and February are the driest months, averaging 8.9 cm/month. May, June, and September are the wettest, average 31.5 cm/month.

Plant Species

Fifteen species of plants were evaluated for growth characteristics on both the scrubber sludge and bottom ash experimental areas. Species used were selected based on one or more of the following criteria: 1) literature indications of usefulness for reclamation purposes; 2) commercial availability; 3) adaptation to eastern Kansas; 4) previous observations of natural vegetation on the LaCygne disposal site; or 5) benefits to wildlife as food or cover. Five of the 15 species were grasses, two were leguminous forbs, two were non-leguminous forbs, and six were trees (Table 3).

Information on seeding rates for Japanese millet, sunflower, and nodding smartweed was provided by the dealers, and for all other non-woody species was obtained from the Riley County Extension Council. Those rates are as follows: tall fescue, 20.3 kg/ha (18 lb/acre); tall wheatgrass, 28.1 kg/ha (25 lb/acre); yellow sweetclover, 13.5 kg/ha (12 lb/acre); Korean lespedeza, 33.8 kg/ha (30 lb/acre); annual ryegrass, 28.1 kg/ha (25 lb/acre); Japanese millet, 45.0 kg/ha (40 lb/acre); sunflower, 11.3 kg/ha (10 lb/acre); nodding smartweed, 22.5 kg/ha (20 lb/acre); and common reedgrass, 9.0 kg/ha (8 lb/acre). Average heights of the tree seedlings purchased were: cottonwood, 75 cm (30 in.); black locust, 40 cm (16 in.); red maple, 40 cm (16 in.); European black alder, 15 cm (6 in.); eastern red cedar, 25 cm (10 in.); and amur maple, 75 cm (30 in.).

Experimental Design

The testing of the selected plant species was conducted by means of six field plots arranged on the disposal areas, three each on No. 1 bottom ash and scrubber sludge. The plots were replicates of one another, and consisted of 14 single-species 1-m-wide rows passing through six 3-m-wide

Table 3. Names and sources of vegetative materials used in Phase I of the LaCygne vegetation study, summer 1982, including purity and germination data for herbaceious species.

Plant Species	Source	% purity	% germination
Tall fescue (*Festuca arundinacea* Schreb.)	Sharp Brothers Seed Co.	97.8	89.0
Tall wheatgrass (*Agropyron elongatum* (Host) Beauv.)	Sharp Brothers Seed Co.	94.0	96.0
Yellow sweetclover (*Melilotus officinalis* (L.) Lam.)	Sharp Brothers Seed Co.	a	a
Korean lespedeza (*Lespedeza stipulacea* Maxim.)	Sharp Brothers Seed Co.	99.2	68.0
Annual ryegrass (*Lolium multiflorum* Lam.)	Sharp Brothers Seed Co.	97.4	97.0
Japanese millet (*Echinochloa crusgalli* (L.) Beauv.)	Mangelsdorf Seed Co.	99.5	85.0
Showy sunflower (*Helianthus laetiflorus* Pers.)	Mangelsdorf Seed Co.	99.0	80.0
Nodding smartweed (*Polygonum lapathafolium* L.)	Wildlife Nurseries, Inc.	a	a
Common reedgrass (*Phragmites australis* (Cav.) Trin.)	Peabody Coal Company Lab	a	a
Cottonwood (*Populus deltoides* Marsh.)	Smith Nursery Company	planted as seedlings	
Black locust (*Robinia pseudoacacia* L.)	Smith Nursery Company	planted as seedlings	
Red maple (*Acer rubrum* L.)	Smith Nursery Company	planted as seedlings	
European black alder (*Alnus glutinosa* L.)	Smith Nursery Company	planted as seedlings	
Eastern red cedar (*Juniperus virginiana* L.)	KSU Extension Forestry	planted as seedlings	
Amur maple (*Acer ginnala* flame)	Forrest Keeling Nursery	planted as seedlings	

[a] data not availabe for these species

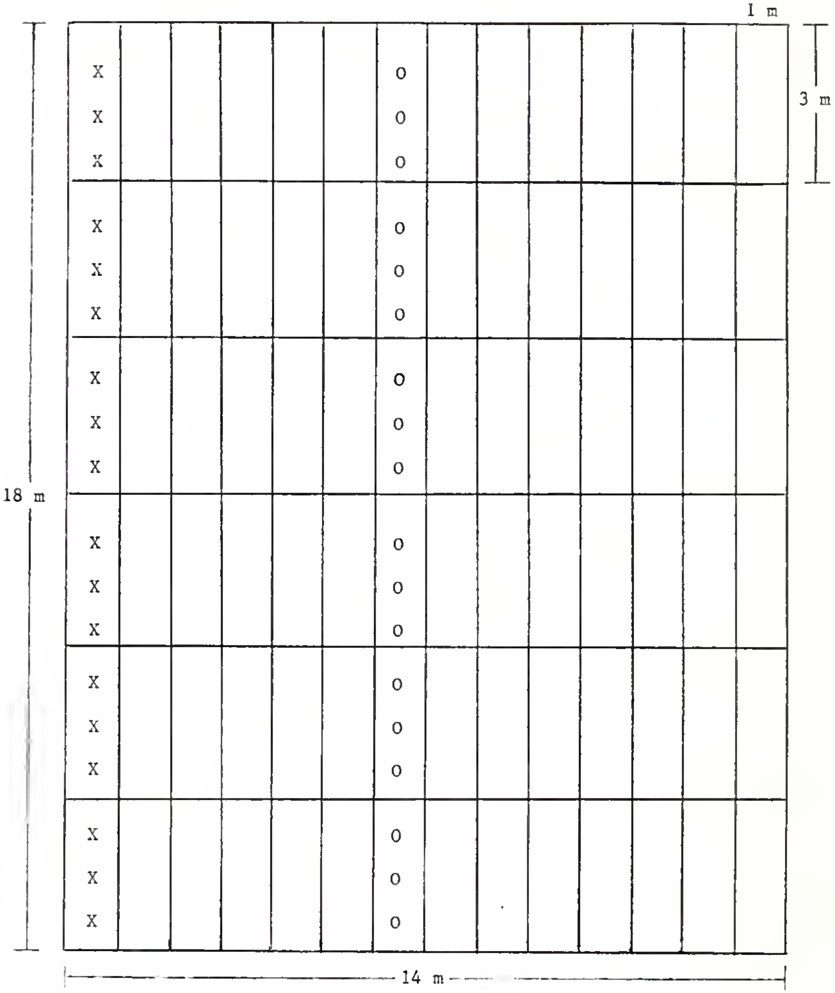
treatment bands. A Berger Instruments model 110C Transit-Level mounted on a tripod was used to mark the dimensions of each plot. Annual ryegrass was to be seeded as a ground cover throughout each tree row, but not in a separate row as were all other species. This produced the total of 14 rows per plot, each containing one of eight herbaceous species or one of six trees.

Eighteen individual units of each species were planted per row, a unit consisting of either a ¼ m^2 planting of seeds or an individual tree seedling (Fig. 3). Seeded squares were spaced ½ m apart within rows, with 2 m separating trees in each of their rows. While the six plots each contained the same species and treatments, the locations of these were randomized within each plot.

Planting Treatments and Equipment

Although there was scattered vegetation occurring naturally on at least portions of the scrubber sludge within the study area, it was quite sparse and provided inadequate evidence that either substrate would support a vigorous ground cover without some amendment. Several materials were tested, as well as fertilizer applications, to determine if an amendment could be located to effectively and economically substitute for topsoil for the stimulation of vegetative growth.

Three introduced materials were selected for use as treatments: cattle manure, woodchips, and prairie hay. All have been documented in the literature as beneficial in soil and/or reclamation experiments. A fourth treatment consisted of a surface mixture of the two test substrates, scrubber sludge and bottom ash. These amendments were tested in order to take advantage of one or more of the desirable characteristics of added organic matter, moisture-retention, shelter from heat, increased substrate



X = typical tree seedling

0 = typical ¼-m square of herbaceous seeds

Figure 3. Design of test plots used in Phase I of the LaCygne vegetation experiments.

porosity, or greater substrate cohesion. Two additional treatment sections of each plot received no mulch material.

A preliminary analysis of both substrates disclosed a deficiency of macronutrients, particularly N and P. To alleviate this, Ferti-Lome 'Tree & Shrub Food' fertilizer, with an $N-P_2O_5-K_2O$ ratio of 19-8-10 (percent by weight), was applied at a rate of 82 kg/ha (73 lb/acre) N. Each of the four mulches was fertilized at this rate, as was one of the unmulched sections of each plot. The sixth and final treatment section of each plot received neither amendment nor fertilizer and served as a control for the others. The position of the various treatment bands was randomized between the six plots (Fig. 4).

With the exception of manure on bottom ash plots 1, 2, and 3 and the ash mix on plot 2, which were added before fertilizing, all plots were fertilized before addition of amendments. Fertilizer was applied using a Scott's 'PF-1' drop spreader, pushed by hand, and was then roto-tilled into the surface using a Briggs & Stratton model 659 4-hp '"Easy-Spin" Merry Tiller'. On scrubber sludge plot 5 the two northernmost treatment bands, woodchips and cow manure, were tilled before being fertilized; all others were first fertilized and then tilled. Following the fertilizer application and incorporation, mulching was accomplished on the appropriate bands and all plots were tilled a second time to mix the treatments into the surface. The two unmulched sections of each plot were also tilled equally with the others.

Cattle manure from the farm of Robert Robbins, 10 km north of Mound City, was loaded by hand onto a pickup and was used to mulch plots 1 and 2, except for the extreme eastern 3 m on plot 2. The balance of the manure needed was obtained from a dairy farm owned by Charles Clark, 15 km north and 10 km east of Fort Scott, Kansas, utilizing a tractor loader and a dump

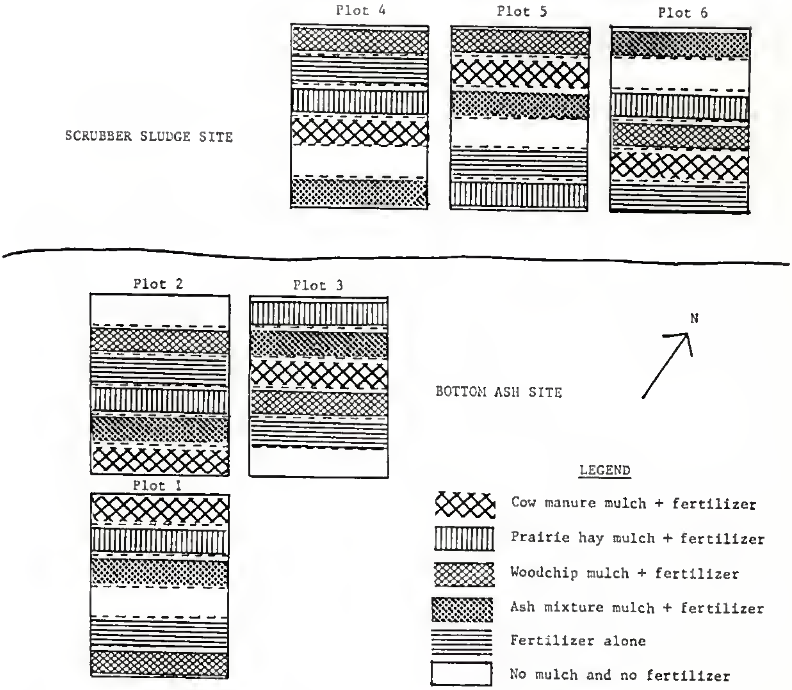


Figure 4. Arrangement of experimental plots on scrubber sludge and bottom ash sites showing randomized 3-m-wide treatment bands in each plot. Vegetative plantings were made lengthwise through the plots across the treatment bsnds.

truck. Manure was spread across the preselected band of each plot to an average depth of 5 cm, then tilled into the surface to a depth of 10-12 cm with the tiller. On bottom ash the manure was tilled into the substrate before fertilizer was applied, whereas on scrubber sludge the fertilizer was applied to the plots before manure.

Woodchips were delivered to the LaCygne test site from the Kansas City area in a KCP&L tree-chipper truck. This material consisted of fresh woodchips averaging 3-6 cm in diameter and included elm leaves, sprigs of cedar, pine needles, and thorny twigs believed to be locust. It had been recently chopped, and though somewhat moist was lightweight and relatively easy to transport and spread by hand. Woodchips were applied following fertilization on each plot, spreading evenly to a depth of 5 cm, then tilling them into the substrate to a depth of 10-12 cm.

Prairie hay, consisting primarily of cordgrass (Spartina pectinata Link), was obtained from the Kansas Fish & Game Commission's Marais des Cygnes Wildlife Management Area, 9 km south of the LaCygne station. The first attempt to apply this mulch was on plot 2, spreading hay 5 cm deep over the preselected band. However, the tiller was unable to cut through this without long hay stems balling around the blades. All hay was then removed, and while one person tilled the ash a second spread hay very thinly (1-2 cm) just ahead, allowing it to mix into the surface 10-12 cm. Finally more hay was scattered over the surface to an average depth of 3 cm, leaving 50% of the substrate visible and 50% hay-covered. Approximately half of a 25-kg bale of hay was used per plot band in this way, treating all plots with this method.

A wheelbarrow and large metal tubs were used to transport bottom ash to scrubber sludge plots and vice versa. Bottom ash was loose and easily spread to an even 5 cm layer over the surface of the selected scrubber sludge bands. Applying sludge to bottom ash was more difficult as it was very wet at the time and tended to adhere together in lumps resembling semi-wet clay. It was impossible to apply a uniform layer, but an average 5 cm depth was attempted. On plot 2, the ash mix was applied before fertilizer, but all others were fertilized first. The treatments were all tilled into the substrate 10-12 cm.

The remaining treatment bands on each plot, the fertilizer and control sections, were then likewise tilled to a depth of 10-12 cm. All fertilizing and addition of amendments was completed within a three-day period during mid-May (Table 4).

Planting Techniques

Prior to planting, seeds of herbaceous species were preweighed into packets based on the seeding rates indicated previously. Sweetclover and lespedeza seeds were first treated with 'Nitragin' legume inoculant, containing the bacteria *Rhizobium meliloti* and *R. trifolii*, to stimulate root nodulation important in N-fixation. Wooden squares each constructed with an inside area of ¼ m^2 were used for planting all seeds. Three squares of each species were planted per mulch band, for a total of 18 squares per row per plot, spaced ½ m apart. Each time a planting square was laid in position, one seed packet was opened and the seed scattered evenly inside the square, then mixed lightly by hand into the surface. All seed was planted within an eight-day period, except for nodding smartweed which was not obtained until a month later (Table 5).

Tree seedlings were kept cool and moist until planting. Long-handled shovels were used to plant trees three per mulch band, 18 per row per plot. Black alder trees were small enough to plant by hand without a shovel. Annual ryegrass was broadcast by hand through each tree row at

Table 4. Dates during May, 1982 when fertilizer and amendments were applied to the treatment sections of each plot.

	NO. 1 BOTTOM ASH						NO. 1 SCRUBBER SLUDGE					
	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6	
Treatment	Fert	Amend	Fert	Amend	Fert	Amend	Fert	Amend	Fert	Amend	Fert	Amend
Manure/Fert	13	11	12	11	13	11	12	13	12[b]	13	12	13
Woodchips/Fert	13	13	12	13	13	13	12	13	12[b]	13	12	13
Hay/Fert	13	13	12	13	13	13	12	13	12	13	12	13
Ash Mix/Fert	13	13	12	12	13	13	12	12	12	12	12	12
Fertilizer	13	a	12	a	13	a	12	a	12	a	12	a

[a] No mulch applied

[b] Roto-tilled before application of fertilizer, all others fertilized before tilling

Table 5. Dates on which each herbaceous species was planted in each plot in May, 1982.

		NO. 1 BOTTOM ASH			NO. 1 SCRUBBER SLUDGE		
	Species	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
	Tall wheatgrass	14	14	14	19	19	20
	Yellow sweetclover	14	14	14	19	19	20
	Korean lespedeza	14	14	14	19	19	20
	Japanese millet	14	14	14	20	19	20
	Showy sunflower	14	14	14	20	19	20
	Tall fescue	14	14	14	20	19	20
	Common reedgrass	21	21	21	19	19	20
	Nodding smartweed[a]	18	18	18	18	18	18
Annual ryegrass	Cottonwood	14	14	14	20	20	20
	Black locust	14	14	14	20	20	20
	Amur maple	14	14	14	20	20	20
	Eastern red cedar	14	14	14	20	20	20
	European alder	14	14	14	20	20	20
	Red maple	14	14	14	20	20	20

[a] Nodding smartweed was planted on 18 June, all other plantings were made in May.

its predetermined seeding rate, then lightly raked into the surface. On plots 4 and 5, ryegrass was seeded but not raked in because the scrubber sludge surface was muddy at the time.

Because of rainy weather, there was a 6-day interval between trees planted on bottom ash and those later planted on scrubber sludge. The later trees were watered and wrapped in plastic and stored at the Marais des Cygnes maintenance shop until they could be planted. During that interval the black locust seedlings suffered damage from mice chewing on them. When planted, locust trees with the healthiest appearance were selected, i.e., ones which were not completely chewed off or those which retained live buds.

Test Plot Measurements

Measurements of seeded species were taken approximately every two weeks, recording seedling density, mean height, and a visual ranking from best to worst ground cover in each row. Density was recorded by randomly placing a 10-cm square inside the planted square and counting seedlings within this area. Sunflowers, however, had been planted at such a low density that they instead were counted within the larger ¼ m^2. The placement of the small density square was determined by selecting two numbers each time from a table of random digits (Snedecor and Cochran, 1980) to represent the distance (cm) inward from the north and east edges of the planted square.

Mean seedling height was determined from the average of the first seedlings, counting from the northeast corner of the small square. Ranking involved assigning a number between 1.0 and 6.0 to each group of plants in each of the six treatments in a row, with 1.0 indicating the highest proportion of ground covered by vegetation and 6.0 the lowest coverage.

Once a month tree survival was also recorded, based on presence or absence of green foliage or live cambium. At this time the density square was placed around the center tree in each treatment, and density and height measurements were recorded for annual ryegrass beneath it. In October the total season's growth in additional height was measured and recorded for each tree. Dead trees, including these still partially alive but with dead tops, were recorded as zero growth so that survival was incorporated as a factor.

Statistical Analysis of Vegetative Data

All growth measurement data were subjected to a split-plot analysis of variance (ANOVA) test to determine species, treatment, and substrate effects, as well as to locate interactions between these variables. A probability of $p < 0.05$ was considered significant for all ANOVA tests. Separate analyses were performed for each sampling date to test main effects on height, density, and ground cover ranking of herbaceous vegetation, and on survival of tree species. A Least Significant Difference (LSD) test was used to determine differences between means of all variables analyzed. A probability of $p < 0.05$ was considered significant for LSD tests. This procedure provided verification at each particular date regarding which treatments were more beneficial and which species were best suited to conditions at the test site, as well as indicating the superior substrate.

Substrate Sampling

Immediately after the establishment of each test plot, and once a month throughout the growing season, substrate samples were collected for analysis. Using a 2-cm diameter tubular soil core sampler, the control section of each plot was sampled to a depth of 5-8 cm. Each core was placed in a plastic-lined sample bag, labelled with the date and plot number, and later taken to the Soil Test Laboratory of the KSU Department of Agronomy. Here they were analyzed for pH, N, P, K, and organic matter content. Extra samples were taken from bottom ash plot 2 and scrubber sludge plot 5 in August, and these were sent to the Soil & Plant Analysis Laboratory operated by the University of Wisconsin-Extension, located at Madison. The purpose of this analysis was to determine the presence of toxic materials in the substrates, identifying B, SO_4-S, and soluble salts.

Also in August a total of 21 samples were collected from throughout the disposal areas, from four different substrates. Using a tape measure and compass, the location of these samples was recorded and marked on a schematic map of the area (Fig. 5). A series of six scrubber sludge samples was taken 15 m apart along a transect extending west from the eastern bottom ash bank, extending through and beyond the natural vegetation located in this area. This transect was located approximately 150 m north of the southeast corner of the scrubber sludge test site. Three more samples (7, 8, and 9) were taken 30 m apart along a similar transect located 100 m north of the first, along the south edge of an abandoned bottom ash dike which once divided the slurry pond.

Two sets of two samples were taken north of this dike, each set consisting of one sample 10 m from the east edge of the pond and the other 100 m out. Samples 10 and 11 were taken approximately 100 m north of the dike, 12 and 13 were collected 250 m north. One sample, 14, was obtained in the northeast corner of the pond, located 45 m southwest of what was determined to be the corner. At the southern edge of the slurry pond, near the test plots, sample 15 was taken 60 m due north of the bottom ash bank. Sample 16 was the final sludge sample, located approximately halfway up the west edge of the pond and 45 m east of the bank.

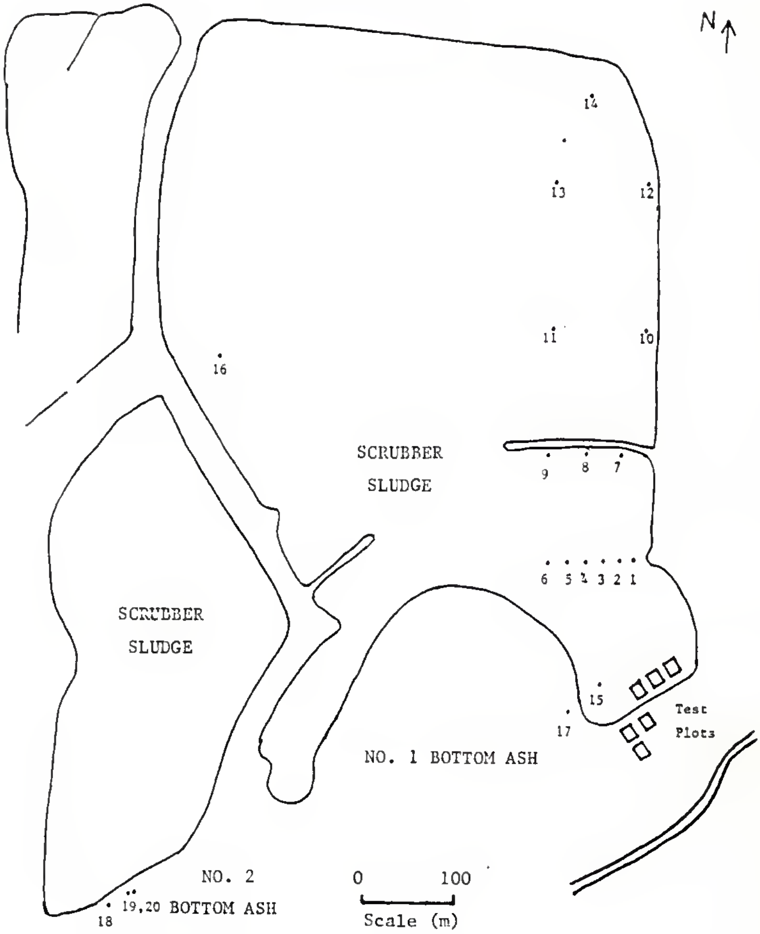


Figure 5. Disposal areas at the LaCygne station, indicating scrubber sludge, No. 1 and No. 2 bottom ash, and locations of 20 substrate samples collected during summer 1982. One additional sample was collected from No. 2 fly ash.

Sample 17 was taken from the No. 1 bottom ash pile, on a slope rising to the west of the test plots. Three samples were then taken from the No. 2 bottom ash pile on the southwest corner of the disposal area. Sample 18 was taken from the slope where there appared to be a mixture of the ash materials and where sparse vegetation occurred. Samples 19 and 20 were taken at the top of the pile in unmixed No. 2 ash, sample 20 taken at a deeper 15-cm depth. Sample 21 was scooped from the surface of a freshly dumped load of No. 2 fly ash approximately 900 m southwest of the test plot site. This ask is very fine-textured and has a powdery consistency, making core samples impossible. Fresh ash was necessary because of its pozzolanic characteristic which causes it to set up like cement rapidly when wet. All substrate samples were analyzed for pH, macronutrients, and organic matter.

Substrate Analysis

The procedures followed in the KSU Soil Test Laboratory for substrate analyses for pH, P, K, and organic matter are outlined by North Dakota Agricultural Experiment Station (1980). A brief description of each procedure is included here, with more detailed outlines of equipment and specific techniques available from the source.

pH. Determination of pH utilizes paired electrodes plugged into a commercial pH meter, which is standardized by using a buffer of known pH. The sample is suspended in water or 0.01 $\underline{M}$ $CaCl_2$, and pH is indicated by the voltage generated between the electrodes, proportionate to the logarithm of the changes in H^+.

Phosphorus. Following a modified Fiske-Subbarrow method, 1 g of substrate is mixed well with 10 ml of 0.025 $\underline{N}$ HCl in 0.03 $\underline{N}$ NH_4F, then filtered through No. 2 filter paper to obtain a clear extract. To 5 ml of extract is added 0.25 ml of acid molybdate solution, then 0.25 ml of aminonaphthol-sulfonic acid. After 15 minutes color is read either as percent transmittance or as optical density. By comparing with a standard curve previously established, ppm P concentration in filtrate is converted to concentration in sample. This is converted to lb/acre by multiplying ppm x 20, and is then converted to kg/ha.

Potassium. A 1 g sample of substrate is mixed with 10 ml of 1 N NH_4OAc, pH 7.0, shaken five minutes on a rotating shaker or one minute by hand. This is filtered through No. 2 filter paper to obtain a clear extract. Galvanometer readings from this unknown are compared to a standard curve previously established, determining ppm K. This is converted to lb/acre and then to kg/ha.

Organic Matter. A sample of 0.1 to 2.0 g of substrate is transferred to a flask, adding 10 ml of 1 N $K_2Cr_2O_7$. To this is gently mixed 20 ml of concentrated H_2SO_4, and this solution is allowed to stand for 30 minutes on an asbestos sheet to prevent rapid heat loss. The suspension is diluted with 200 ml of water, then 10 ml of 85% H_3PO_4 and 0.2 g of NaF are added to complex Fe^{3+}. After adding 10 drops of ferroin indicator the solution is titrated with 0.5 N Fe^{2+} to a burgundy endpoint. By running a reagent blank to standardize the solution, the percent organic matter may be computed based on the amount of Fe^{2+} required to reach the endpoint.

Nitrogen. The determination of NH_4 follows a procedure described by Technicon Industrial Systems (1977a). This is a method in which an emerald-green endpoint is formed by the reaction of ammonia in the sample with test reagents (sodium salicylate, sodium nitroprusside, and sodium hypochlorite). The reaction occurs in a solution at pH 12.8-13.0, and the resulting complex is read on a colorimeter.

A description of the technique used to determine NO_3 can be found in Technicon Industrial Systems (1977b). In this process, nitrate in soil extract is reduced to nitrite by a copper-cadmium reductor column. The nitrite forms a diazo compound when reacted with sulfanilamide, and this compound reacts with N-1-naphthylethylenediamine dihydrochloride to form a dark red endpoint, also read on a colorimeter.

Liegel et al. (1980) describe the procedures used by the Wisconsin Soil & Plant Analysis Laboratory for determination of B, SO_4-S, and soluble salts.

Boron. To 20 g of sample is added 40 ml of near-boiling distilled water, then covered and refluxed for five minutes. Upon removal from heat, two drops of 20% CaCl solution is added, then cooled and filtered through B-free filter paper. A 0.25 ml portion of extract is mixed with 2 ml of curcumin reagent, then evaporated to remove all visible liquid. The sample is then dissolved in 10 ml of 95% ethyl alcohol, transferred to a colorimeter tube and read with a colorimeter within two hours. These readings are compared to a standard curve graduated in ppm.

Sulfate-Sulfur. A 10-g sample of substrate is mixed with 25 ml of $Ca(H_2PO_4)_2$-HOAc, adding 0.1 g of activated charcoal (purified by boiling in 6 N hydrochloric acid, then oven-drying). The sample is well shaken and filtered through No. 2 filter paper previously cleansed of SO_4-S. Filtrate is mixed in a tube with $BaCl_2$-gum-arabic-HOAc solution. Colorimeter readings of this solution can be compared to a standard curve to compute ppm in solution.

Soluble Salts. To 20 g of substrate is mixed 40 ml of distilled water, then left to stand for 15 minutes. This is transferred to the conductivity cell of a conductivity bridge, temperature maintained at room temperature, and the bridge is balanced. The conductivity is read and multiplied by the cell constant.

Statistical Analysis of Substrate Data

Results of the monthly substrate sample analyses were subjected to an ANOVA to determine significant differences in elemental composition between the two substrates, with an LSD test to indicate the substrate with the greater mean value of each characteristic. A probability of $p < 0.05$ was considered significant for both the ANOVA and the LSD. Additional LSD tests were computed to determine monthly changes in concentrations of the five characteristics analyzed, to indicate which months' samples contained the highest or lowest levels. This would help identify any trends associated with monthly aging and weathering.

Survey of Invading Vegetation

In August, samples of the naturally-occurring vegetation on the disposal area were collected and identified. On scrubber sludge, the majority of the vegetation was concentrated along the eastern edge of the slurry pond, against the bottom ash bank. By pacing in a north-south direction along the bank at varying distances from the edge, the major vegetated portion of the pond was sampled. An attempt was made to sample each individual species only one time, taking a good representative specimen. Plants were located visually, the most conspicuous plants being selected preferentially, yet an effort was made to sample those smaller, more hidden, and less conspicuous species as well. Each plant was dug out using a hand trowel, extracting as much of the intact root system as possible, then placed in a plastic bag. All specimens were subsequently pressed and labelled to identify collection site. There was also sparse vegetation scattered irregularly along the west edge of the ash pond, but there were no species observed which had not been collected from the east side.

The bottom ash bank to the southwest of the sludge plots, separating these from those on bottom ash, also contained a very conspicuous strip of vegetation. Specimens were again located and collected in the manner described above, and placed in a plant press with a location label for later identification.

The manure section on each scrubber sludge plot supported a great deal of thick vegetation differing from those species intentionally planted. Two different species were observed and collected from the manure treatment band of plot 5, the center plot. These were likewise labelled and pressed.

Unit No. 2 bottom ash is dumped near the edge of a Unit No. 1 bottom ash pile at the southwest edge of the disposal area (Fig. 5). There was sparse vegetation occurring along the bank which sloped down to the scrubber sludge surface to the north. This bank appeared to include a mixture of Unit No. 1 and No. 2 bottom ash in varying degrees. There were a few scattered plants on top of the pile but most were found on the slope. Two species were collected, labelled and pressed. All plants collected from each area were taken to the KSU Herbarium where they were dried and then identified by the staff, and are presently stored in the Herbarium collection for future reference.

Obtaining Climatological Data

Following completion of Phase I experimental field work, data regarding precipitation and ambient temperature were obtained for the LaCygne area. The National Oceanic and Atmospheric Administration gathers climatological data from across the U. S., and records for Kansas are available from the KSU Department of Physics. The monitoring station nearest the powerplant, 8 km west in LaCygne, records precipitation only. Two Kansas stations also monitoring temperature are located at Paola, 20 km northwest of LaCygne, and Mound City, 28 km southwest of LaCygne. Since both locations are approximately equal distances from the plant in different directions, records from each were obtained. Data from all three monitoring stations will then be used to present a pattern of precipitation and temperature for the area surrounding the LaCygne Generating Station.

PHASE I

1 April 1982 - 31 March 1983

RESULTS

Herbaceous Species Height Data

All seeded herbaceous species germinated successfully on both bottom ash and scrubber sludge experimental plots, but common reedgrass and nodding smartweed failed to produce any significant cover. The analysis of variance detected no significant differences in overall plant height between the two test substrates on 4 June, the first measuring date, but indicated the two were significantly different for each subsequent measurement (Table 6). A comparison of mean plant height measured on both substrates at biweekly intervals indicates the significant superiority of scrubber sludge over bottom ash (Fig. 6). The result was that beyond 17 July the bottom ash plots yielded insufficient data for further analysis, with almost total failure of all planted vegetation, while plants on scrubber sludge continued to survive and grow.

The LSD test of mean plant heights of herbaceous species across the six treatments on either substrate indicates those treatments which stimulated more superior vegetative growth. In comparing the means of every other measurement (4-week intervals) for the first half of the season, the manure plus fertilizer treatment was identified as producing the greatest plant height on both substrates (Fig. 7). On 4 June woodchips plus fertilizer was statistically equal to manure, ash mix and hay mulch were equal, and fertilizer only and control were equal, but significantly poorer than the others. On 3 July woodchips, ash mix, and hay were all statistically equal in growth, but less than manure. Fertilizer alone produced significantly lower plant height, but significantly better than the control.

Table 6. P-values from analysis of variance tests to detect significant differences in height between substrates, treatments, and species, as well as interactions between these three, on each date measured in 1982.

	JUNE 4 Height	JUNE 19 Height	JULY 3 Height	JULY 17 Height
substrate	NS[a]	0.0084	0.0001	0.0002
treatment	0.0001	0.0001	0.0001	0.0001
species	0.0009	0.0001	0.0001	0.0001
trt/sub	0.0004	0.0401	0.0001	0.0001
spec/sub	0.0111	0.0001	0.0001	0.0001
trt/spec	NS	0.0001	0.0001	0.0001
trt/spec/sub	0.0006	NS	0.0001	0.0001
	JULY 29[b] Height	AUG 17[b] Height	AUG 28[b] Height	SEP 10[b] Height
treatment	0.0001	0.0001	0.0001	0.0039
species	0.0001	0.0001	0.0001	0.0001
trt/spec	0.0001	0.0001	0.0001	0.0065

[a] Not significant ($p > 0.05$)

[b] Insufficient bottom ash data for substrate comparisons, analysis of scrubber sludge only.

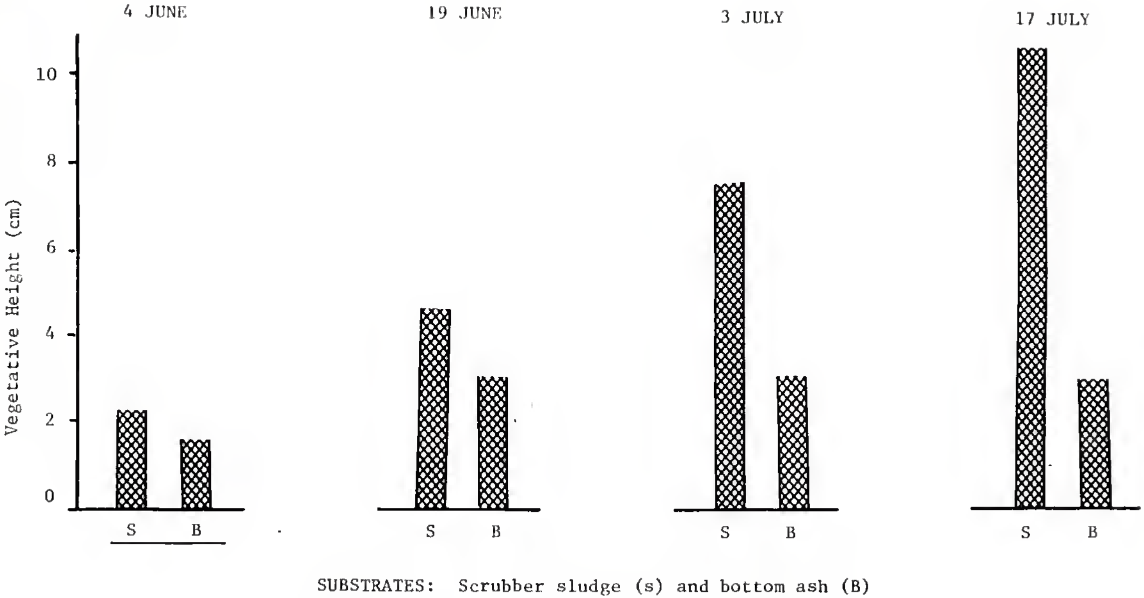
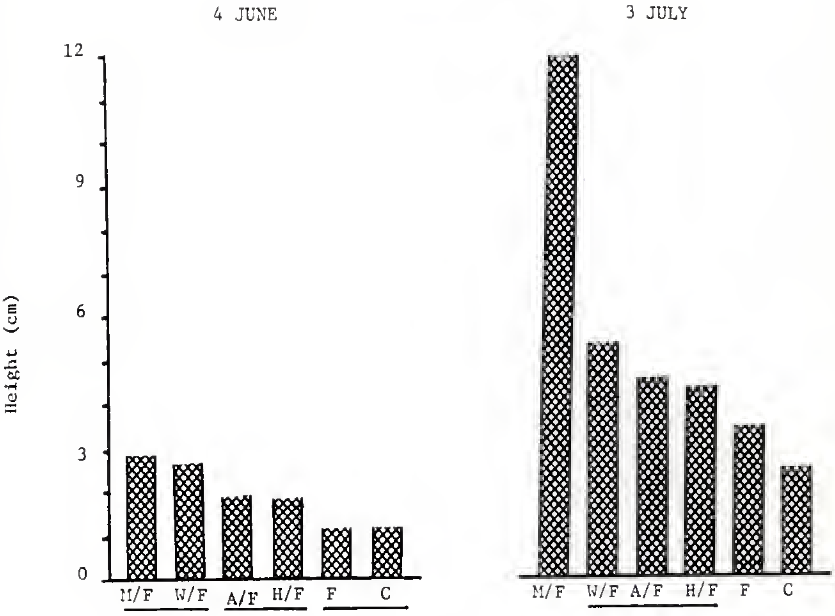


Figure 6. Mean vegetative height across all species and treatments as affected by the two test substrates, scrubber sludge and bottom ash, during 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).



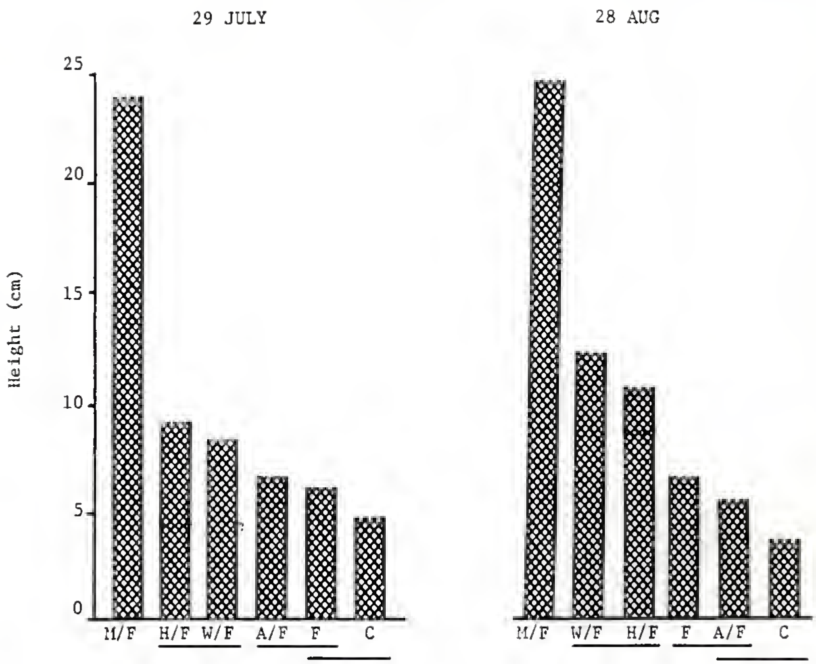
TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), hay plus fertilizer (H/F), ash mix fertilizer (A/F), fertilizer only (F), and control (C).

Figure 7. Mean vegetative height on both bottom ash and scrubber sludge substrates as affected by the various treatments, recorded on 4 June and 3 July, 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

Significant interactions between treatments and substrates on these dates can primarily be explained by variations in plant growth on various bottom ash treatments (Appendix, Fig. 1 and 2). On 4 June the ash mix treatment actually stimulated taller growth on bottom ash than on scrubber sludge, while bottom ash plant height on woodchips and manure were slightly less than that on sludge. The remaining treatments exhibited extreme differences between the two substrates. Plant height on all bottom ash treatments was lower than that on corresponding treatments on scrubber sludge on 3 July. Yet differences between woodchips were slight while those between manure were extreme, although bottom ash manure growth exceeded height on four of the scrubber sludge treatments.

The significant treatment/species/substrate interactions indicate different responses on either substrate for the same treatment/species combination. For example, on 4 June sunflower was recorded as quite tall on bottom ash and yet only moderate in height on scrubber sludge, while tall wheatgrass was just the opposite (Appendix, Fig. 3). On 3 July, all species and treatments were exhibiting quite low growth on bottom ash, except for manure, while those on scrubber sludge were significantly higher (Appendix, Fig. 4). Millet exhibited particularly good growth on manure on both substrates, greater than all other species.

In comparing mean heights recorded at every other measurement during the latter half of the season on scrubber sludge only, manure is again seen to be a significantly better treatment (Fig. 8). On both 29 July and 28 August, hay and woodchips were statistically equal, but significantly less superior than manure. On 29 July ash mix and fertilizer were equal, as were fertilizer and the control, yet ash mix was significantly better than the control. On 28 August fertilizer and ash mix were equal, as were ash



TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C).

Figure 8. Mean vegetative height on scrubber sludge as affected by the various treatments, recorded on 29 July and 28 August, 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

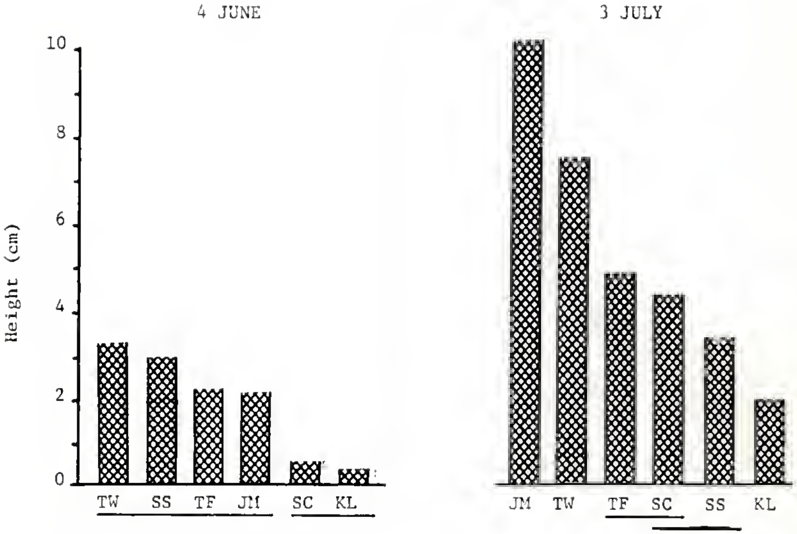
mix and control, while fertilizer was now significantly better than the control.

With only slight variations, the trend throughout the entire season appears to be toward increased plant height with addition of organic treatments. Manure plus fertilizer consistently produced the best growth, with the control generally producing the least.

Mean plant height can also be compared between the various test species at 4-week intervals during the first half of the season on both substrates (Fig. 9) and the latter half on scrubber sludge only (Fig. 10). The first measurement, on 4 June, saw tall wheatgrass, showy sunflower, tall fescue, and Japanese millet producing statistically equal height. Sweetclover and Korean lespedeza were significantly and equally inferior in height. On 3 July Japanese millet was significantly the tallest species, followed by tall wheatgrass. Fescue and sweetclover were equal, as were sweetclover and sunflower, yet fescue was significantly taller than sunflower. Lespedeza produced the lowest plant height.

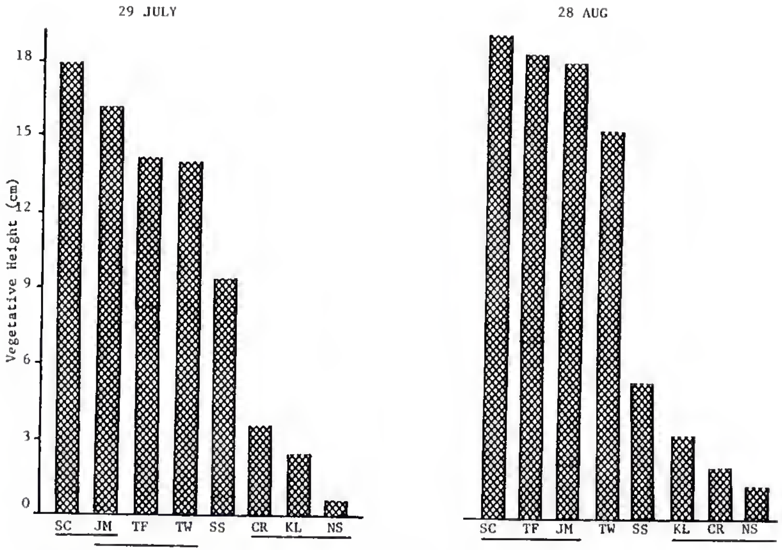
Species/substrate interactions were significant at both of these early season dates, and can be particularly attributed to responses of Korean lespedeza and showy sunflower (Appendix, Fig. 5 and 6). In both instances, lespedeza growth on scrubber sludge is nearly equally as poor as on bottom ash. Sunflower height on 4 June was actually considerably lower on sludge than on bottom ash, and by 3 July is approximately equal on the two substrates. Reedgrass, which grew too poorly to be included in analysis by July, was also recorded as equally poor on both substrates at the earlier measurement. All other species exhibited markedly superior growth on scrubber sludge, increasingly so by July.

Lespedeza, sunflower, and millet all appear to be contributing to significant treatment/species interaction on 3 July (Appendix, Fig. 7).



SPECIES: Tall wheatgrass (TW), tall fescue (TF), Japanese millet (JM), sweetclover (SC), Korean lespedeza (KL), showy sunflower (SS).

Figure 9. Mean vegetative height of species across all treatments on bottom ash and scrubber sludge, recorded on 4 June and 3 July, 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).



SPECIES: Tall wheatgrass (TW), tall fescue (TF), Japanese millet (JM), sweetclover (SC), Korean lespedeza (KL), common reedgrass (CR), nodding smartweed (NS), showy sunflower (SS).

Figure 10. Mean vegetative height on species across all treatments on scrubber sludge, recorded on 29 July and 28 August, 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

Essentially, manure is still seen as the superior treatment overall, control the poorest, with the other treatments ranking between them. However, lespedeza performed as poorly or even worse on two treatments other than control, namely fertilizer only and ash mix. Ash mix mean height increased dramatically for millet, then decreased again for sunflower. Growth of millet on manure also is somewhat of a deviation, with a value nearly doubling all other species' heights.

By 29 July, common reedgrass and nodding smartweed were able to be measured on scrubber sludge, but produced the lowest height along with lespedeza. Sweetclover and millet were statistically inseparable, and millet was equal with fescue and wheatgrass, while sweetclover was significantly taller than both these latter. Sunflower was an intermediate plant following the more superior species yet produced significantly better than the poorest. On 28 August sweetclover, fescue, and millet were equally superior to all others, and lespedeza, reedgrass, and smartweed were again equally the poorest. Between the two extremes, wheatgrass was significantly better than showy sunflower.

There appears to be no single factor which solely influenced the treatment/species interactions at these later dates (Appendix, Fig. 8 and 9). Response of each species to each particular treatment varied tremendously. The only consistent pattern is that manure produced generally more superior growth, yet even this is altered for smartweed on both dates, and reedgrass and sunflower on 28 August.

Due to differences in the methods used to plant and also measure annual ryegrass, recording density and height only beneath the center tree of each treatment every four weeks, this data was analyzed separately. Bottom ash data was included for analysis only for the first measurement on 19 June, with the analysis of variance detecting a significant difference between substrates already at this early date, scrubber sludge again proving more superior (Table 7).

There were significant differences between treatments for all but the final measurement, the LSD indicating that manure plus fertilizer produced significantly the tallest ryegrass across all tree rows for the first three months (Fig. 11). The control was the poorest treatment on 19 June, statistically equal to fertilizer, which in turn was not statistically distinguishable from all others but manure. On 17 July manure was significantly different from all other treatments, which were all equally inferior. On 17 August the control was again the poorest, yet it was statistically equal to woodchips which was indistinguishable from hay, fertilizer, and ash mix. At only one date, 17 July, was there a significant difference between species (Table 7), "species" referring to the tree rows in which ryegrass was sown.

Herbaceous Species Density Data

The analysis of variance detected a significant difference in the density of vegetation produced on the two test substrates throughout the first four measurements of the summer (Table 8), with bottom ash data omitted from later analyses. A comparison of mean density recorded on these dates indicates the magnitude of the difference between the two substrates (Fig. 12). At only four dates through the season was there a significant difference in treatments.

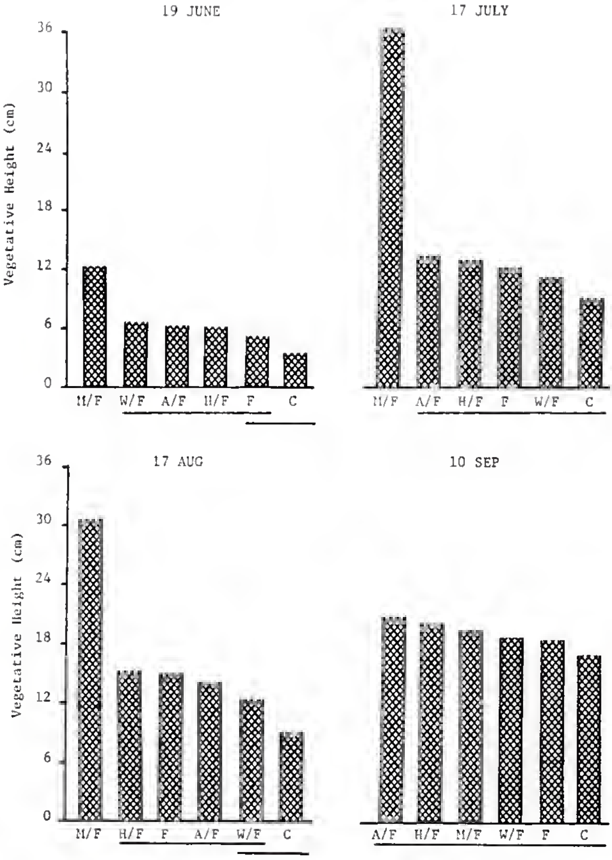
Treatment differences on 4 June were not significant, but by 3 July the LSD indicated manure as the superior treatment (Fig. 13). Ash mix, woodchips, and hay were all statistically equal, as were woodchips, hay fertilizer, and control. Ash mix was significantly better, however, than either fertilizer or control. On 29 July manure, hay, and woodchips were

Table 7. P-values from analysis of variance tests to detect significant differences in height between substrates, treatments, and species of tree row in which annual ryegrass was planted.

	JUNE 19 Height	JULY 17 Height	AUG 17 Height	SEP 10 Height
substrate	0.0050	a	a	a
treatment	0.0001	0.0001	0.0001	NS
species	NS[b]	0.0308	NS	NS
trt/spec	NS	NS	NS	NS
trt/sub	0.0492	a	a	a
spec/sub	NS	a	a	a
trt/spec/sub	NS	a	a	a

[a] Insufficient bottom ash data for substrate comparisons, analysis of scrubber sludge only.

[b] Not significant ($p > 0.05$)



TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), ash mix plus fertilizer (A/F), hay plus fertilizer (H/F), fertilizer only (F), and control (C).

Figure 11. Mean vegetative height of annual ryegrass on both substrates on 19 June and on scrubber sludge only on 17 July, 17 August, and 10 September, 1982, as affected by the various treatments. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 8. P-values from analysis of variance tests to detect significant differences in density between substrates, treatments, and species, as well as interactions between these three, on each date measured in 1982.

	JUNE 4 Density	JUNE 19 Density	JULY 3 Density	JULY 17 Density
substrate	0.0049	0.0015	0.0001	0.0006
treatment	NS[a]	NS	0.0005	NS
species	0.0001	0.0001	0.0001	0.0001
trt/sub	NS	NS	0.0071	NS
spec/sub	0.0001	0.0001	0.0001	0.0001
trt/spec	NS	NS	0.0003	NS
trt/spec/sub	NS	NS	NS	NS
	JULY 29[b] Density	AUG 17[b] Density	AUG 28[b] Density	SEP 10[b] Density
treatment	0.0162	0.0010	0.0001	NS
species	0.0001	0.0001	0.0001	0.0001
trt/spec	0.0001	0.0010	0.0001	0.0384

[a] Not significant ($p > 0.05$)

[b] Insufficient bottom ash data for substrate comparisons, analysis of scrubber sludge only

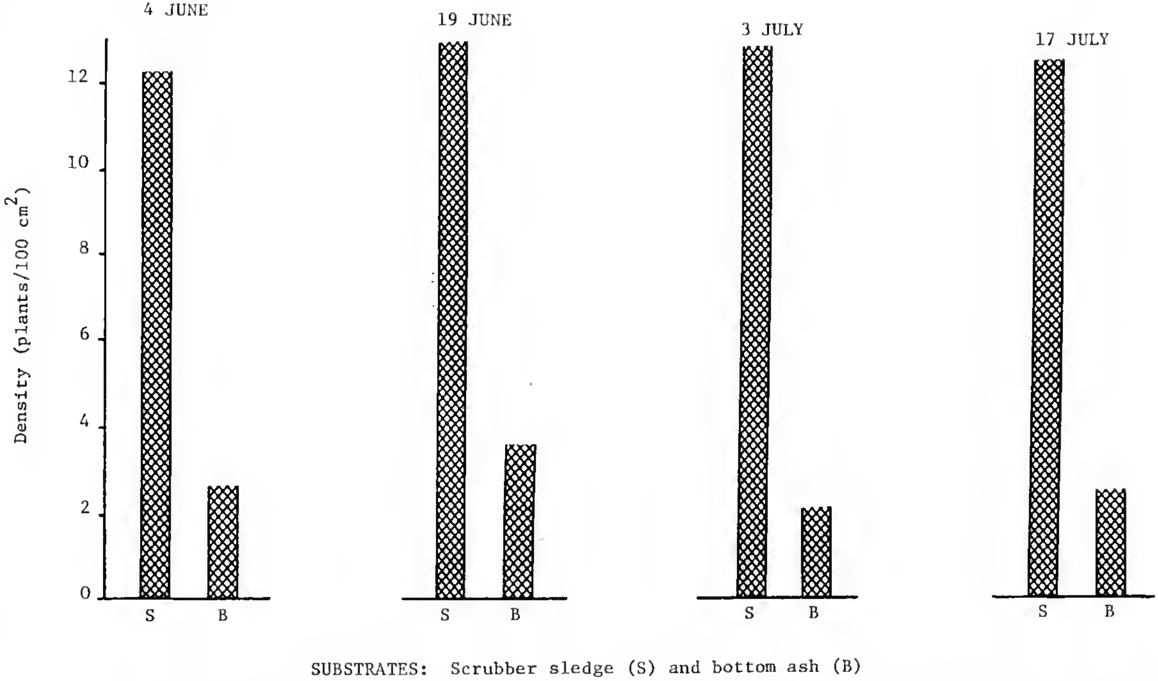
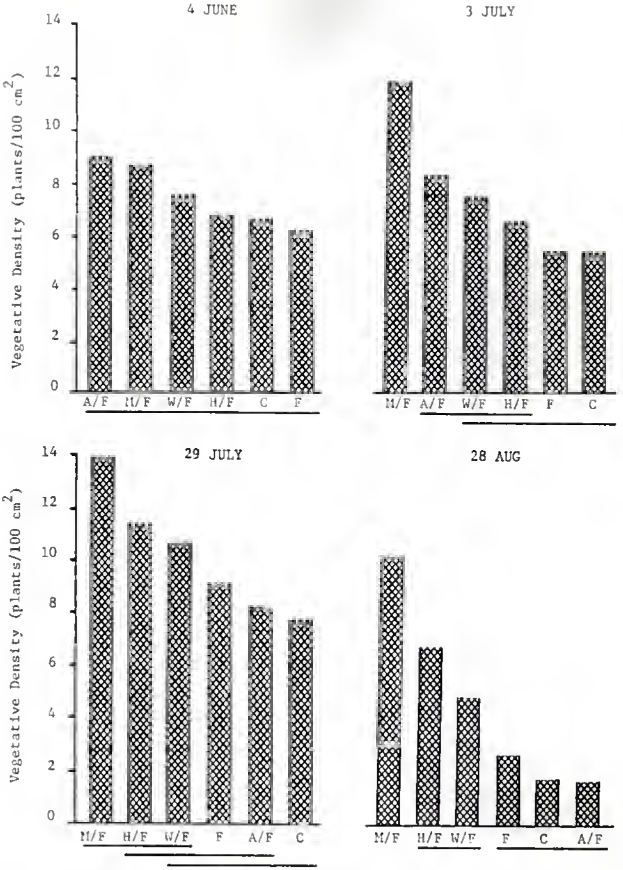


Figure 12. Mean vegetative density across all species and treatments as affected by the two test substrates, scrubber sludge and bottom ash, during 1982.



TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F, hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C).

Figure 13. Mean vegetative density on both substrates on 4 June and 3 July and on scrubber sludge alone on 29 July and 28 August, 1982, as affected by the various treatments. Bars underscored by the same line are not significantly different ($p > 0.05$).

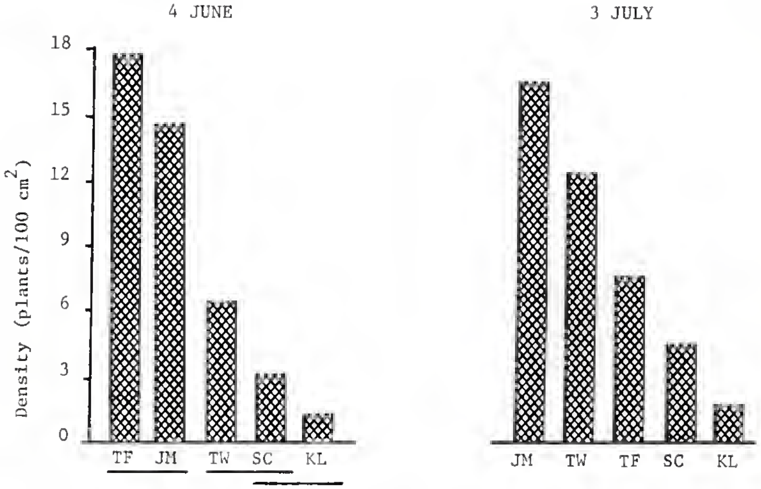
statistically indistinguishable, as were hay, woodchips, fertilizer, and ash mix, with these latter three also equal to control. By 28 August manure was significantly superior to all others, followed by hay and woodchips, and then by fertilizer, control, and ash mix.

There is such a significant difference between density produced by all treatments on the two substrates that the factors responsible for the treatment/substrate interaction detected on 3 July are not immediately apparent. Woodchips stimulated the densest growth of any treatment on bottom ash, and the lowest value on scrubber sludge, and this no doubt contributed to the interaction effect, even though scrubber sludge was still significantly more superior (Appendix, Fig. 10).

There were significant differences between species density at each data measured (Table 8). Showy sunflower was omitted from analysis of density, as it was measured on a scale of plants/0.25 m^2 rather than plants/100 cm^2. Smartweed and reedgrass were again omitted from early-season analysis due to later germination and overall poor growth on bottom ash.

Of the five remaining species, tall fescue and Japanese millet produced the best density on 4 June, followed by wheatgrass and sweetclover which were statistically equal, and lespedeza which was equal with sweetclover (Fig. 14). On 3 July there were significant differences between each species. Millet was superior, followed by wheatgrass, fescue, sweetclover, and lespedeza, in descending order.

Significant species/substrate interaction on 4 June appears to be a result of drastically reduced scrubber sludge densities of both lespedeza and reedgrass (Appendix, Fig. 11). These low values decreased the otherwise superior overall scrubber sludge mean to a point equalling that of bottom ash. The same is true of lespedeza density on scrubber sludge recorded on 3 July (Appendix, Fig. 12), with this value representing the



SPECIES: Tall wheatgrass (TW), tall fescue (TF), Japanese millet (JM), sweetclover (SC), Korean lespedeza (KL).

Figure 14. Mean vegetative density of species across all treatments on bottom ash and scrubber sludge, recorded on 4 June and 3 July, 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

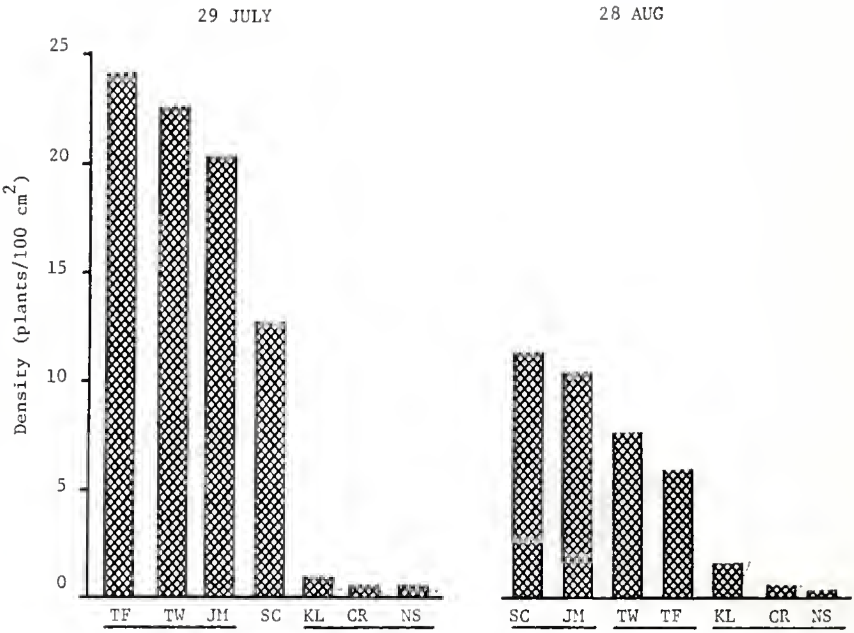
sole deviation from the significant increase in scrubber sludge over bottom ash.

The treatment/species interaction detected on 3 July was simply the result of each species responding quite differently on each treatment (Appendix, Fig. 13). As with height interactions, the superiority of manure as a treatment was the only partially consistent element. This was altered only for fescue and lespedeza, with manure ranking as the third and second best treatment, respectively.

Fescue, wheatgrass, and millet were equally superior on scrubber sludge on 29 July, followed by sweetclover and then lespedeza, reedgrass, and smartweed (Fig. 15). Sweetclover had become a dominant species by 28 August, equally superior with millet. Wheatgrass and millet were statistically equal and followed in significance, with lespedeza, reedgrass, and smartweed again the poorest species.

The interactions detected between treatments and species on these two dates again have no readily apparent and simple explanation. The density of each species was affected quite differently by the six treatments (Appendix, Fig. 14 and 15). Sweetclover and tall wheatgrass appeared to exhibit the greatest degree of variation in densities across all treatments.

Density of annual ryegrass was significantly better on scrubber sludge than on bottom ash for the only date on which both substrates were compared, 19 June (Table 9). Significant treatment effects were detected only twice, on 17 July and on 10 September, with significant species differences noted only on 19 June. A comparison of mean density produced by the various treatments on 17 July and 10 September yielded differing results (Fig. 16). The LSD indicates manure plus fertilizer as producing good ryegrass density in July, inseparable from hay and fertilizer alone,



SPECIES: Tall wheatgrass (TW), tall fescue (TF), Japanese millet (JM), sweetclover (SC), Korean lespedeza (KL), common reedgrass (CR). nodding smartweed (NS).

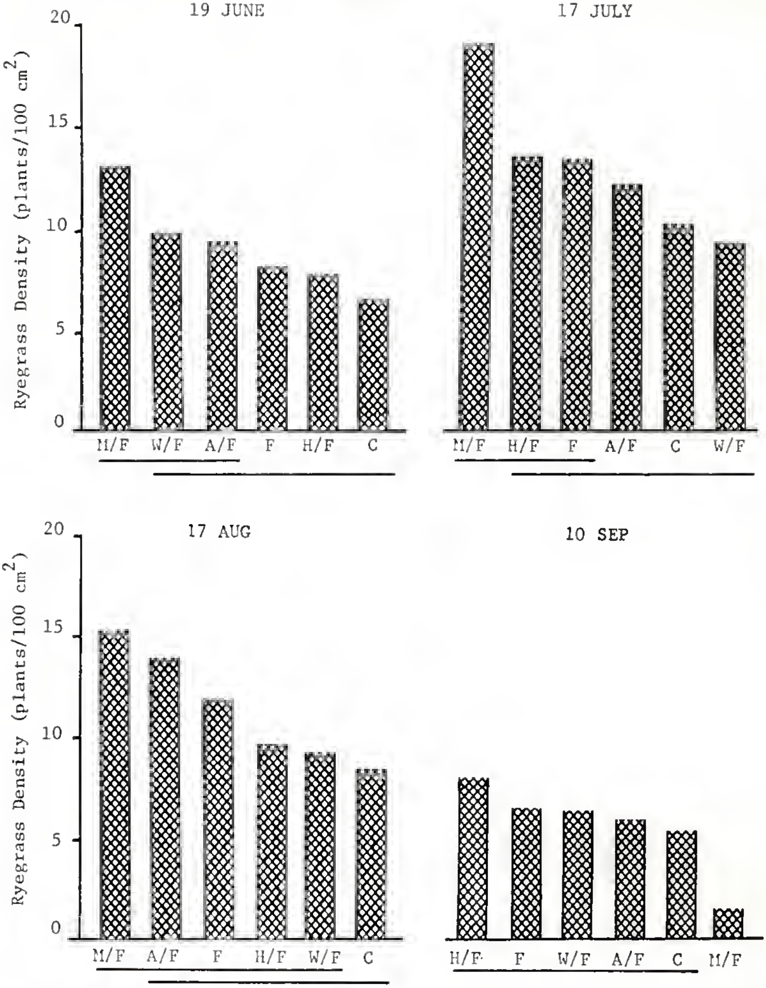
Figure 15. Mean vegetative density of species across all treatments on scrubber sludge, recorded on 29 July and 28 August, 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 9. P-values from analysis of variance tests to detect significant differences in density between substrates, treatments and species of tree row in which annual ryegrass was planted.

	JUNE 19 Density	JULY 17 Density	AUG 17 Density	SEP 10 Density
substrate	0.0050	a	a	a
treatment	NS[b]	0.0480	NS	0.0150
species	0.0452	NS	NS	NS
trt/spec	NS	NS	NS	NS
trt/sub	NS	a	a	a
spec/sub	NS	a	a	a
trt/spec/sub	0.0093	a	a	a

[a] Insufficient bottom ash data for substrate comparisons, analysis of scrubber sludge only

[b] Not significant ($p > 0.05$)



TREATMENTS: Manure plus fertilizer (M/F), hay plus fertilizer (H/F), fertilizer only (F), ash mix plus fertilizer (A/F), control (C), and woodchips plus fertilizer (W/F).

Figure 16. Mean plant density of annual ryegrass on both substrates on 19 June, and sludge for the remainder of the season, as affected by the various treatments during 1982.

these latter two in turn being indistinguishable from the remaining treatments. Yet in September, manure is determined to be the poorest treatment, significantly different from all other treatments. This is the first divergence from the pattern of overall superiority heretofore established by the manure treatment.

Ryegrass exhibited sufficient variation in density between species of tree, treatment, and substrate to cause a significant interaction on 19 June. Each tree species seemed to elicit a different ryegrass growth from treatment to treatment on either substrate (Appendix, Fig. 16). Only amur maple maintained any sense of consistency with moderately low values of ryegrass density throughout.

Herbaceous Species Cover Ranking Data

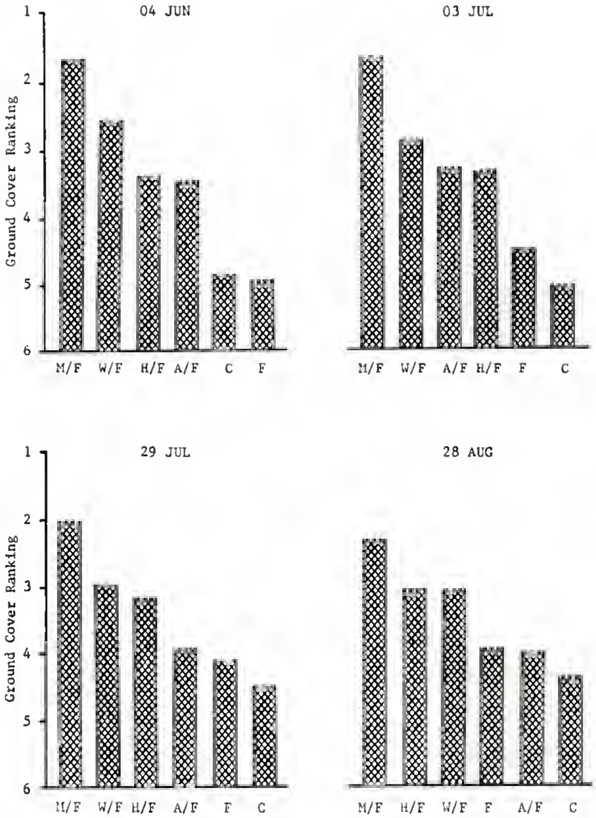
The nature of the ground cover ranking utilized for all herbaceous species except ryegrass resulted in each species and each substrate receiving an identical mean ranking score of 3.5. As such, the ANOVA was possible only for treatment effects, the ranking essentially serving as a measure of the effectiveness of the microclimate within each treatment section. Since treatments were ranked against one another with no zeros assigned, data from both substrates were available for analysis throughout the summer. There were significant differences detected between treatments, with significant interaction effects, for each set of data analyzed (Table 10).

A comparison of mean cover ranking for the first two months indicated that manure plus fertilizer was significantly a superior treatment, while the fertilizer only and control sections were the poorest (Fig. 17). Woodchips on 4 June were statistically inseparable from manure, and also from hay and ash mix, yet manure was significantly different from these

Table 10. P-values from analysis of variance tests to detect significant differences in ground cover ranking between treatments, including interactions during 1982.

	JUNE 4 Cover Rank	JUNE 19 Cover Rank	JULY 3 Cover Rank	JULY 17 Cover Rank
treatment	0.0003	0.0001	0.0001	0.0001
trt/sub	0.0229	0.0198	0.0003	0.0024
trt/spec/sub	0.0225	0.0001	0.0001	0.0001
	JULY 29 Cover Rank	AUG 17 Cover Rank	AUG 28 Cover Rank	SEP 10 Cover Rank
treatment	0.0001	0.0001	0.0001	0.0006
trt/sub	0.0007	0.0002	0.0036	[a]
trt/spec/sub	0.0001	0.0001	0.0001	[a]

[a] Insufficient data to complete analysis



TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C)

Figure 17. Mean vegetative cover ranking on both bottom ash and scrubber sludge substrates as affected by the various treatments, recorded during 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

latter two as from control and fertilizer alone. Manure was the best treatment on 3 July, followed by woodchips, ash mix, and hay, then by fertilizer, and then by control.

Significant treatment/substrate interaction on 4 June was caused by both ash mix and woodchips receiving a higher ranking value (indicating poorer ground cover) on scrubber sludge than on bottom ash (Appendix, Fig. 17). All other treatments ranked significantly better on scrubber sludge. On 3 July woodchips again ranked much poorer on scrubber sludge, with ash mix and control essentially equal for both substrates (Appendix, Fig. 18). Rankings of manure, hay, and fertilizer paralleled one another, with bottom ash consistently poorer.

The significant treatment/species/substrate interactions for 4 June and 3 July cannot be easily interpreted upon examination of the data (Appendix, Fig. 19 and 20). The only statements which can be made are that there was a great deal of variability in vegetative cover ranking between all three variables, and that there tended to be a shift toward lower (more desirable) values for vegetation on scrubber sludge.

Manure was again superior on both 29 July and 28 August, with woodchips and hay inseparable (Fig. 17). Ash mix, fertilizer, and control were significantly the poorest treatments on both dates. These results reinforce the conclusion that organic amendments, manure in particular, were more desirable than inorganic ash mix or no treatment at all for stimulating vegetative growth on bottom ash and scrubber sludge.

Oddly enough, the treatment/substrate interactions detected on 29 July and 28 August result from scrubber sludge averaging better rankings than bottom ash on only two treatments, manure and hay (Appendix, Fig. 21 and 22). Fertilizer and ash mix are equally ranked on each substrate on

29 July, with woodchips and control ranking better on bottom ash. Each of these four treatments ranked better on bottom ash on 28 August.

This cover ranking was a relative rating of the various treatments within each plot, and did not relate to vegetation on any other plot. So while a particular treatment may have ranked better on bottom ash than it did on scrubber sludge, this does not conclude that the actual growth was better, but merely that it was better compared to the other treatments within the bottom ash substrate.

The differences recorded for cover rankings on woodchips and manure mulches are the primary factors contributing to treatment/species/substrate interactions on 29 July and 28 August. Data reveal that across both substrates these mulches produced much better rankings on each of these dates (Appendix, Fig. 23 and 24). The differences are more striking on bottom ash, where these mulches represent an extremely positive deviation from the poor growth otherwise noted.

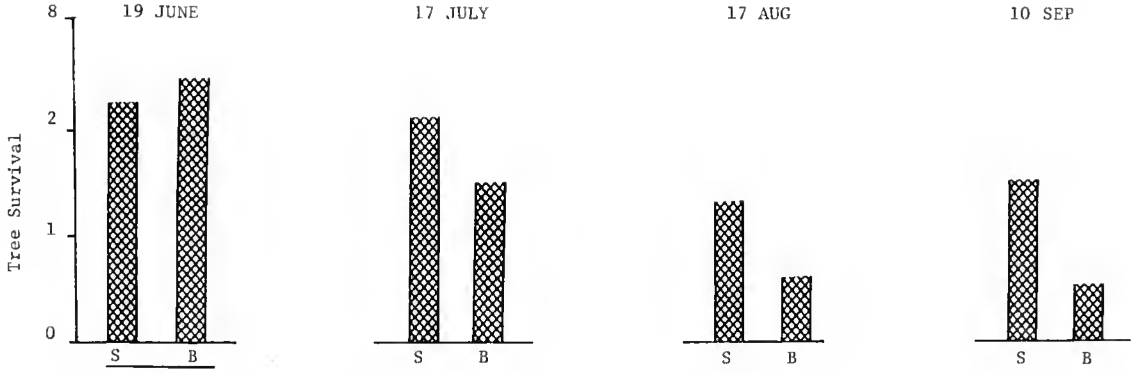
Tree Survival and Growth

Survival of tree species on both substrates was analyzed by comparing mean number of surviving individuals per treatment-species combination as recorded each month. The ANOVA of these data indicated significant differences between substrates for all but the initial measurement, significant treatment differences for only the final two of the four measurements, and significant species effects at every date (Table 11). The magnitude of the difference between the two substrates increased as the summer progressed, with scrubber sludge averaging much higher survival rates (Fig. 18). A comparison of mean survival of all species on the six treatments during the latter half of the summer identified woodchips as significantly better than all others for both dates (Fig. 19). Although hay produced

Table 11. P-values from analysis of variance tests to detect significant differences between substrates, treatments, and species, analyzing mean tree survival (number surviving out of a possible three per treatment-species block) on each date measured, 1982.

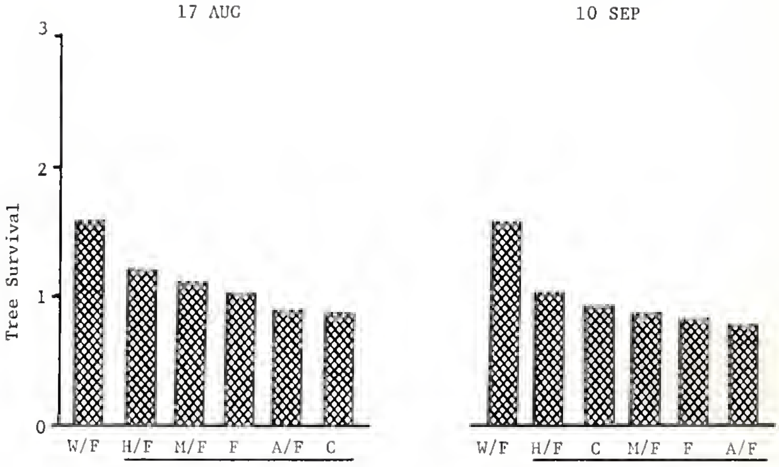
	JUN 19	JUL 17	AUG 17	SEP 10
substrate	NS[a]	0.0021	0.0020	0.0008
treatment	NS	NS	0.0016	0.0002
species	0.0001	0.0001	0.0001	0.0001
trt/spec	NS	0.0215	0.0001	NS
trt/sub	NS	NS	NS	NS
species/sub	0.0006	0.0006	0.0003	0.0001

[a] Not significant ($p > 0.05$)



SUBSTRATES: Scrubber sludge (S), bottom ash (B)

Figure 18. Mean number of trees surviving (3 possible) on each treatment-species combination as affected by the two test substrates. Bars underscored by the same line are not significantly different ($p > 0.05$).



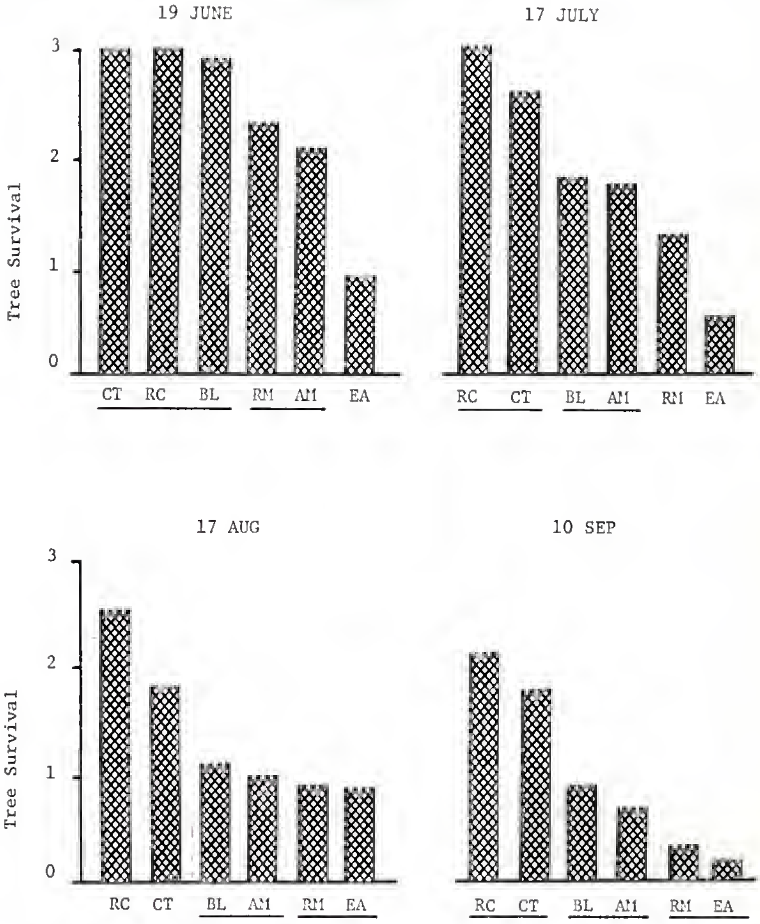
TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C).

Figure 19. Mean number of trees surviving (of a possible three) on each treatment-species combination, as affected by the various treatments in 1982. Bars underscored by the same line are not significantly different ($p > 0.05$).

the second highest mean survival both months, it was both times statistically inseparable from the remaining four treatments.

Cottonwood and red cedar averaged the highest survival of all species on 29 June, followed closely by black locust, with no significant difference between these three (Fig. 20). Red maple and amur maple were the next in order of superiority, with European alder the poorest species. On 17 July cedar and cottonwood were still statistically equal and superior, although cottonwood averaged slightly lower than cedar. Locust and amur maple were equal, followed by red maple and then alder again poorest. Cedar was the significantly superior species on 17 August, with cottonwood second. Locust and amur maple were statistically equal, as were red maple and alder, the latter two exhibiting the lowest survival. By 10 September cedar and cottonwood were again separated by no significant difference, with the other four remaining in order as they has been in August.

The one significant interaction throughout each month was that of species x substrate (Table 11). The results of this were similar for each date measured, thus a comparison of the interaction means for 10 September, determining final season's survival (Table 12), serves as an example of all previous measuring dates. The interaction becomes obvious upon comparison of cottonwood and red cedar mean survival on the two substrates. Cedar exhibited greater survival than any other species on bottom ash, while it was second to cottonwood on scrubber sludge. Cottonwood, on the other hand, averaged lower on bottom ash, equal with amur maple. If bottom ash data had been omitted due to poor overall survival, cottonwood would have averaged the best species (on scrubber sludge). Yet it was cedar's ability to survive on bottom ash when others could not which resulted in its elevated survival rate.



SPECIES: Cottonwood (CT), red cedar (RC), black locust (BL), red maple (RM), amur maple (AM), European alder (EA)

Figure 20. Mean number of trees surviving (of a possible three), on each treatment-species combination in 1982, indicating species means. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 12. Species x substrate mean survival as recorded on 10 September, 1982.

Species	Mean Survival[a]	
	Bottom Ash	Scrubber Sludge
European alder	0.0	0.11
Amur maple	0.67	0.83
Red cedar	1.44	2.78
Cottonwood	0.67	2.94
Black locust	0.22	1.56
Red maple	0.06	0.56

[a] Number of surviving trees per treatment (3 = maximum)

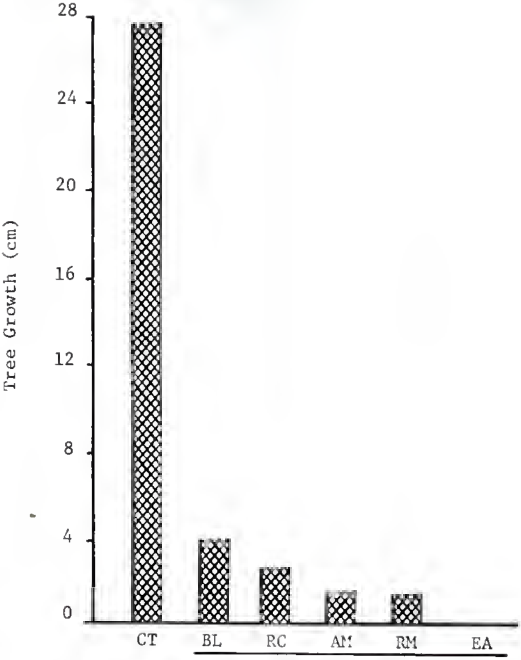
By the time total season's new tree growth was measured on all plots in October, the die-off of plants on bottom ash was widespread. Because of this virtual failure of all vegetation, these data were omitted from the analysis. The ANOVA was used to determine species and treatment effects on tree growth on scrubber sludge, with significant differences determined for each (p-values of .0001 and .0331, respectively). Cottonwood trees produced significantly greater height increases than all other species, averaging more than seven times greater than black locust, the second highest ranking species (Fig. 21). Locust and the remaining four species were found to be statistically inseparable, with a difference of 3.7 cm between the extremes.

Examination of treatment means indicated that manure plus fertilizer stimulated the greatest increase in mean growth of all species on scrubber sludge (Fig. 22). The remaining five treatments were statistically inseparable, with a difference of only 1.54 cm between the two extremes represented by the control and fertilizer only treatments.

Monthly Substrate Analysis

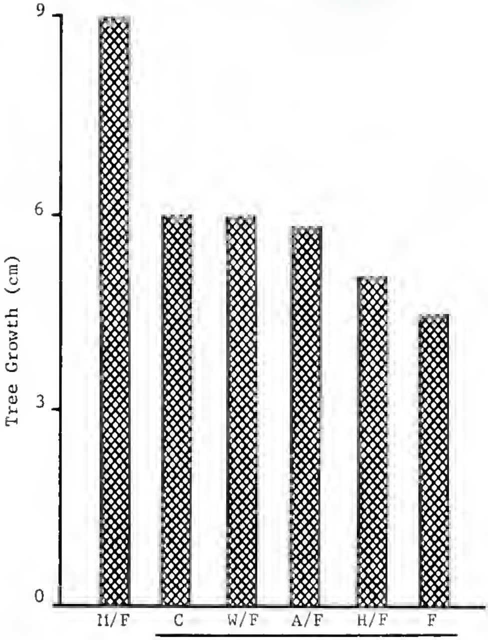
The bottom ash substrate at the LaCygne site was nearly neutral, averaging pH 7.1 (Table 13), ranging from pH 6.2 to 8.3 (Appendix, Table 1). Bottom ash contained approximately 10.5 kg/ha of P and 100.2 kg/ha of K. Organic matter and N were both present in very low quantities in this ash. Scrubber sludge was more basic than bottom ash, averaging pH 8.1 (Table 13), ranging from pH 7.6 to 8.5 (Appendix, Table 1). Average P levels were 6.3 kg/ha and average K was 455.4 kg/ha. Organic matter and N were also present in very low concentrations in scrubber sludge.

The ANOVA test at the 0.05 level detected significant differences between substrate levels of pH, K, and organic matter, with scrubber sludge



SPECIES: Cottonwood (CT), black locust (BL), red cedar (RC), Amur maple (AM), red maple (RM), European alder (EA).

Figure 21. Mean 1982 seasonal height increases of each tree species across all treatments on scrubber sludge. Bars underscored by the same line are not significantly different ($p > 0.05$).



TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C).

Figure 22. Mean 1982 seasonal height increases of all tree species as affected by the various treatments on scrubber sludge. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 13. Characteristics of No. 1 bottom ash and scrubber sludge substrates at the LaCygne disposal site, presented as means (± S.D.) of samples collected from each test plot six times during the summer, 1982. P-values result from ANOVA.

Characteristic	Bottom Ash	Scrubber Sludge	p-values
pH	7.1 (± 0.6)	8.1 (± 0.3)	.0246
Nitrogen (ppm)	0.3 (± 0.4)	2.9 (± 4.6)	NS[a]
Phosphorus (kg/ha)	10.5 (± 7.4)	6.3 (± 5.2)	NS
Potassium (kg/ha)	100.2 (± 167.7)	455.4 (± 146.7)	.0018
Organic matter (%)	0.6 (± 0.5)	1.7 (± 0.5)	.0028

[a] Not significant ($p > 0.05$)

values determined higher for each (Table 13). Although P was determined higher on bottom ash and N higher on scrubber sludge, these differences were not significant between the two substrates. The LSD test of mean elemental compositions at each month across both substrates yielded somewhat inconclusive results (Table 14). Three of the characteristics analyzed (pH, P, and organic matter) were determined at their highest values in the earliest month sampled, May. Beyond this there appear no trends to indicate either increases or declines in specific composition with increasing time.

Analysis of Additional Substrate Samples

The compositional analysis of substrate samples collected at 16 locations on the scrubber sludge disposal area indicated some degree of variation between the samples (Table 15). Samples 1-6, which passed through and beyond the thickest concentration of vegetation at the eastern edge of the sludge pond, exhibited a gradual increase in pH with increasing distance from the bank. Sample 6 was located beyond the range of all but a scattering of vegetation. The total pH increase from sample 1 to 6 was 0.7, and while the collection of only one sample at each location precluded the validity of using the ANOVA, this appears not to be significant. This pH increase of 0.7 represented the extent of the range for all scrubber sludge samples.

No other sludge characteristic measured indicated variations which could be interpreted as significant, except for a higher K concentration (525 kg/ha) determined for sample 15, taken near the test plots. This value stood out from all others, but all other measurements for this sample were within conceivable ranges, so no explanation is readily apparent for this deviation. Nitrogen levels appear to fluctuate somewhat as would be

Table 14. Results of LSD tests to determine monthly changes in substrate composition, monthly values arranged in descending order of magnitude for each characteristic. Months underscored by the same line are not significantly different ($p > 0.05$).

Characteristic	Monthly Values				
pH	MAY (8.1)	SEP (7.7)	OCT (7.6)	JUL (7.4)	AUG (7.1)
Nitrogen	OCT (3.08)	AUG (0.95)	SEP (0.70)		
Phosphorus	MAY (14.6)	AUG (9.4)	JUL (8.6)	SEP (8.6)	OCT (4.1)
Potassium	JUL (505.4)	SEP (275.3)	AUG (260.7)	OCT (256.0)	MAY (132.0)
Organic matter	MAY (1.4)	JUL (1.36)	OCT (1.03)	AUG (1.0)	SEP (0.9)

Table 15. Characteristics of 21 substrate samples collected in August 1982 from the LaCygne Station disposal area. Samples 1-19 were from a depth of 5-8 cm, No. 20 was from a depth of 15 cm and No. 21 was from the surface. Analysis by KSU Soil Test Laboratory.

Sample No.	pH	ppm N	kg/ha P	kg/ha K	% O. M.
			Scrubber Sludge		
1	7.7	3.3	7	299	1.1
2	7.9	2.4	7	245	1.4
3	8.0	2.6	12	240	1.3
4	8.2	3.6	6	269	1.4
5	8.2	1.5	2	231	1.3
6	8.4	3.0	6	381	1.4
7	8.2	0.2	7	267	2.1
8	8.0	0.8	7	135	1.4
9	8.0	2.6	9	264	1.4
10	8.1	1.1	15	248	1.3
11	8.0	1.5	6	232	1.5
12.	8.2	0.8	11	293	2.0
13	8.2	0.9	11	286	1.9
14	8.3	0.2	7	260	1.8
15	8.4	1.1	10	515	2.0
16	8.2	1.1	9	397	1.6
			No. 1 Bottom Ash		
17	12.0	2.6	10	129	2.5
			No. 2 Bottom Ash		
18	8.3	0.8	25	70	1.1
19	8.9	0.8	16	83	1.6
20	9.6	0.6	17	38	0.5
			No. 2 Fly Ash		
21	13.0	3.4	13	377	0.8

expected, and were not considered unusual by the staff of the KSU Soil Test Laboratory, particularly for samples of such shallow depth (5-8 cm).

Samples of No. 1 bottom ash and No. 2 fly ash were obviously quite different from all others due to high pH readings (12.0 and 13.0, respectively). For bottom ash this may have been the result of sampling or analytical error, as this was much higher than pH levels determined from test plots on bottom ash. The analysis of all other constituents is consistent between this and other samples. The No. 2 fly ash sample also is well within the range of other samples for all characteristics determined other than pH.

Sample analyses of No. 2 bottom ash differed from all others in that they indicated higher levels of P and considerably lower levels of K. Among the three samples of this substrate the highest P concentration was detected on the slope of the pile where the two bottom ash types may have mixed (sample 18), and K levels were similar both here and at the top of the pile, with decreased K detected at a deeper 15-cm sample (20). Values of pH, N, and organic matter were consistent with other samples.

Analysis for toxic quantities of B, SO_4-S, and soluble salts of samples collected from bottom ash (plot 2) and scrubber sludge (plot 5) indicated striking differences between the two substrates (Table 16). Scrubber sludge contained higher levels of all three constituents, with 87.5 times the B, 13.8 times the SO_4-S, and 30.7 times the salt level as did bottom ash. These elevated B and salt levels may sometimes inhibit normal plant growth on scrubber sludge (E.E. Schulte, Director, Wisconsin Soil & Plant Analysis Laboratory, personal comm.). Results from our test plantings do not substantiate this growth inhibition, as vegetation planted on scrubber sludge was far superior to that on bottom ash.

Table 16. Results of analyses of boron, SO_4S, and soluble salts in samples collected from bottom ash (plot 2) and scrubber sludge (plot 5) in August, 1982. Analysis by Wisconsin Soil & Plant Analysis Laboratory.

Substrate	Boron (ppm)	Sulfate-Sulfur (ppm)	Soluble Salts (mmhos/cm)
Bottom Ash	0.4	26.0	0.6
Scrubber Sludge	35.0	360.0	18.4

Identification of Naturally Invading Vegetation

Specimens of the vegetation occurring naturally on various waste areas which were collected in August 1982 and subsequently identified indicated that the scrubber sludge surface contained the greatest species variety (Table 17). The majority of these were found along the eastern edge of the slurry pond, over 50% located within 40 m of the bottom ash bank (Fig. 23), with scattered individuals located along the western edge on the far side of the pond. There was very little noticeable vegetation occurring anywhere across the width of this area, with all but the edges appearing devoid of cover.

Plants collected from along the No. 1 bottom ash bank separating the two test sites were primarily growing in bottom ash, but were found on the downward sloping edge of the bank. This area was more subject to settling and blowing, creating a mixture of bottom ash and scrubber sludge material, as well as other wind-borne particles. Both plant species collected from No. 2 bottom ash were located growing on the slope of a pile, where some degree of mixing of both bottom ashes and even scrubber sludge was quite possible. Species taken from the manure mulch of scrubber sludge plot 5 were representatives of the dominant vegetation associated with this mulch, and are presumed to have been introduced with it.

Temperature and Precipitation of the LaCygne Area

Mean ambient temperatures recorded monthly at Paola and Mound City, Kansas indicate the similarities between these stations (Appendix, Table 2), which are located within 50 km of one another. While these year-long records are of value, particular interest must focus on the growing season to determine conditions to which the test vegetation were subject. A graphic presentation of the data for this critical period, April through

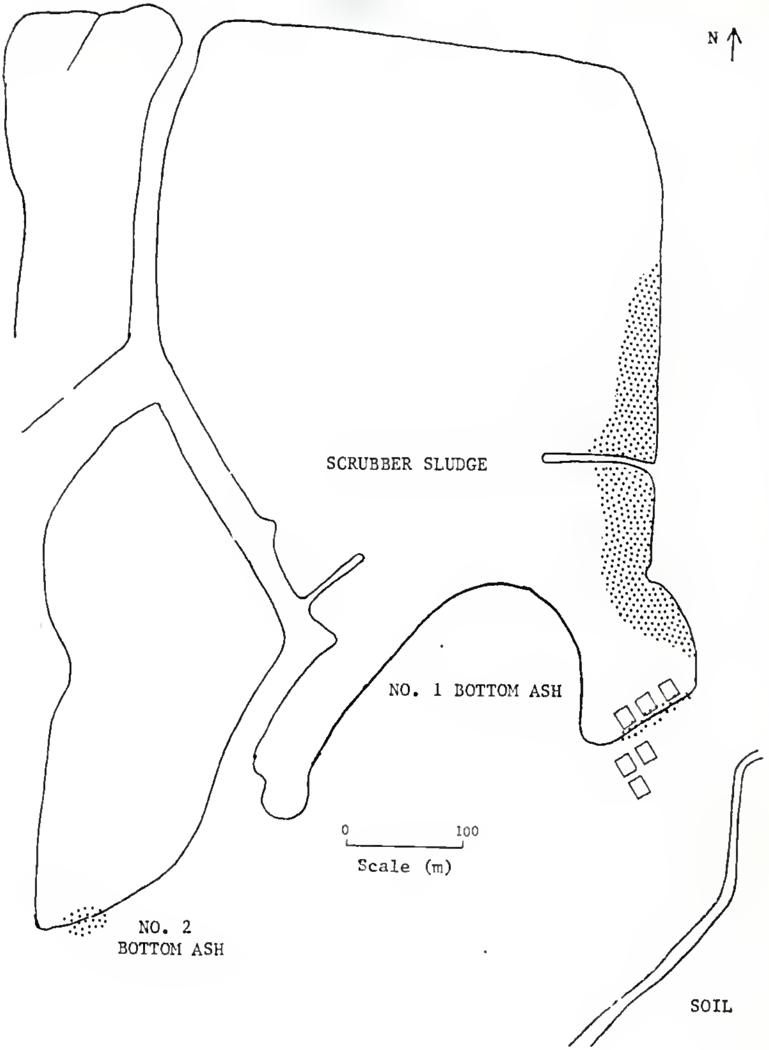


Figure 23. Disposal areas at the LaCygne station, with August 1982 vegetative concentrations at each collection site indicated by stippled areas.

Table 17. Plant species collected in August 1982 from various locations within the La Cygne waste disposal areas and test site.

Location	Common Name	Scientific Name
No. 1 Scrubber Sludge	Pigweed	*Amaranthus rudis* Sauer
	Lamb's quarter	*Chenopodium album* L.
	Nutsedge	*Cyperus odoratus* L.
	Barnyard grass	*Echinochloa crusgalli* (L.) Beauv.
	Sunflower[a]	*Helianthus* sp.
	Summer cypress	*Kochia scoparia* (L.) Schrad.
	Willow lettuce	*Lactuca saligna* L.
	Prickly lettuce	*Lactuca serriola* L.
	Yellow sweetclover	*Melilotus officinalis* (L.) Lam.
	Virginia creeper	*Parthenocissus* sp.
	Pokeweed	*Phytolacca americana* L.
	Knotweed	*Polygonum aviculare* L.
	Mild water pepper	*Polygonum hydropiperoides* Michx.
	Knotweed	*Polygonum ramosissimum* Michx.
	Dock	*Rumex* sp.
	Giant foxtail	*Setaria faberii* Herrm.
	Horse nettle	*Solanum carolinense* L.
	Narrow-leaved cattail	*Typha angustifolia* L.
	Cocklebur[a]	*Xanthium* sp.
No. 1 Bottom Ash Bank Between Test Plot Sites	Common ragweed	*Ambrosia artemisifolia* L.
	Eyebane	*Euphorbia nutans* Lag.
	Sunflower[a]	*Helianthus* sp.
	Giant foxtail	*Setaria faberii* Herrm.
	Tall goldenrod	*Solidago canadensis* L.
	Cocklebur[a]	*Xanthium* sp.
No. 2 Bottom Ash	Flower-of-an-hour	*Hibiscus trionum* L.
	Giant foxtail	*Setaria faberii* Herrm.
No. 1 Scrubber Sludge Manure Mulch	Pigweed	*Amaranthus rudis* Sauer
	Rice cutgrass	*Leersia oryzoides* (L.) Swartz.

[a] No specimen collected; genus identification made in the field.

September, revealed a relatively steady increase in temperature to a peak in July, with a very slight decline in August (Fig. 24). September temperatures decreased still further, to approximately equal those of June.

Also included in this comparison are 'normal' temperatures, determined from an average of 30 years' records from Mound City (Appendix, Table 2). These records reveal that 1982 was a relatively typical growing season. Temperature deviations from normal were quite moderate for April, May, and June, and were virtually nonexistent for July, August, and September.

Precipitation was the other critical element monitored to characterize the climate of the study area during field investigations. There tended to be somewhat more variability in these data between the three locations monitored, LaCygne, Paola, and Mound City, with the most striking discrepancies occurring in June and July (Appendix, Table 3). During these months Paola received approximately double the precipitation received by each of the other two locations. During the growing season there was a sharp drop-off of precipitation received at both LaCygne and Mound City, and this, more than an increase at Paola, contributed to the difference (Fig. 25).

Normal precipitation records based on the 30-year average were available from LaCygne and Paola (Appendix, Table 3). These records indicated that April was somewhat drier than normal, while May was considerably wetter at both locations. June records provide exactly opposite data for the two stations, with LaCygne receiving less rain than normal and Paola receiving more. July received less precipitation than is normally encountered at either station, more dramatically so at LaCygne. August was wetter at both locations, while both reported much less precipitation than normal during September.

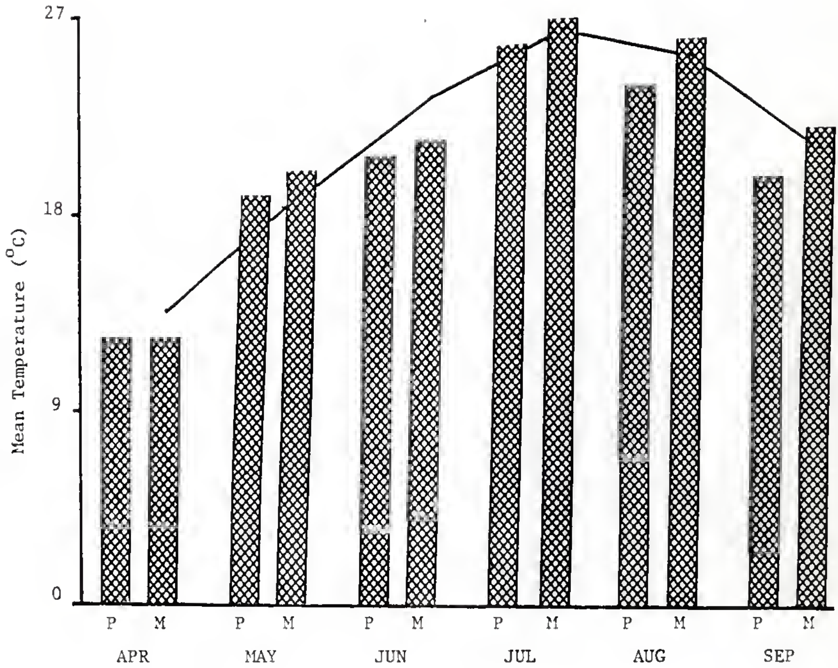


Figure 24. Mean monthly temperatures recorded at Paola (P) and Mound City (M), Kansas during the period April-September, 1982. Curved line represents normal Mound City temperatures, determined from a 30-year average.

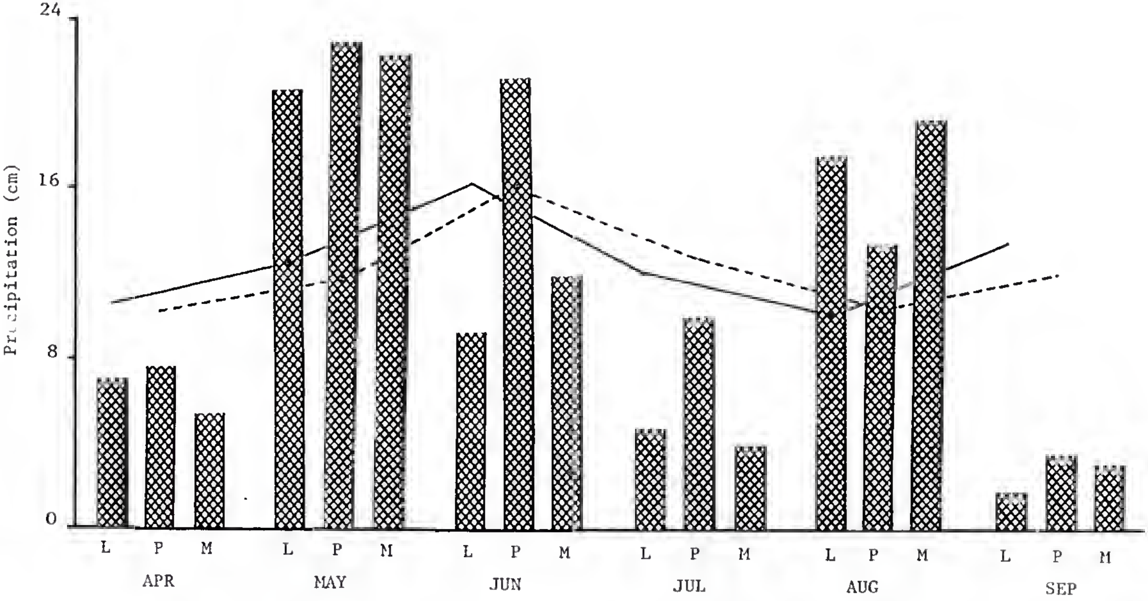


Figure 25. Mean monthly precipitation recorded at LaCygne (L), Paola (P), and Mound City (M), Kansas during the period April-September, 1982. Solid line represents LaCygne normal precipitation, dashed line Paola normal precipitation, determined from the 30-year average.

PHASE I

1 April 1982 - 31 March 1983

DISCUSSION

Growth of Vegetation on Bottom Ash and Scrubber Sludge

All nine herbaceous and six woody species planted in test plots during Phase I exhibited better growth on scrubber sludge than on bottom ash throughout the summer. Herbaceous plant density and height measurements, and tree survival and growth, were significantly greater for plants on scrubber sludge, indicating the relative effectiveness of this substrate as a growth medium. The differences in plant response on bottom ash and scrubber sludge may in part be due to the physical differences of these substrates. Woodward-Clyde Consultants (1981b) determined the texture of LaCygne Unit No. 1 bottom ash to resemble coarse sand, while scrubber sludge was described as considerably finer-grained.

This could allow for a greater capacity to retain moisture within scrubber sludge. Fly ash, one of the principle components of scrubber sludge, has been determined to classify, texturally, from 63-80% silt, with a capacity to hold 30-50% available water (Nebgen et al., 1978; Jacobs et al., 1982). I observed very obvious differences in moisture content of the two LaCygne substrates when collecting samples for nutrient analysis. Throughout the driest portions of the season, when little or no moisture was evident in bottom ash to the depth of the core samples (8 cm), scrubber sludge samples remained quite moist.

This finer texture should feasibly benefit plants growing on scrubber sludge in yet another manner besides water availability. Fly ash added to mine spoils was observed to alter the substrate texture sufficiently to allow greater root penetration by plants used in reclamation efforts

(Adams et al., 1972). Given the east with which a metal core sampler penetrated the scrubber sludge compared with bottom ash, it is not difficult to imagine the beneficial effect on plant root development in the sludge substrate.

Bottom ash is characterized by a black, almost glassy appearance, while scrubber sludge is a dull gray. It seems logical to assume that the potential for radiant heating must be greater on bottom ash, possibly to the detriment of plant growth. During investigations to reclaim disturbed sites, Bramble (1952) reported that extreme surface temperatures, particularly on dark-colored lands, can be sufficient to restrict vegetation on these sites. During the hottest portions of the summer on 1982, when National Oceanic and Atmospheric Administration (NOAA) records reported average temperatures for the LaCygne area of nearly 27° C, radiant heating may well have been an adverse factor on bottom ash, particularly as there was still little vegetative growth to provide shade.

The differences in moisture retention again become important here, with NOAA records indicating that peak summer temperatures were coincident with extremely low precipitation. This effect likely created a double stress for vegetation growing on bottom ash, with greater demand for water occurring at a time when little was available.

Herbaceous Species Survival and Growth

Five of the nine herbaceous species exhibited superior growth characteristics on scrubber sludge in 1982: tall wheatgrass, tall fescue, yellow sweetclover, Japanese millet, and annual ryegrass. Both fescue and ryegrass have been documented as providing good growth on fly ash-amended acid mine spoils (Adams et al., 1971; 1972). Yellow sweetclover was reported to naturally invade a New York powerplant ash pond, producing a thick stand of vegetation averaging 1-1½ m tall (Furr et al., 1975). Sweetclover was also observed as a component of the naturally occurring vegetation on the LaCygne scrubber sludge pond, so its favorable response was not surprising.

Tall wheatgrass was included in a description of species recommended for disturbed area reclamation efforts, as were ryegrass, fescue, and sweetclover (U. S. Environmental Protection Agency, 1976). Japanese millet was initially selected for test planting because of its ability to tolerate moist substrates, such as mud flats, and for its potential benefits to wildlife (Martin et al., 1951).

During June measurements showy sunflower was one of the taller species, yet density and cover ranking were quite low and its continued growth was very poor. This cultivated sunflower apparently was not as well adapted to conditions as the LaCygne site as the wild Helianthus observed growing naturally on the slurry pond. Korean lespedeza germinated quite successfully on both substrates, then did not produce significant growth on any treatment. This may have been due to its affinity for more shaded areas, whereas in this test it was planted on bare substrate to provide its own cover (T. M. Barkley, KSU Division of Biology Herbarium, personal communication).

Common reedgrass and nodding smartweed both germinated extremely poorly and subsequent growth was not significant. Because of the difficulty in distinguishing seedlings of many test species from those naturally occurring within test plots, it was unknown whether reedgrass actually germinated at all. Although reported distribution of Phragmites australis (=communis) includes Miami County Kansas, just north of LaCygne (Great Plains Flora Association, 1977), field germination of seeds is reportedly often very low, with planting of rhizome sections preferable to seeding (Haslam, 1971; 1972). Harris and Marshall (1960) conducted germination tests using Phragmites seed collected from naturally occurring mature plants. Two out of four trials resulted in no germination, the remaining two germinated at 30% and 50%. Nodding smartweed was expected to do well for the same reasons as Japanese millet, both species observed in various Kansas managed wetland areas. Smartweed was also collected from natural vegetation on the scrubber sludge site. It may have been the later planting date (18 June vs. 14-21 May for all other herbaceous species) which contributed to smartweed's poor response.

The organic amendments produced significantly better recorded values of plant height, density, and ground cover across all species tested, with cattle manure plus fertilizer consistently the superior treatment. Manure was expected to add essential nutrients and organic matter, determined lacking in both substrates. Chandra and Seckler (1980) found cattle and buffalo manure in India to contain 1.12% N, 1.08% P, and 0.79% K, oven dry weight. Soil application of high rates of cattle manure resulted in increases in total soil N, organic C, NO_3, N mineralization, and general biological activity compared with untreated plots (Smith et al., 1980). Lund and Doss (1980) reported increased N uptake by cereal grains following manure application. Poultry manure applied to pulverized fuel ash prior to planting increased N levels and greatly improved yields of barley and perennial ryegrass compared with those of untreated ash (Rippon and Wood, 1973; 1974). While excessive N has been reported to cause germination injury to seedlings, this could be avoided by allowing time following manure application for volatilization of NH_4 (Adriano et al., 1973).

Woodchips plus fertilizer and prairie hay plus fertilizer each provided approximately equally beneficial results for vegetative growth, but less than manure. Wood bark has been reported as extremely beneficial as an aid in the establishment of plant species on disturbed sites in West Virginia (Sarles and Emanuel, 1977) and Kentucky (Henry et al., 1981). Gartner et al. (1973) have reported hardwood bark mulch as a growth medium as possessing excellent water holding capacity, providing a well-drained and well-aerated medium from which plants can readily obtain moisture, containing all minor essential plant elements, and exhibiting an ion exchange capacity greater than that of peat.

Amendments of straw and/or naturally occurring dead plant material have exhibited such reported benefits as soil additions of NO_3, K, and organic matter (Stephenson and Schuster, 1945), reductions in surface temperature and increases in moisture availability, even on hot dry days (Hopkins, 1954). It was believed that both woodchips and hay at LaCygne provided valuable surface protection from wind, heat, and drying, as well as possible additions of some essential nutrients.

Three remaining treatment sections (surface mixtures of bottom ash and scrubber sludge plus fertilizer, fertilizer only, and a control) were each characterized by significantly reduced plant growth. These results suggest that application of organic materials, which reportedly increase levels of nutrients and organic matter (Stephenson and Schuster, 1945), was considerably more effective for stimulating superior plant growth than application of inorganic treatments.

Tree Species Survival and Growth

Survival of individual tree species throughout the summer of 1982 was greatest for eastern red cedar and cottonwood, both of which may be found growing abundantly in many areas in Kansas. These species averaged nearly double the survival rate of black locust and amur maple, the next highest survivors. Both red maple and European alder exhibited significant mortality by summer's end.

Cottonwood and black locust reportedly survived more than 10 years on Indiana spoils banks (DenUyl, 1962), and have been recommended as readily adapted to similar spoils in Kansas, along with European alder (Callagher and Naughton, 1980). Black locust has further been reported by Ceyer and Rogers (1972) among the best surviving woody species on mined lands in Kansas. Locust trees were damaged by rodents while in storage prior to planting, and then sustained subsequent damage from rabbits which foraged on the test plots. This was the only woody species singled out in this way, and while this observation refutes reports of black locust's low palatability to wildlife species (Martin et al., 1951), it no doubt contributed to the low survival rate of locust. Perhaps additional trials of locust planting, fencing individual seedlings, would yield more successful results.

European alder trees were planted as much smaller seedlings than all other tree species, averaging 15 cm in height, and were in poor condition when received for planting. As there was not sufficient time to place a reorder for more durable seedlings, these individuals were utilized. Some mortality was anticipated, but the results were more severe than expected. Since alder had been reported to grow well on fly ash (Scanlon and Duggan, 1979), and also on a slurry pond in Tennessee (Duggan and Scanlon, 1974), it might be of interest to test this species again at LaCygne at some future date.

Red maple was identified as a nturally invading species on acidic Pennsylvanic strip-mined lands (Bramble, 1952), but it did not survive well on the LaCygne site. The preference of this tree for slightly acid, moist conditions, limited at high pH (Dirr, 1983), may have been the cause of its failure on more alkaline LaCygne substrates. Although exhibiting somewhat better survival than red maple, amur maple still maintained very low rates of survival. Acer ginnala reportedly is adaptable to a variety of soils and pH ranges, but prefers moist, well-drained soils (Dirr, 1983). LaCygne bottom ash certainly was not moist, nor was scrubber sludge well-drained. Stephens (1973) reported that amur maple was not known to be established in Kansas (outside of cultivated plantings).

Initial planting of amur maple at LaCygne was actually the result of an error. Amur maple was mistakenly shipped in place of another species, autumn olive (Elaeagnus umbellata), which had been ordered for this experiment because it provides good wildlife food and cover and is valuable for erosion control, particularly on stripmine spoils (Allan, 1959). Since the maple seedlings arrived in a semi-dormant state, with no distinguishing foliage, the error was not detected until the trees were being planted. This left no time to reorder the originally intended species, and so amur maple was incorporated into the experimental design.

Average increase in tree height over the season was significantly greater for cottonwood than all other species, averaging seven times greater than black locust, the second ranking species. Since dead trees were included in this analysis (zero growth), these results also reflect cottonwood's higher rate of survival. No significant differences were detected between locust and the four remaining species. This was believed due jointly to a low mean growth increase in red cedar trees, although survival was high, and to low survival of all others, although in some cases growth of individual survivors may have been substantial (as with black locust).

Seedlings of many plant species reportedly can be quite vulnerable to abrasive damage from wind, especially when ground cover is low (Nobel, 1981). Wind-blown particles such as sand and dust may cause sufficient cuticle damage to decrease the survival rate. Continuous strong winds can also increase the transpiration rate, and "leaf water deficits" can develop as a result of surface wear from abrasion, often simply from leaves and stems rubbing together in high winds. The flat exposed surfaces of both test substrates at LaCygne would have been quite conducive to this type of wind-related damage, with bottom ash particles no doubt providing a very abrasive agent.

Significant differences in tree survival were detected between treatments for the latter half of the season only, August and September, with the result that woodchips plus fertilizer produced the greatest survival. This is an interesting deviation from the pattern observed for all herbaceous growth data, when manure was consistently the superior treatment. My observations agreed with those of Sarles and Emanuel (1977) in which woodchips provided the most uniform and long-lasting surface cover of any amendment, less subject to either blowing or movement by precipitation. On black bottom ash particularly this no doubt reduced the negative effects of radiant heating. Other advantages to use of hardwood bark have been discussed (Gartner et al., 1973). No significant differences separated any of the other treatments, indicating their similarities for providing survival benefits for the six tree species tested during Phase I.

No explanation is immediately apparent why manure was determined the most beneficial treatment in terms of tree growth, while woodchips had maintained the highest survival. It may be that while woodchips offered greater physical relief and moisture availability (Sarles and Emanuel, 1977; Gartner et al., 1973), thereby improving chances for survival, manure probably added vital nutritional components which stimulated greater growth of trees which did survive (Smith et al., 1980; Lund and Doss, 1980).

Substrate Characteristics

Chemical analysis of scrubber sludge and bottom ash across the season offered little explanation for the marked differences in vegetative growth characteristics observed on these substrates. While scrubber sludge contained statistically higher levels of organic matter, these levels were still less than half those reported to occur in normal mineral soils (Buckman and Brady, 1969). Both N and P were found at statistically equal levels in both substrates, but N was 500 times less than normal soil levels (Buckman and Brady, 1969), while P was 60 times less than normal levels of soil (Tisdale and Nelson, 1966). Pulverized fuel ash in Britain was determined virtually devoid of N, largely due to the coal combustion process (Brown, 1982).

The average pH of scrubber sludge (8.1) was higher than that of bottom ash (7.1), an increase which may be considered at least partially undesirable for optimum plant growth. Varying pH levels can markedly affect plant root absorption of both cations and anions, with maximum rates of uptake generally occurring between pH 5 and 7 (Moore, 1974). However, decreasing pH below 5 is reportedly much more detrimental to nutrient uptake than is increasing above 7, with pH of 9 to 10 acceptable in some circumstances.

Scrubber sludge was further characterized by a significant increase in concentrations of K, with levels four times those of bottom ash. Yet it is questionable whether this element was solely responsible for the substrate growth differences observed, even though normal K levels reported for soils are only 1½ times greater than these scrubber sludge concentrations (Tisdale and Nelson, 1966). And although fly ash has been determined to contain relatively high amounts of K (Adriano et al., 1980), Nebgen et al. (1978) suggest that both P and K may possibly be found in scrubber sludge in forms not readily available for uptake by plants, minimizing their nutritional benefits.

Scrubber sludge contained much higher levels of SO_4-S, B, and soluble salts than bottom ash, with particular concern addressed these latter two elements. Normal soil B levels are reported to range 2-100 ppm, with an average of 10 ppm (Allaway, 1968). Levels of B analyzed from 15 fly ashes averaged 234-618 ppm, with high B concentrations generally associated with high pH (Mulford and Martens, 1971). So while B has been suggested as the dominant toxic element in fly ash (Holliday et al., 1958), the LaCygne scrubber sludge mean B value of 35.0 ppm appears not excessive.

Plank and Martens (1974) have discouraged the application of large quantities of fly ash as a soil amendment, because of potential soluble salt damage. Elevated salt content of various fly ashes has been reported by Graham (1981) and Kussow et al. (1980), with the latter publication also reporting rapid leaching of Na, B, and SO_4-S from ash-amended soils. These elements appeared not to significantly affect overall plant growth at LaCygne, with scrubber sludge exhibiting far superior plant growth to bottom ash. This suggests that other factors, such as the physical characteristics discussed previously, were more important than elemental composition in affecting substrate effectiveness.

Naturally Occurring Vegetation

Scrubber sludge supported natural plant growth much more readily than did bottom ash. There were three times as many species located on scrubber sludge than on Unit No. 1 bottom ash. Those plants collected on both Unit No. 1 and Unit No. 2 bottom ash were located near the edges of piles in mixtures of various substrates.

Analysis of substrate samples taken across the study site offered no explanation for the profusion of vegetation located along the eastern edge of the sludge disposal pond, to the south and west of the bottom ash bank, while the remaining surface area was virtually devoid of vegetation. No location or distance-related changes in substrate composition could be detected. This suggests that other factors, either biochemical or physical, were playing a greater role.

One possible explanation is that the vegetated area was the site of deposition of wind-borne seeds and organic particles. Both Nelson (1981) and Grace (1977) have reported that airborne particles moving toward a large obstruction will be carried forward some distance by their own momentum, even though air is deflected around the object. Actual deposition or impaction efficiency may be proportional to windspeed, depending on size and density of particles, with greatest deposition occurring along the windward side of the object, much less on the leeward side. With prevailing southerly winds during the summer at LaCygne (Kenny et al., 1982), this deposition could occur in approximately the area observed to be vegetated first along the bottom ash bank enclosing the slurry pond. Then as vegetation became established along this area, it would have created a new edge for wind obstruction, allowing for the gradual advance of the width of this vegetation across the surface of the disposal pond.

PHASE I

1 April 1982 - 31 March 1983

SUMMARY AND CONCLUSIONS

As part of a study investigating coal ash waste reclamation without the use of topsoil, a series of six test plots was established on disposal areas at KCP&L's LaCygne Generating Station, 50 km south of Kansas City. Three plots were each established on bottom ash and scrubber sludge, designed to test not only differences between these two substrates but also the effectiveness of six planting treatments for stimulating growth of 15 test species. Plots were monitored regularly, recording mean height, density, and ground cover of herbaceous species, and survival and growth of woody species. Each substrate was analyzed monthly for pH, organic matter, and macronutrients. Surveys were made late in the season to characterize the vegetation naturally invading the study sites. At the end of the year, temperature and precipitation records were obtained for the LaCygne area, both for 1982 and for an average of 30 years of records.

Data collected during this investigation support the following conclusions:

1. Scrubber sludge at LaCygne appeared capable of supporting adequate vegetative growth, whereas bottom ash did not. This tended to hold true both for test species planted in experimental plots and for vegetation naturally occurring on the disposal areas.

2. Organic amendments (manure, hay, and woodchips) stimulated plant growth better than either inorganic ash mix, fertilizer alone, or the control section. Most species planted on manure produced consistently superior growth characteristics, while those on woodchips grew comparatively well on bottom ash, including increased tree survival on both substrates.

3. Five cool-season species, tall fescue, tall wheatgrass, Japanese millet, yellow sweetclover, and annual ryegrass, were the most successful of nine non-woody species tested during all Phase I field trials.

4. Cottonwood and eastern red cedar exhibited the highest survival rates of all six tree species, cottonwood producing significantly increased growth throughout the season. Even though black locust exhibited a low survival rate, individual trees which did survive grew well and appeared in good condition by season's end.

5. Although the 1982 growing season was normal in terms of average temperature, it was limited by a lack of adequate moisture, particularly during the hottest period, July.

PHASE II

1 April 1983 - 31 March 1984

METHODS AND MATERIALS

Study area

The primary emphasis of Phase II experimental efforts was on the evaluation of the effectiveness of scrubber sludge, through continued monitoring of previously-established test plots and the creation of new plots to be located on the same disposal area. To alleviate some problems facing Unit No. 1 bottom ash reclamation, Unit No. 2 ash was evaluated as an amendment to Unit No. 1 ash and as a separate growth medium. To accomplish this, a level Unit No. 2 bottom ash work site was prepared immediately adjacent to the Unit No. 1 bottom ash test plots. This provided an area of an approximate 50:50 mixture of the substrates between the two distinct ash types. To serve as a control for all experimental procedures the natural soil of the region was also evaluated in planting tests. An area of prairie sod located approximately 100 m south of the test plots was plowed and disked, and then subjected to the same treatments as were test substrates. In this way all experimentation was conducted in one localized area subject to the same weather.

Plant Species

Four new grass species were selected for evaluation during Phase II field experimentation. These four (seeding rates provided by the Riley County Extension Council) were perennial ryegrass (28.1 kg/ha; 25 lb/acre), western wheatgrass (13.5 kg/ha; 12 lb/acre), little bluestem ((.0 kg/ha; 8 lb/acre), and switchgrass (6.7 kg/ha; 6 lb/acre). Purchased from the same commercial source as many of the Phase I species (Table 18), they were added to expand the variety of herbaceous species tested. The addition of

Table 18. Names and sources of grass species added for evaluation in Phase II of the Lacygne vegetation study, including purity and germination data.

Plant Species	Source	% purity	% germination
Perennial ryegrass (*Lolium perenne* L.)	Sharp Brothers Seed Co.	95.7	90.5
Western wheatgrass (*Agropyron smithii* Rydb.)	Sharp Brothers Seed Co.	93.1	85.0
Little bluestem (*Andropogon scoparius* L.)	Sharp Brothers Seed Co.	40.1	79.0
Switchgrass (*Panicum virgatum* L.)	Sharp Brothers Seed Co.	98.1	79.0

four grasses to the nine herbaceous species planted during Phase I produced a total of 13 species for evaluation during Phase II. Annual ryegrass was planted in the same manner as the other herbaceous species, instead of beneath tree seedlings. No trees were planted during Phase II.

Experimental Design

Four test plots established in Phase II contained different plant species from those in Phase I and utilized eight treatments rather than six, but were basically identical in design to Phase I plots. The four plots were replicates of one another, consisting of 13 1-m-wide single-species rows passing through 8 3-m-wide treatment bands within 13 x 24 m plots. Rather than multiple plots on each substrate, each plot was located on a diffrent substrate, one each on a mixture of Unit No. 1 and Unit No. 2 bottom ash (plot 7), Unit No. 2 bottom ash alone (plot 8), scrubber sludge (plot 9), and soil (plot 11). While each plot contained the same species and treatments, the locations of these contents were randomized from plot to plot.

One additional larger plot (20 x 25 m) was established on scrubber sludge (plot 10), consisting of eight 2.5-m-wide rows of vegetation passing through five 5-m-wide treatment bands (Fig. 26). The purpose of this plot was to evaluate the most successful species, based on Phase I results, on a larger scale than was possible with small individual planted squares as used in the four replicate plots. Four of the eight rows consisted of tall fescue, tall wheatgrass, yellow sweetclover, and Japanese millet. The remaining four rows contained combinations of these species, planted with different types of equipment.

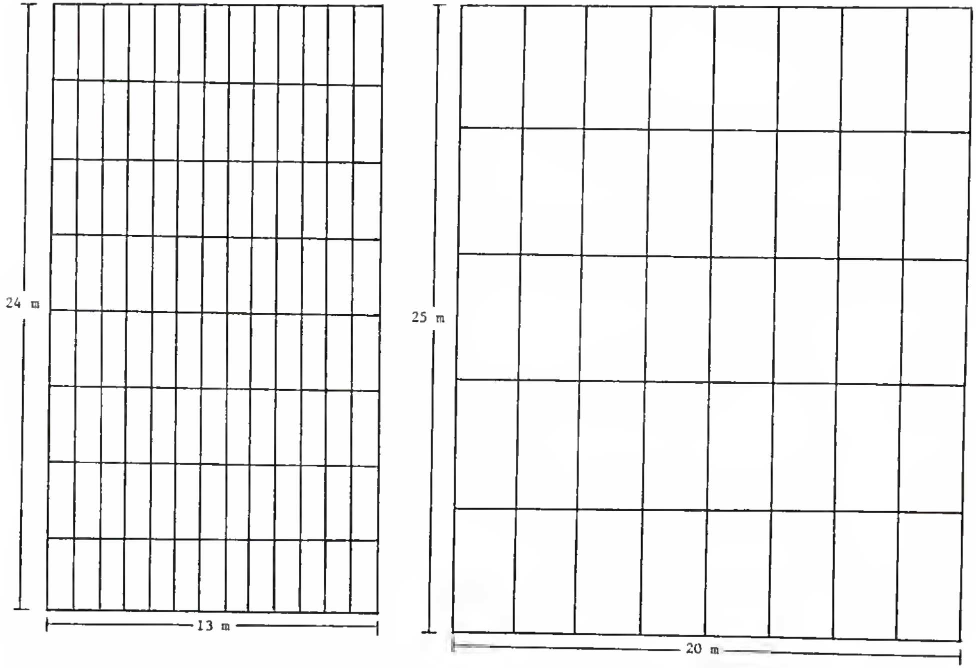


Figure 26. Design of test plots used in Phase II of the LaCygne vegetation study, summer 1983.

Planting Treatments and Equipment

Two new treatments were introduced into Phase II to accompany the six evaluated during Phase I. The first of these was simply a doubling of the fertilizer application, from 82 to 164 kg/ha (146 lb/acre) N. The second was an introduced amendment, 'Milorganite' processed sewage material, with an N-P_2O_5-K_2O-Fe ratio of 6-2-0-4.5, applied in conjunction with the normal fertilizer application. All treated sections of all plots were fertilized before receiving substrate treatments, with the various treatments roto-tilled into the surface as per 1982. Fertilizer spreading and tilling equipment was also the same used in Phase I.

Cattle manure was again obtained from Charles Clark, Fort Scott. Due to the continuous rainy weather it was extremely wet and in consistency resembled a thick paste. Manure was spread across the appropriate bands of the four replicate plots to a depth of 5 cm, 3 cm on the larger scrubber sludge plot, then tilled into the surface 10-12 cm. Only one of two manure treatments on the larger plot was fertilized, at a rate of 82 kg/ha (73 lb/acre) N.

Woodchips were provided by KCP&L, delivered from Kansas City in a chipper truck. These were applied to a depth of 5 cm on the four smaller plots, and tilled into the surface 10-12 cm.

Prairie hay was used to amend the scrubber sludge plot and both bottom ash plots, following the procedure adopted in 1982. The quantity of this hay available was limited, so the soil plot was treated with fescue hay. This had been cut into much smaller pieces, and tilled into the surface much more readily, providing a somewhat more uniform application. Half of a bale of hay was used, approximately 12 kg/plot.

Scrubber sludge was applied to a depth of 5 cm to both bottom ash plots, while only Unit No. 1 bottom ash was applied to the scrubber sludge plot before incorporation. The soil plot was treated with a combination of Unit No. 1 bottom ash and scrubber sludge, each applied to a depth of 2-3 cm, then simultaneously tilled into the surface 10-12 cm.

Milorganite was purchased in granular form and applied at the dealer's recommended rate of 1335 kg/ha (27 lb/1000 ft^2; 1187 lb/acre) using the fertilizer drop spreader. This spread a very thin layer on the surface, and when tilled into the ash it did not significantly alter the texture of the substrates.

The single and double fertilizer treatments were each applied to all plots using the same spreader, and then were tilled to a depth of 10-12 cm. These treatments, as well as the control, were also tilled a second time as per all other treatments. The wet conditions at the study site hindered all work, with fertilizing and mulching of scrubber sludge and bottom ash plots extending over a 6-week period from early April to mid May, while completion of the soil plot was delayed until June (Table 19).

Planting Techniques

Seeds of all herbaceous species were preweighed into plastic bags according to their seeding rates, sweetclover and lespedeza seeds having first been inoculated with Rhizobium bacteria. The planting procedure was identical to that employed in 1982 to plant herbaceous species in Phase I plots. The scrubber sludge plot was planted on 17 May, with the two bottom ash plots completed the following day. The delayed soil plot was planted on 10 June.

The larger scrubber sludge plot was planted mechanically rather than by hand, with rows containing solid strips of vegetation rather than

Table 19. Schedule of fertilizing and amending of all plots during Phase II.

	Plot 7 No. 1/No. 2 Bottom Ash		Plot 8 No. 2 Bottom Ash	
Treatment	Fert	Amend	Fert	Amend
Manure/Fert	16 Apr	18 May	16 Apr	18 May
Woodchips/Fert	16 Apr	16 Apr	16 Apr	16 Apr
Hay/Fert	16 Apr	16 Apr	16 Apr	16 Apr
Ash/Mix/Fert	16 Apr	16 Apr	16 Apr	16 Apr
Milorganite/Fert	16 Apr	23 Apr	16 Apr	23 Apr
Single Fert	16 Apr	a	16 Apr	a
Double Fert	16 Apr	a	16 Apr	a

	Plot 9 Scrubber Sludge		Plot 11 Soil	
Treatment	Fert	Amend	Fert	Amend
Manure/Fert	9 Apr	17 May	10 Jun	10 Jun
Woodchips/Fert	16 Apr	16 Apr	10 Jun	10 Jun
Hay/Fert	16 Apr	16 Apr	10 Jun	10 Jun
Ash Mix/Fert	9 Apr	9 Apr	10 Jun	10 Jun
Milorganite/Fert	9 Apr	23 Apr	10 Jun	10 Jun
Single Fert	9 Apr	a	10 Jun	a
Double Fert	9 Apr	a	10 Jun	a

	Plot 10 Scrubber Sludge	
Treatment	Fert	Amend
Manure/Fert	9 Apr	18 May
Manure	b	18 May
Single Fert	9 Apr	a
Double Fert	16 Apr	a

[a] no amendment applied

[b] no fertilizer applied

individual squares. The four single-species rows were all planted using the original fertilizer spreader, a Scott's 'PF-1' drop spreader. One row was planted to a mixture of Japanese millet and yellow sweetclover and one row to a mixture of tall fescue and tall wheatgrass, also using the drop spreader. The final two rows contained these same two mixes, planted with an Ortho cyclone spreader. This plot was planted on 18 May. When two species were mixed together in the same row, each was sown at one half its recommended seeding rate.

Test Plot Measurements

Measurements of species in plots 7, 8, 9, and 11 were taken biweekly, recording seedling density, mean height, and a ground cover ranking. Density and height were measured utilizing random placement of a 10-cm square, as was done in 1982. An altered cover ranking was employed during 1983 measurements to better quantify ground cover. Each individual 0.25 m^2 of vegetation was independently assigned a value corresponding to precent ground cover. Numerical rankings were assigned as 0 (0% cover), 1 (1-25%), 2 (26-50%), 3 (51-75%), and 4 (76-100%).

Scrubber sludge plot 10 was also monitored biweekly, assigning each species/treatment block a ground cover value using the system described above. Two researchers working independently each ranked the plot, and the mean of the two sets of values became the scores for the plot on each particular date.

Test plots planted in Phase I were also monitored every two weeks during 1983. Individual 0.25 m^2 plantings in each plot were ranked using the cover ranking system described above. Individual tree survival was recorded biweekly.

Statistical Analysis of Vegetative Data

All growth measurement data were subjected to an analysis of variance (ANOVA) test to determine significant main effects and interactions. A probability of $p < 0.05$ was considered significant for all ANOVA tests. Separate analyses were performed for each sampling date to test main effects on height, density, and ground cover ranking of herbaceous vegetation, and on survival of tree species. A Least Significant Difference (LSD) test was used to determine differences between means of all variables analyzed. A probability of $p < 0.05$ was considered significant for LSD tests. This procedure provided verification at each particular date regarding which treatments were more beneficial and which species were best suited to conditions at the test site, as well as indicating the superior substrate.

Substrate Sampling

Substrate core samples 10 cm in depth were collected monthly from the control section of each plot throughout the growing season. A 2-cm diameter metal soil corer was used to collect samples, as was done in 1982, and samples were bagged and labelled. In June and September, samples were taken from each treatment across each plot, to quantify treatment effects on the substrate. The KSU Agronomy Department's Soil Test Laboratory analyzed all samples for substrate pH, N, P, K, and organic matter.

In June and September four additional samples were collected outside the test plots, from unmodified sections of scrubber sludge, soil, and the two bottom ash substrates. These were analyzed for B, SO_4-S, Mo, S, Se, and soluble salts.

Also in September 1983, 16 point locations from throughout the scrubber sludge disposal area at which samples had been collected in 1982 were relocated and were again sampled for analysis of pH, N, P, K, and organic matter content.

One final set of substrate samples was collected from the scrubber sludge disposal area on 8 October. Four samples were taken 30 m apart along a transect approximately 150 m north of the southeast corner of the scrubber sludge test site, extending west from the eastern edge of the disposal pond (Fig. 27). This was approximately the same location from which samples 1-6 originated in Phase I the previous year, with this new transect extending 120 m west of the bottom ash bank rather than 90 m. Four locations were sampled to a depth of 10 cm, each separated into four distinct 2.5-cm increments, bagged and labelled. These 16 samples were than analyzed for B, SO_4-S, Mo, S, Se, and soluble salts.

Substrate Analysis

The procedure used by the KSU Soil Test Laboratory for analysis of all samples for determination of N (Technicon Industrial Systems, 1977a, 1977b) and for pH, P, K, and organic matter (North Dakota Aricultural Experiment Station, 1980) were the same utilized to process all 1982 samples. Similarly, 1983 analysis for B, SO_4-S, and soluble salts conducted by the Wisconsin Soil & Plant Analysis Laboratory followed the same procedure as used in 1982 (Liegel et al., 1980).

Determination by the Wisconsin lab of levels of Mo, S, and Se in 1983 samples also followed a procedure outlined by Liegel et al. (1980). The analysis used was actually described as an analysis of plant tissue, for determination of a total of 13 different elements, using a plasma emission spectrophotometer.

The sample is placed into a digestion tube, preheating the aluminum digestion block to 100° C. The tube receives 5 ml of concentrated HNO_3

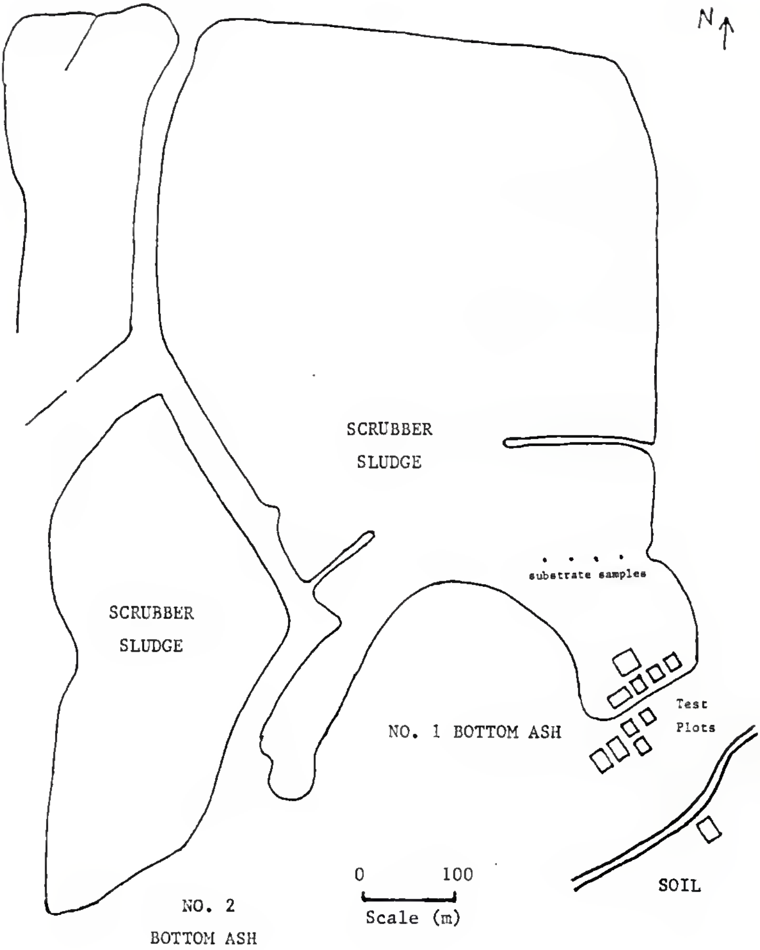


Figure 27. Disposal areas at the LaCygne station, indicating the location of four scrubber sludge sample points north of the test plot site.

and is placed in the block within a perchloric hood for fume removal. After 30-45 minutes the tube is removed and shaken, then returned to the block, adding 3 ml of concentrated $HClO_4$. Heat is increased to 215° C and the solution is boiled approximately 90 minutes, leaving 3-4 ml of solution in the tube. This is refluxed until a white smoke appears over the tube, then is cooled sufficiently to handle while still warm. Solution is diluted to 50 ml for plasma emission spectrophotometry. Using working standards prepared from stock solutions, concentration of each element in ppm is calculated.

Survey of Invading Vegetation

Specimens of plants naturally invading the study site were collected in July and again in September 1983, to obtain representatives of all species present. Plants were located and collected visually, extracting as much of the intact root system as possible, labelled and pressed for identification. Collections were made on the scrubber sludge disposal area, the Unit No. 1 bottom ash bank to the south of this area, the soil adjacent to the control plot, and the manure treatment on scrubber sludge plot 9.

In September the scrubber sludge vegetation was mapped, collecting plant specimens from the same 16 point locations at which substrate samples were collected. Plants were collected within a 15-cm radius of each sample point, taking only one of each species present. This was accomplished in order to help quantify the dominant species and their abundance relative to one another.

All plants collected were identified at the KSU Herbarium, and are in storage there for future reference.

Climatological Data

The National Oceanic and Atmospheric Administration records for temperature and precipitation for calendar year 1983 were obtained from the KSU Department of Physics. As per 1982, temperature data from Paola and Mound City and precipitation data from these locations and LaCygne were recorded. These data were used to characterize the 1983 growing season in particular, and to make comparisons between Phase I and Phase II weather conditions.

Monitoring Substrate Temperature and Moisture

In order to help determine treatment effects on plant root environment as well as provide explanations for growth differences between treatments and species, subsurface temperature and moisture were monitored during Phase II. Thermister probes were placed at depths of 2 cm and 15 cm within the control, the double fertilizer, and the manure plus fertilizer treatments on both scrubber sludge plots, the Unit No. 2 bottom ash plot, and the soil plot.

On large scrubber sludge plot 10, probes were placed under tall fescue, fescue plus tall wheatgrass, wheatgrass alone, Japanese millet, millet plus sweetclover, and sweetclover alone. On the other three plots, probes were placed under annual ryegrass, fescue, millet, lespedeza, perennial ryegrass, switchgrass, tall wheatgrass, and sweetclover. All probes were attached to an Omega Engineering Corp. therimister switch bracketed to a wooden base, which was placed at the periphery of the treatment strip in each plot. The switches were covered with 2-gallon plastic pails when not in use to protect them from the elements. The wire leads of the probes, which ran from the plant species to the switch, were buried approximately 5 cm below the substrate surface to prevent rodent damage.

For monitoring moisture, two Beckman Instruments gypsum blocks were buried, one at 2 cm and one at 15 cm under the same species and treatments as were thermister probes, except for the double fertilizer treatment on Unit No. 2 bottom ash, and Korean lespedeza, annual ryegrass, tall wheatgrass, and the double fertilizer treatment of the soil plot. The two blocks were attached to a wooden stake that was secured into the substrate with excess cord buried. No rodent damage of the exposed cord occurred during the summer.

Temperature and moisture readings were taken every two weeks beginning 24 June and ending 13 September. Substrate temperatures were recorded for a 24-hour period at 1200, 1500, 1800, 2100, 0600, 0900, and 1200. Moisture readings were taken at 1200, 1500, 0600, and 1200. These values were then averaged to obtain mean 24-hour readings for each date.

Data recorded from moisture block measurements exhibited a great deal of variability, possibly due to the high electrolyte content of the ash substrates, and were unsatisfactory for use in monitoring substrate moisture. Therefore, core samples were taken biweekly, at depths of 2 cm and 15 cm beneath tall fescue and yellow sweetclover on the control and manure plus fertilizer treatments of the same plots, with moisture determined as percent by weight before drying. Samples were placed in plastic-lined bags immediately upon collection, then were dried at 65° C for 48 hours, weighed before and after drying.

PHASE II

1 April 1983 - 31 March 1984

RESULTS

Herbaceous Species Height Data

Four of the 13 species planted in the smaller test plots germinated very poorly and failed to produce significant growth during the summer of 1983. These were common reedgrass, nodding smartweed, little bluestem, and Korean lespedeza. Since each test plot represented a different substrate with no replications, the ANOVA could not be used as a test of substrate effects. Significant differences in height were detected between species at only half the dates measured, with no differences detected between treatments (Table 20). The poor growth of species planted on the two plots containing bottom ash substrates was similar to that of vegetation on Unit No. 1 bottom ash in Phase I, therefore no data from these plots were included in any analyses beyond the first date measured, 10 June. Data from the soil plot were first collected on 25 June, incorporating with scrubber sludge data for that and all subsequent measurements.

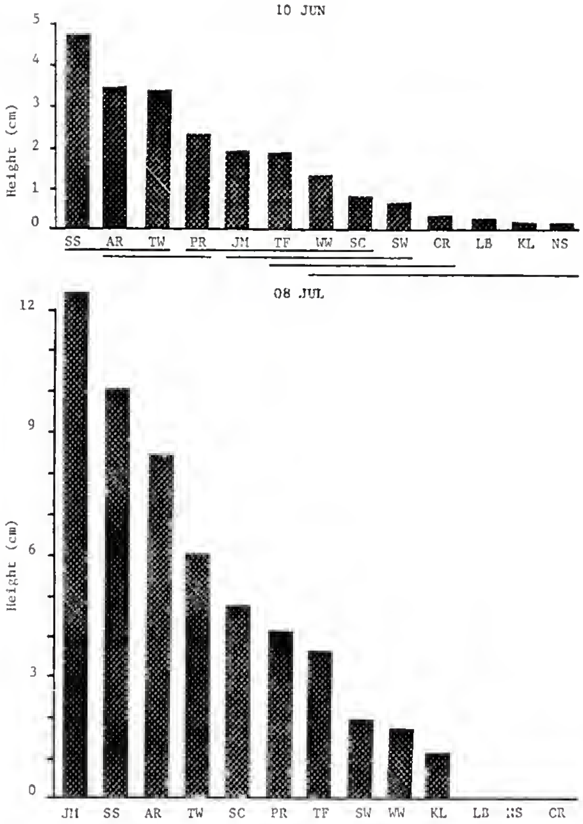
A comparison of mean species height on 10 June across all treatments on scrubber sludge and both bottom ash substrates indicates those species which initially produced taller growth (Fig. 28). Showy sunflower was observed as the tallest species, yet the LSD determined annual ryegrass and tall wheatgrass to be statistically equal with sunflower. Perennial ryegrass was determined statistically equal to annual ryegrass and tall wheatgrass, as well as to millet, fescue, western wheatgrass, and yellow sweetclover. Each species was determined within a group inseparable from another species group, with clear distinctions difficult to render. This relationship continued through 8 July for plant height recorded on soil and

Table 20. P-values from analysis of variance tests to detect significant differences in vegetative height between treatments and species, as well as interactions between treatments and species, on each date measured in 1983.

	P-values							
Variable	10 JUN[a]	25 JUN	08 JUL	22 JUL	04 AUG	19 AUG	03 SEP	24 SEP
Treatment	NS[b]	NS	NS	NS	NS	NS	NS	NS
Species	0.001	NS	0.008	0.002	0.001	0.001	NS	NS
Trt/spec	0.001	NS	NS	NS	0.0151	NS	NS	NS

[a] analysis included bottom ash and scrubber sludge only; all other dates included scrubber sludge and soil only.

[b] not significant ($p < 0.05$)



SPECIES: Japanese millet (JM), showy sunflower (SS), annual ryegrass (AR), Tall wheatgrass (TW), sweetclover (SC), perennial ryegrass (PR), tall fescue (TF), switchgrass (SW), western wheatgrass (WW), Korean lespedeza (KL), little bluestem (LB), nodding smartweed (NS), and common redgrass (CR).

Figure 28. Mean vegetative height of species across all treatments on bottom ash and scrubber sludge on 10 June and on sludge and soil on 8 July. Bars underscored by the same line are not significantly different (LSD test at the 0.05 level).

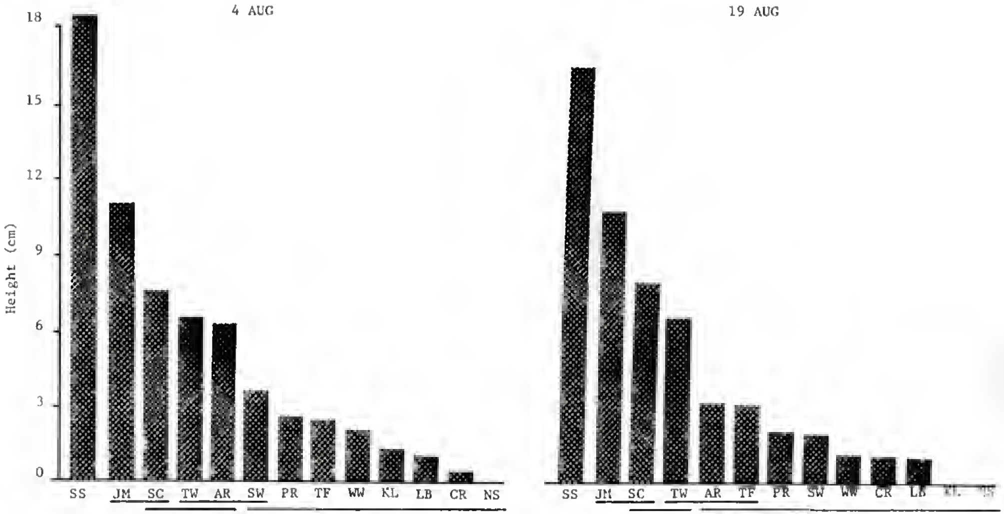
scrubber sludge (Fig. 28). Mean plant height had increased dramatically since early June, and three species were determined the tallest: millet, sunflower, and annual ryegrass. The LSD again was unable to clearly separate each individual species. The two species making the greatest increases in height were millet and sweetclover.

By 4 August sunflower was significantly the tallest species on soil and scrubber sludge, followed by millet and sweetclover (Fig. 29). Tall wheatgrass, annual ryegrass, and switchgrass comprised the next group of species in order of height. This represents a dramatic increase in the mean height of switchgrass in comparison to other species. Sunflower was still the tallest species on 19 August, again followed by millet and sweetclover (Fig. 29). Height of sweetclover was statistically indistinguishable from that of tall wheatgrass, which was itself equal to annual ryegrass and tall fescue. For both these August dates reedgrass, lespedeza, little bluestem, and smartweed were among the lowest growing species.

Significant interactions between treatments and species were detected at only two dates during the summer, and may be a reflection of the poor overall growth during the Phase II field season.

Herbaceous Species Density Data

When the data for vegetative density measurements were subjected to the ANOVA, the lack of significant effects was striking. No treatment differences were detected at any date, species differences at only three dates, and interaction only one time (Table 21). The LSD test of mean species density at 10 June and 8 July, although a month apart and involving different substrate plots, revealed the same species to exhibit the greatest density (Fig. 30). Perennial and annual ryegrass, fescue, millet,



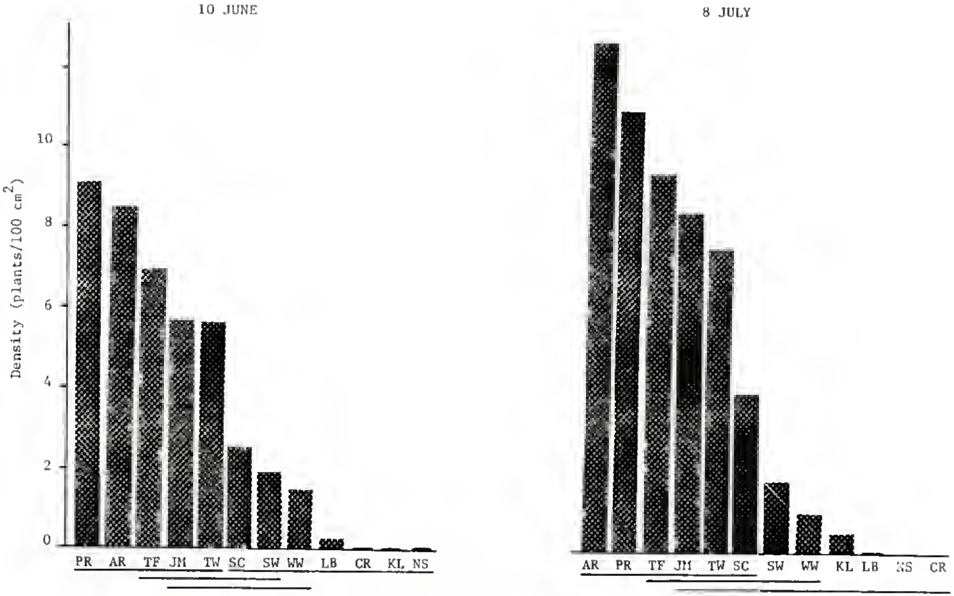
SPECIES: Showy sunflower (SS), Japanese millet (JM), sweetclover (SC), tall wheatgrass (TW), annual ryegrass (AR), switchgrass (SW), perennial ryegrass (PR), fescue (TF), western wheatgrass (WW), Korean lespedeza (KL), little bluestem (LB), common redgrass (CR), nodding smartweed (NS).

Figure 29. Mean vegetative height of species across all treatments on scrubber sludge and soil, measured on 4 August and 19 August, 1983. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 21. P-values from analysis of variance tests to detect significant differences in vegetative density between treatments and species, as well as interactions between treatments and species, on each date measured in 1983.

	P-values							
Variable	10 JUN	25 JUN	08 JUL	22 JUL	04 AUG	19 AUG	03 SEP	24 SEP
Treatment	NS[a]	NS	NS	NS	NS	NS	NS	NS
Species	0.0026	0.0108	0.0491	NS	NS	NS	NS	NS
Trt/spec	NS	NS	NS	0.0481	NS	NS	NS	NS

[a] not significant ($p > 0.05$)



SPECIES: Perennial ryegrass (PR), annual ryegrass (AR), tall fescue (TF), Japanese millet (JM), tall wheatgrass (TW), sweetclover (SW), switchgrass (SW), western wheatgrass (WW), little bluestem (LB), common reedgrass(CR), Korean lespedeza (KL), nodding smartweed (NS).

Figure 30. Mean density of species across all treatments on bottom ash and scrubber sludge on 10 June and on sludge and soil on 8 July, 1983. Bars underscored by the same line are not significantly different ($p > 0.05$).

and tall wheatgrass were all significantly inseparable in June, with sweetclover added to this group in July. Lespedeza, bluestem, smartweed, and reedgrass were the poorest species as measured by density. The solitary interaction on 22 July is believed not to have significantly affected the results of these analyses.

Herbaceous Species Cover Ranking Data

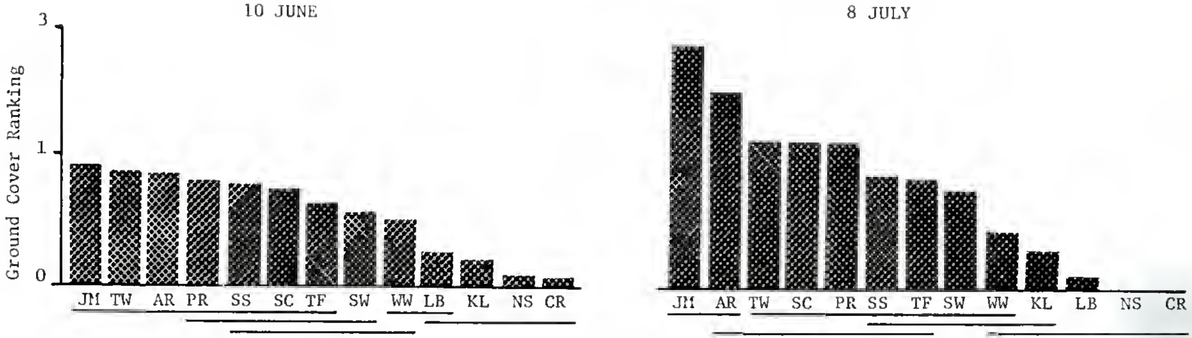
The paucity of significant effects continued when the ANOVA was used to test ground cover ranking data. Significant treatment differences were detected at two data collection dates, species effects at three dates, but there were no interactions between any variables (Table 22). A comparison of mean species ground cover ranking between 10 June on both bottom ash substrates and scrubber sludge and 8 July on soil and sludge showed an increase in cover ranking for the later date (Fig. 31). Whereas rankings of seven species were inseparable by significant differences determined by the LSD test on 10 June, millet and annual ryegrass exhibit somewhat more of a distinction by 8 July. The relative order in which species were ranked varies little from June to July, however, and the difference is primarily one of magnitude.

Mean cover rankings on each treatment on 22 July were nearly duplicated when measurements for 19 August were analyzed (Fig. 32 and 33). Cover rankings on manure, Milorganite, and the single fertilizer application were all statistically equal and were significantly higher than other treatments both dates. Woodchips averaged the fourth best rank both dates, followed by hay and then double fertilizer on 22 July, these two just the reverse on 19 August. Ash mix and the control were the lowest ranking treatments each date. Although the LSD did not determine manure ranking to be significantly diffrent from those of two other treatments, the observed

Table 22. P-values from analysis of variance tests to detect significant differences in vegetative ground cover ranking between treatments and species, as well as interactions between treatments and species, on each date measured in 1983.

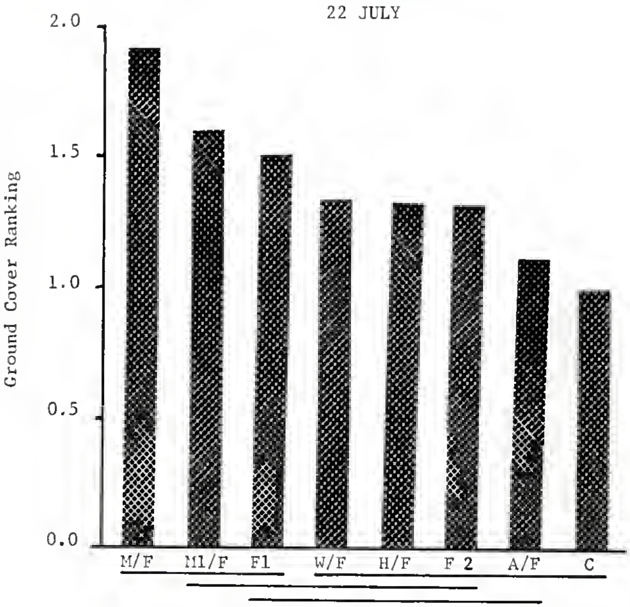
	P-values							
Variable	10 JUN	25 JUN	08 JUL	22 JUL	04 AUG	19 AUG	03 SEP	24 SEP
Treatment	NS[a]	NS	NS	0.0289	NS	0.0445	NS	NS
Species	0.0001	0.0090	0.0017	NS	NS	NS	NS	NS
Trt/spec	NS	NS	NS	NS	NS	NS	NS	NS

[a] not significant ($p > 0.05$)



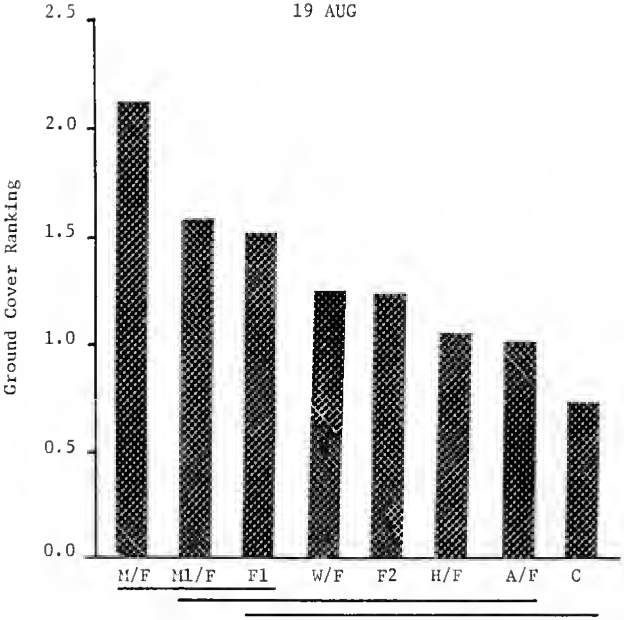
<u>SPECIES</u>: Japanese millet (JM), tall wheatgrass (TW), annual ryegrass (AR), perennial ryegrass (PR), showy sunflower (SS), tall fescue (TF), switchgrass (SW), western wheatgrass (WW), little bluestem (LB), Korean lespedeza (KL), nodding smartweed (NS), common redgrass (CR).

Figure 31. Mean ground cover ranking of species across all treatments on bottom ash and scrubber sludge on 10 June, and on sludge and soil on 8 July, 1983. Bars underscored by the same line are not significantly different ($p > 0.05$).



Treatments: Manure plus fertilizer (M/F), Milorganite plus fertilizer (MI/F) single fertilizer (F1), woodchips plus fertilizer (W/F), Hay plus fertilizer (H/F), double fertilizer (F2), ash mix plus fertilizer (A/F), and control (C).

Figure 32. Mean ground cover ranking on scrubber sludge and soil as affected by the various treatments, recorded on 22 July, 1983. Bars underscored by the same line are not significantly different ($p > 0.05$).



Treatments: Manure plus fertilizer (M/F), Milorganite plus fertilizer (M/F), single fertilizer (F1), woodchips plus fertilizer (W/F), double fertilizer (F2), hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), and control (C).

Figure 33. Mean ground cover ranking on scrubber sludge and soil as affected by the various treatments, recorded on 19 August, 1983. Bars underscored by the same line are not significantly different ($p > 0.05$).

difference between manure mean cover ranking and that of Milorganite represents the greatest difference between any two treatments for both these dates.

Ground Cover Ranking of Large Scrubber Sludge Plot 10

Each of the four species and combinations of these species germinated successfully on large scrubber sludge plot 10. Lack of replication of this plot precluded the use of ANOVA for making statistical analyses. Comparing species or seed mixtures as they performed across all possible treatments, tall wheatgrass and the wheatgrass/fescue mixture planted with an alternate (cyclone) seeder each received the highest average 1983 ranking of 2.0, or 26-50% ground cover (Table 23). Tall fescue ranked nearly as high at 1.9, followed by the wheatgrass fescue mixture planted with the drop spreader, sweetclover, and a millet/sweetclover mixture planted also with the drop spreader, each receiving an average rank of 1.7. The alternate millet/clover mixture ranked 1.5 and Japanese millet alone received 1.4, the lowest mean ranking.

Mean ranking of the five treatments across all vegetation combinations followed an obvious trend (Table 23), with nearly a three-fold difference between the highest and lowest rankings. Manure plus fertilizer received the highest average rank of 2.8, with manure alone slightly lower at 2.6. It is interesting to note that both single and double fertilizer applications produced ground cover of equal rank, 1.2. The control section was slightly lower than these treatments, with a rank of 1.0 (1-25% cover). A point worth noting is that none of the species or treatments produced sufficient ground cover to receive an average biweekly rank above 2.0 (26-50% cover) until 22 July (Appendix, Table 4).

Table 23. Mean seasonal ground cover ranking by species or species combination across all treatments, as well as for each treatment across all species, on scrubber sludge plot 10 during 1983.

Species	Rank ($\bar{X}$)	Treatment	Rank ($\bar{X}$)
Tall wheatgrass	2.0	Manure/fert	2.8
Wheatgrass/fescue[a]	2.0	Manure 2	2.6
Tall fescue	1.9	Double fert	1.2
Wheatgrass/fescue	1.7	Single fert	1.2
Yellow sweetclover	1.7	Control	1.0
Millet/sweetclover	1.7		
Millet/sweetclover[a]	1.5		
Japanese millet	1.4		

[a] planted with a cyclone seeder, all others planted using a drop seeder

Ranking Scale: 0 = no ground cover

1 = 1-25% ground cover

2 = 26-50% ground cover

3 = 51-75% ground cover

4 = 76-100% ground cover

Substrate Temperature

Because of the compositional differences between test plots in which temperature was monitored, these data were analyzed in two different ways. The first ANOVA included both scrubber sludge plots 9 and 10, Unit No. 2 bottom ash plot 8, and soil plot 11, comparing only data from those species identical on each. Those species were tall wheatgrass, Japanese millet, sweetclover, and tall fescue. The second ANOVA compared only scrubber sludge plot 9 with the bottom ash and soil plots, and incorporated all species monitored on these three plots. In addition to the species just mentioned this analysis included perennial and annual ryegrass, switchgrass, and lespedeza. Treatments included in both analyses were manure plus fertilizer, double fertilizer, and control.

When comparing four species across all four plots monitored, the ANOVA detected infrequent differences between either treatments or substrates (Table 24). Treatment differences were significant at 2-cm depth on only 8 July and 2 September, and at 15 cm on only 24 June and 22 July. Only one significant difference was noted between species, at 15 cm on 24 June. The lack of test plot replications precluded the use of ANOVA for making statistical comparisons between substrates.

On both 8 July and 2 September, the control section was recorded as having the highest substrate temperature at 2 cm across all species and plots, while manure plus fertilizer was the lowest (Fig. 34). In July the control and double fertilizer were statistically indistinguishable, significantly higher than manure. These two were again statistically equal in September, while differences between double fertilizer and manure plus fertilizer were also nonsignificant, making the distinction between control and manure less sharp.

Table 24. P-values from analysis of variance tests to detect significant differences in substrate temperature between treatments and species, on both the large and small scrubber sludge plots, Unit No. 2 bottom ash plot, and the soil plot, monitored during Phase II.

	P-values						
Variable	24 JUN	08 JUL	22 JUL	04 AUG	29 AUG	02 SEP	13 SEP
2 cm							
Treatment	NS[a]	0.0271	NS	NS	NS	0.0400	NS
Species	NS	NS	NS	NS	NS	NS	NS
Trt/spec	NS	NS	NS	NS	NS	NS	NS
15 cm							
Treatment	0.0315	NS	0.0381	NS	NS	NS	NS
Species	0.0202	NS	NS	NS	NS	NS	NS
Tr/tspec	0.0115	NS	NS	NS	NS	NS	NS

[a] not significant ($p > 0.05$)

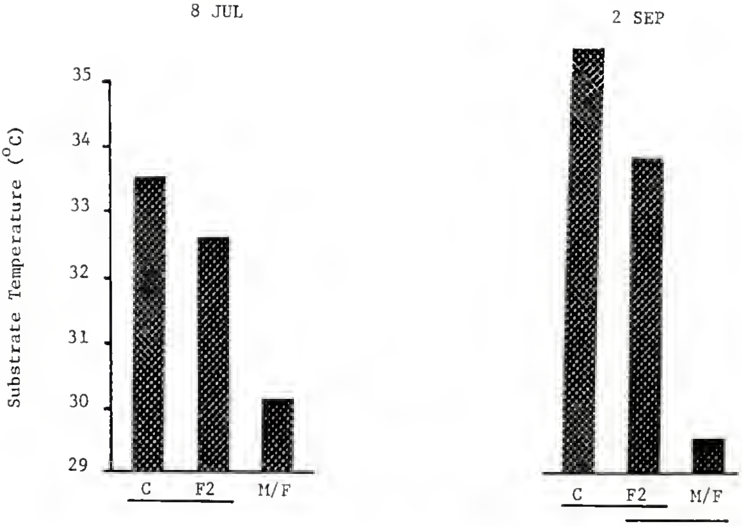


Figure 34. Mean substrate temperature recorded at 2-cm depth across all species on four plots (large and small scrubber sludge, No. 2 bottom ash, and soil) as affected by control, double fertilizer, and manure plus fertilizer treatments. Bars underscored by the same line are not significantly different ($p > 0.05$).

Mean substrate temperature recorded on the three treatments at 15 cm on 24 June exhibits the same pattern, with control and double fertilizer statistically equal and significantly higher than manure plus fertilizer (Fig. 35). When mean temperatures recorded for the four species on this same date were compared, tall wheatgrass exhibited the highest temperature and tall fescue the lowest (Fig. 36). Yet the level of significance between these extremes is complicated, with wheatgrass and millet appearing nonsignificant, as were fescue and sweetclover, and millet and sweetclover were also statistically equal.

The ANOVA which included all species which were monitored across three plots was also characterized by a paucity of significant effects (Table 25). No differences were detected at any date at the 2-cm depth, while only species differences were noted at 15 cm, on five of the biweekly measurements. Treatment differences were all nonsignificant.

If mean 15-cm temperatures for all species are compared at monthly intervals for July, August, and September, similarities are apparent (Fig. 37). Tall wheatgrass and perennial ryegrass exhibited the highest temperatures on each of these dates, and lespedeza was lowest on two dates and second lowest on one date. Sweetclover and millet tended to exhibit temperatures which were similar to wheatgrass and perennial rye, with fescue, annual ryegrass, and switchgrass arranged in variable order. Levels of significance indicate that all these species exhibited temperatures that were quite similar, with a slight tendency toward higher temperature beneath those species exhibiting better growth characteristics, as determined previously.

Although neither ANOVA was able to test for substrate differences due to lack of test plot replications, a comparison has been made between 15-cm temperatures on the four plots monitored, comparing the mid-point in the

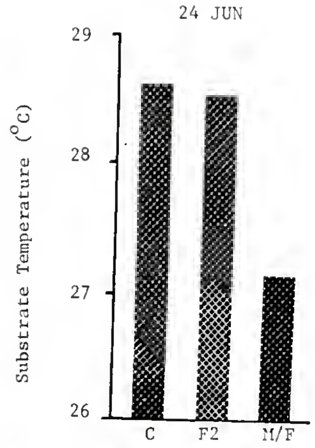


Figure 35. Mean substrate temperature recorded at 15-cm depth across all species on four test plots, as affected by the control, double fertilizer, and manure plus fertilizer treatments. Bars underscored by the same line are not significantly different ($p > 0.05$).

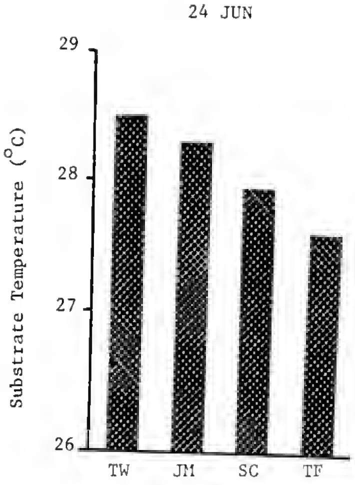
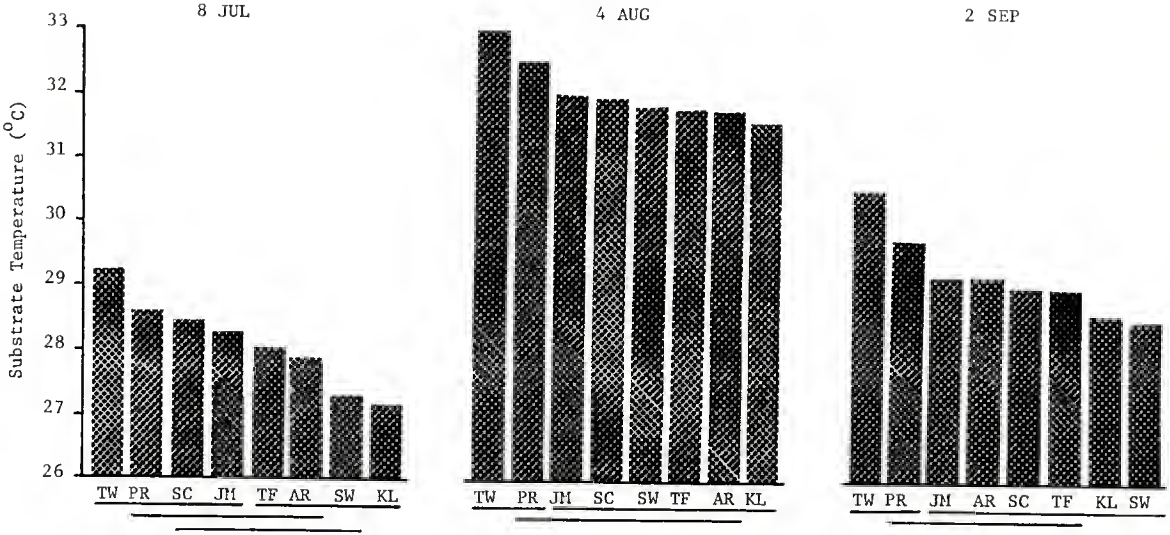


Figure 36. Mean substrate temperature recorded at 15-cm depth across four test plots, as influenced by growth of tall wheatgrass, Japanese millet, sweetclover, and tall fescue. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 25. P-values from analysis of variance tests to detect significant differences in substrate temperature between treatments and species, on scrubber sludge plot 9, Unit No. 2 bottom ash plot 8, and soil plot 11, monitored during Phase II.

	P-values						
Variable	24 JUN	08 JUL	22 JUL	04 AUG	19 AUG	02 SEP	13 SEP
2 cm							
Treatment	NS[a]	NS	NS	NS	NS	NS	NS
Species	NS	NS	NS	NS	NS	NS	NS
Trt/spec	NS	NS	NS	NS	NS	NS	NS
15 cm							
Treatment	NS	NS	NS	NS	NS	NS	NS
Species	0.0004	0.0306	NS	0.0170	0.0116	0.0060	NS
Trt/spec	NS	NS	NS	NS	NS	NS	NS

[a] not significant ($p > 0.05$)



SPECIES: Tall wheatgrass (TW), perennial ryegrass (PR), sweetclover (SC), Japanese millet (JM), tall fescue (TF), annual ryegrass (AR), switchgrass (SW), and Korean lespedeza (KL).

Figure 37. Mean 1983 substrate temperature recorded at 15-cm depth across small scrubber sludge plot 9, Unit No. 2 bottom ash plot 8, and soil plot 11, as influenced by various species' growth. Bars underscored by the same line are not significantly different (> 0.05).

summer with the end (Fig. 38). Although nonstatistical, this comparison indicates that both scrubber sludge plots averaged higher temperatures than either Unit No. 2 bottom ash or soil. The bottom ash was higher than soil on 22 July, with soil higher on 13 September. It is interesting to note that the small scrubber sludge plot 9 was recorded at higher average temperature than plot 10 on both dates. Yet it is questionable whether these or any of the differences noted would prove significant under statistical testing.

Substrate Moisture

The ANOVA to test for differences in substrate moisture between treatments and species, using data from core samples taken beneath fescue and sweetclover on the control and manure plus fertilizer treatments, detected no significant effects of any variable at any date measured. A nonstatistical comparison was made of mean substrate moisture at each depth on each test plot, at 22 July and 13 September, halfway through the season and at the end (Fig. 39). This indicated an obvious difference in moisture content between scrubber sludge and the other two substrates, differences which may well have proven significant had statistical testing been possible. Scrubber sludge averaged more than double the moisture content of either No. 2 bottom ash or soil.

In July both Unit No. 2 bottom ash and the plot containing a mixutre of No. 1 and No. 2 bottom ash developed a very hard 'pan' layer 8-9 cm below the ash surface. The pan was extremely difficult to penetrate with the core sampler, and totally prevented sampling to a depth of 15 cm. By August the soil plot had developed a similar hard layer at approximately the same depth, while scrubber sludge remained easily penetrable to a depth of at least 50 cm. This is why no 15-cm moisture data is available for

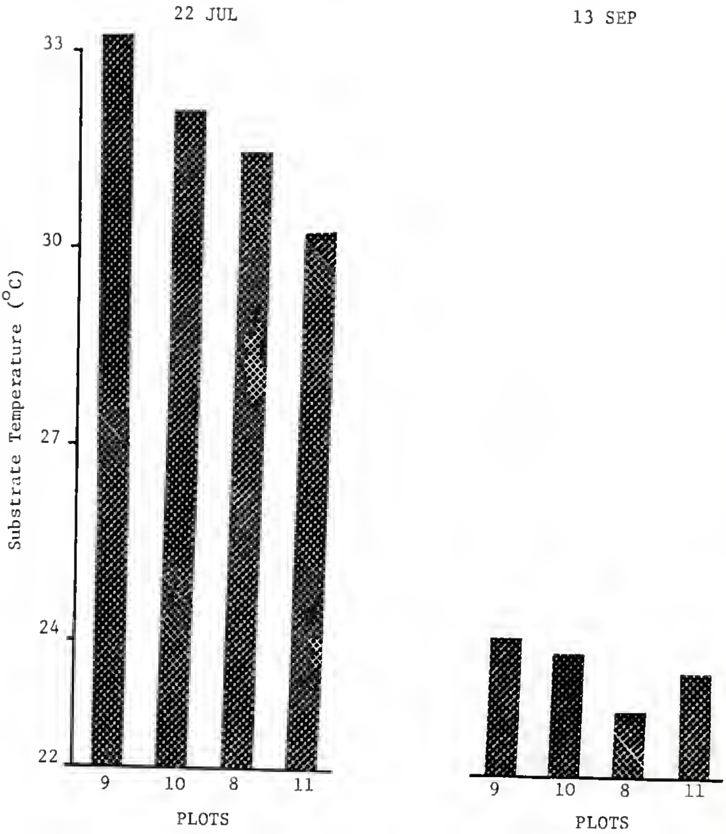
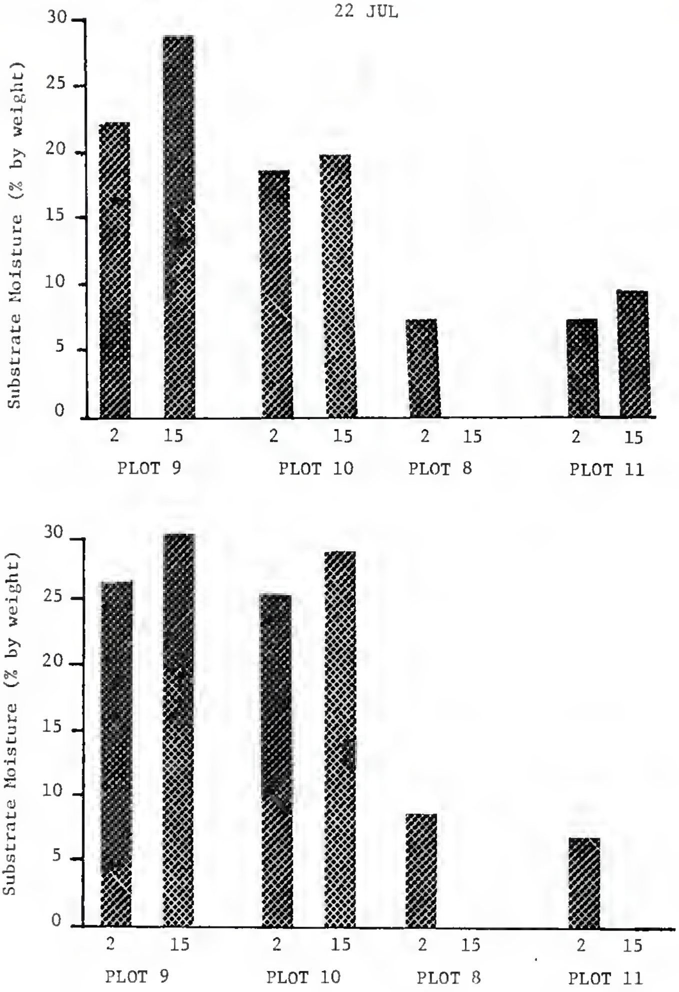


Figure 38. Mean substrate temperature across all treatments and species recorded at 15-cm depth on scrubber sludge plots 9 and 10, bottom ash plot 8, and soil plot 11, on 22 July and 13 September, 1983.



[a] substrate unable to be sampled to this depth.

Figure 39. Mean substrate moisture content across all treatments and species which were monitored on scrubber sludge plots 9 and 10, Unit No. 2 bottom ash plot 8, and soil plot 11, recorded at 2-cm and 15-cm depths.

plot 8 on 22 July, or for plots 8 and 11 on 13 September (Fig. 39). It is unknown whether this pan layer either contributed to or was a result of lower moisture levels in these substrates.

Cover Ranking of 1982 Herbaceous Species

Analysis of the biweekly ground cover ranking of herbaceous species on Phase I test plots monitored during Phase II indicated significant effects throughout the summer (Table 26). Substrate differences were detected at every date measured, except for 4 August when bottom ash data were unavailable. Treatment and species differences were significant at every date.

A comparison of monthly mean cover ranking across both substrates indicates that the differences between scrubber sludge and bottom ash increased in magnitude as the measuring period progressed (Fig. 40). Average vegetative ranking on bottom ash remained the same from June to July, while scrubber sludge increased. By September the scrubber sludge ranking had increased still further, as bottom ash declined.

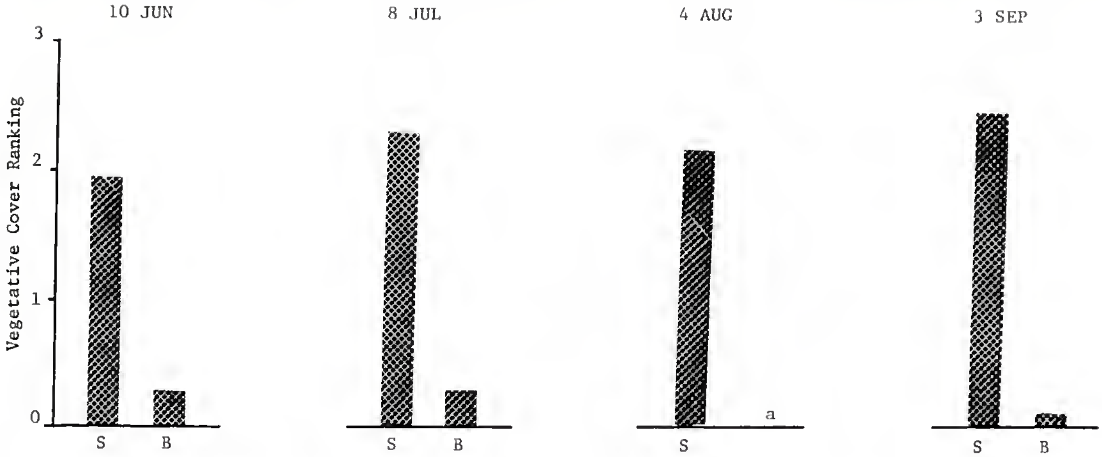
The LSD indicated manure plus fertilizer as the significantly superior treatment each month, producing average ground cover rankings more than double those of any other treatment during both June and July (Fig. 41). August was characterized by an increase in cover ranking of all treatments, with manure averaging between 3.0 (51-75% cover) and 4.0 (76-100% cover). All rankings declined proportionately in September. Hay and woodchips consistently averaged as the two best treatments following manure, with ash mix ranking equally as well as these two on 8 July.

Tall wheatgrass was indicated as the species receiving the highest cover ranking on each of these monthly dates, significantly better than all others (Fig. 42). Tall fescue, sweetclover, and millet were the next best

Table 26. P-values from analysis of variance tests to detect differences in vegetative ground cover ranking between substrates, treatments, and species, as well as interactions between these variables, on Phase I test plots monitored during Phase II.

	P-values							
Variable	10 JUN	25 JUN	08 JUL	22 JUL	04 AUG	19 AUG	03 SEP	24 SEP
Substrate	0.0001	0.0001	0.0001	0.0001	a	0.0001	0.0001	0.0001
Treatment	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Species	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Trt/sub	0.0001	0.0001	0.0001	0.0001	a	0.0001	0.0001	0.0001
Spec/sub	0.0001	0.0001	0.0001	0.0001	a	0.0001	0.0001	0.0001
Trt/spec	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Trt/spec/sub	0.0001	0.0001	0.0001	0.0001	a	0.0001	0.0001	0.0001

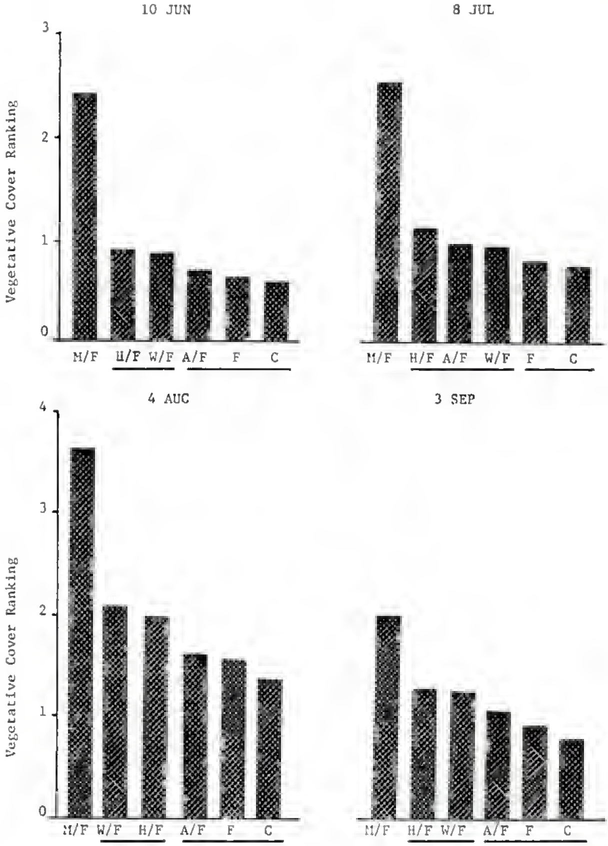
[a] insufficient bottom ash data available, analysis of scrubber sludge only



[a] insufficient bottom ash date to complete substrate analysis.

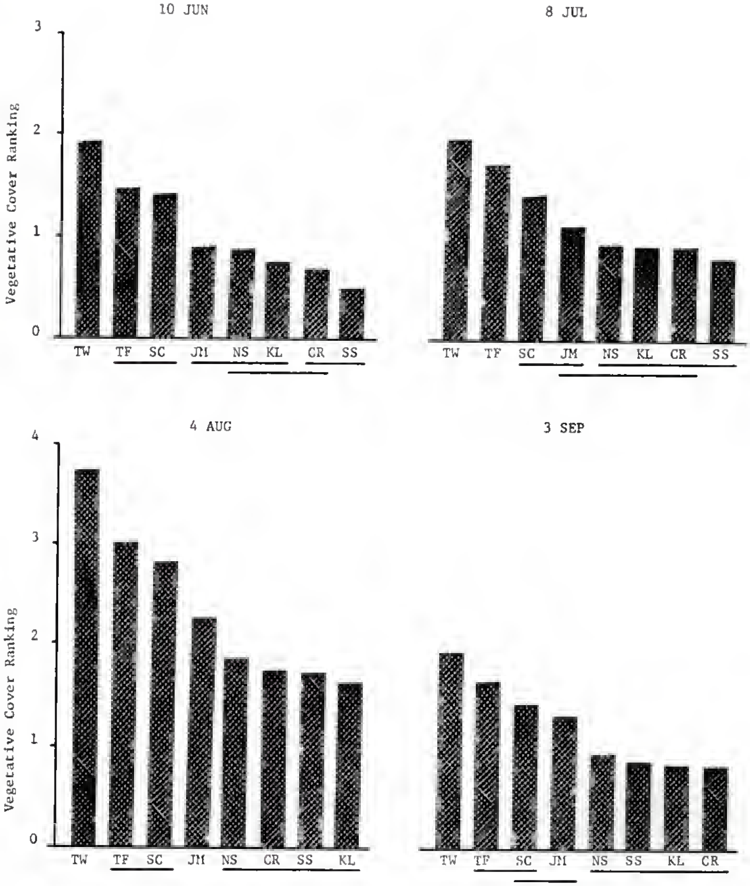
<u>SUBSTRATES</u>: Scrubber sledge (S), bottom ash (B)

Figure 40. Mean vegetative ground cover ranking of all herbaceous species, except annual ryegrass, across all treatments, as affected by the two test substrates; No. 1 bottom ash and scrubber sludge. Data from Phase I test plots monitored during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).



TREATMENTS: Manure plus fertilizer (M/F), woodchips plus fertilizer (W/F), hay plus fertilizer (H/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C).

Figure 41. Mean vegetative ground cover ranking of all herbaceous species except annual ryegrass, across both substrates, as affected by the various treatments. Data from Phase I test plots monitored during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).



SPECIES: Tall wheatgrass (TW), tall fescue (TF), sweetclover (SC), Japanese millet (JM), nodding smartweed (NS), common redgrass (CR), showy sunflower (SS), and Korean lespedeaz (KL).

Figure 42. Mean vegetative ground cover ranking of all herbaceous species except annual ryegrass, across both substrates and all treatments. Data from Phase I test plots monitored during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).

species in terms of ground cover, in that other. Fescue and sweetclover were statistically equal on 10 June, with millet equal to several other species. Fescue was significantly separate on 8 July, while sweetclover and millet rankings were statistically indistinguishable, and that of millet in turn was equal with other species. Fescue and sweetclover rankings were again equal on 4 August, and millet ranking was separate from all other species, ranking fourth. By 3 September cover rankings of fescue and sweetclover were indistinguishable, as were clover and millet. The remaining four species consistently exhibited less desirable cover rankings.

Annual ryegrass in Phase I plots was again monitored separately, ranking each treatment block as a whole rather than segregating into three distinct unit squares. The ANOVA detected significant differences at each date where data were available for both substrates (Table 27). Treatment differences were indicated at every date, while species differences (referring to tree rows in which ryegrass was grown) were detected at four dates. Because bottom ash data were missing for several dates, monthly comparisons of mean ryegrass values may only be made for the later date in each month, allowing a presentation of more useful information.

The differences between ryegrass cover rankings of the two test substrates were quite striking from the very beginning of summer to the final measurement (Fig. 43). By July the bottom ash average rank was less than 0.1, and was 0.0 by summer's end. Scrubber sludge averaged rankings above 2.0 for the latter half of the season.

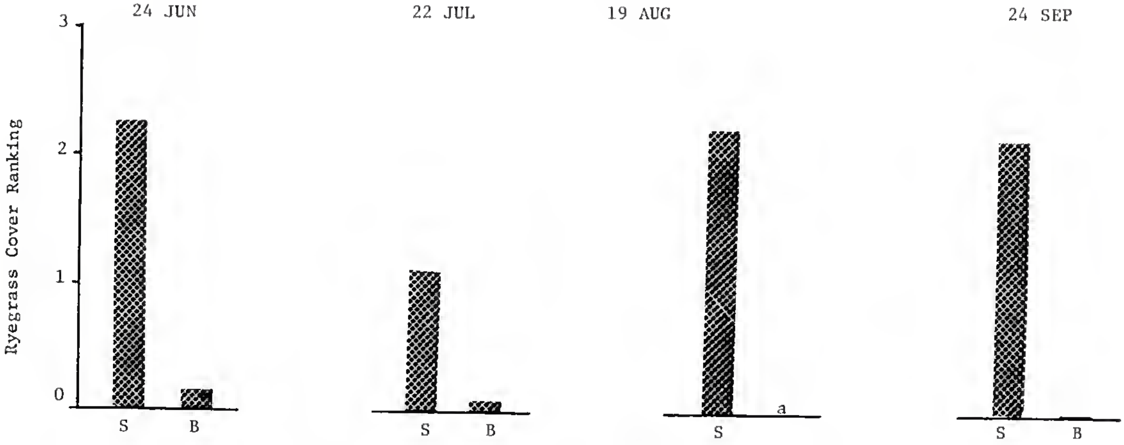
Treatments ranked very similarly with ryegrass as with previously discussed non-woody species. Manure and fertilizer always ranked significantly better than all other treatments, with the other two organic amendments, hay and woodchips, tending to produce higher average values than

Table 27. P-values from analysis of variance tests to detect differences in annual ryegrass ground cover ranking between substrates, treatments, and tree species, as well as interactions, on Phase I plots monitored during Phase II.

	P-values							
Variable	10 JUN	24 JUN	09 JUL	22 JUL	04 AUG	19 AUG	03 SEP	24 SEP
Substrate	0.0001	0.0001	a	0.0001	a	a	0.0001	0.0001
Treatment	0.0001	0.0001	0.0003	0.0001	0.0026	0.0091	0.0005	0.0001
Species	NS[b]	NS	NS	0.0001	0.0001	0.0001	NS	0.0001
Trt/sub	NS	NS	a	0.0101	a	a	0.0005	0.0001
Spec/sub	NS	NS	a	0.0001	a	a	NS	0.0001
Trt/spec	0.0001	0.0001	0.0001	0.0001	0.0001	0.0306	0.0001	0.0001
Trt/spec/sub	NS	NS	a	0.0001	a	a	0.0001	0.0001

[a] insufficient bottom ash data available, analysis of scrubber sludge only

[b] not significant ($p > 0.05$)



[a]insufficient bottom ash data to complete substrate analysis.

<u>SUBSTRATES</u>: Scrubber sludge (S), bottom ash (B)

Figure 43. Mean annual ryegrass ground cover ranking across all treatments as affected by the two test substrates, No. 1 bottom ash and scrubber sludge. Data from Phase I test plots monitored during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).

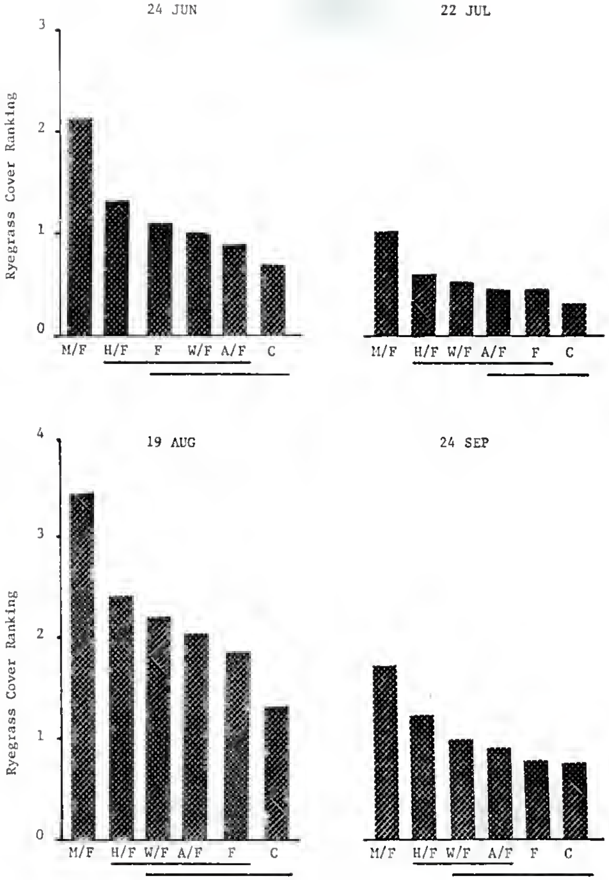
the ash mix or non-mulch treatments (Fig. 44). Yet overall differences between the five treatments other than manure tended to be statistically nonsignificant, as indicated by the LSD on ech date.

Since the ANOVA test for species effects was comparing the same grass species within rows of different tree species, a lack of significant results should not be surprising. In comparing the data from the same four monthly dates, no clear conclusions are evident to indicate which tree stimulated better ryegrass growth (Fig. 45). There are no significant differences noted on 24 June. European alder and amur maple averaged significantly equal ryegrass rankings on 22 July, yet amur maple was also equal with all other remaining species. On 19 August cottonwood, red maple, amur maple, and alder were all statistically indistinguishable, yet so were both maples, alder, red cedar, and black locust. A similar situation existed on 24 September, with the relative rankings of the six trees reordered. So while significant differences did exist on some dates, no tree species can be identified as producing consistently higher or lower ground cover ranking of annual ryegrass throughout the measuring period.

Survival of 1982 Tree Species

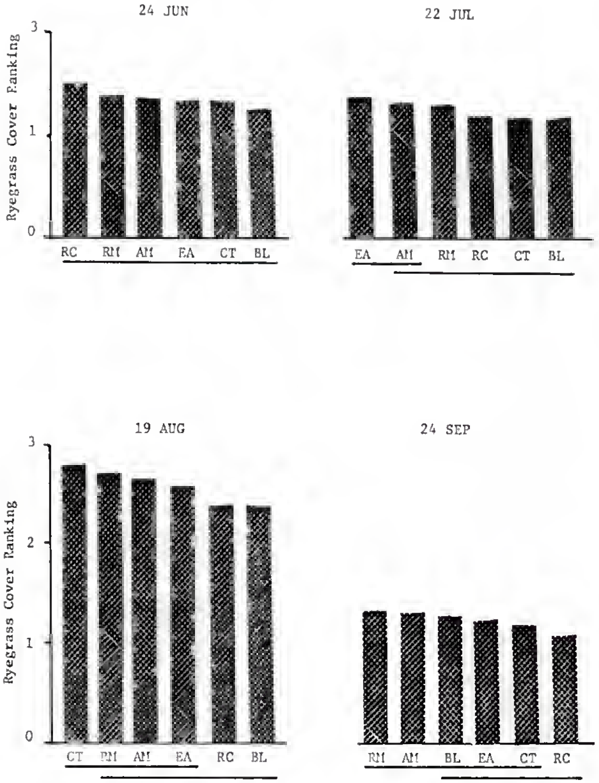
The ANOVA of biweekly recordings of mean survival on Phase I test plots monitored during Phase II detected significant differences between substrates, treatments, and species for each date (Table 28). There were insufficient bottom ash data on 4 August to complete the substrate analysis. Otherwise, all main effects were significant throughout.

Differences in tree survival between bottom ash and scrubber sludge were not as marked as those seen previously for herbaceous species, yet scrubber sludge was significantly superior each month (Fig. 46). Results do indicate that by September there was virtually no tree survival on bottom ash.



TREATMENTS: Manure plus fertilizer (M/F), hay plus fertilizer (H/F), woodchips plus fertilizer (W/F), ash mix plus fertilizer (A/F), fertilizer only (F), and control (C).

Figure 44. Mean annual ryegrass ground cover ranking across both substrates as affected by the various treatments. Data from Phase I test plots monitored during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).



SPECIES: Cottonwood (CT), red maple (RM), amur maple (AM), European alder (EA), red cedar (RC), black locust (BL).

Figure 45. Mean annual ryegrass ground cover ranking within each tree row across both substrates and all treatments. Data from Phase I test plots monitored during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 28. P-values from analysis of variance tests to detect significant differences between substrates, treatments, and species, analyzing mean tree survival (number surviving out of a possible three per treatment) on Phase I plots monitored during Phase II.

	P-values							
Variable	10 JUN	24 JUN	09 JUL	22 JUL	04 AUG	19 AUG	03 SEP	24 SEP
Substrate	0.0002	0.0088	0.0039	0.0010	a	0.0001	0.0001	0.0001
Treatment	0.0014	0.0004	0.0006	0.0009	0.0054	0.0001	0.0190	0.0096
Species	0.0001	0.0001	0.0001	0.0001	0.0001	0.0141	0.0001	0.0001
Trt/sub	NS[b]	NS	NS	NS	a	0.0001	NS	0.0276
Spec/sub	0.0001	0.0006	0.0005	0.0001	a	NS	0.0001	0.0001
Trt/spec	0.0015	NS	NS	0.0192	NS	0.0056	0.0001	0.0061
Trt/spec/sub	NS	NS	NS	NS	a	NS	0.0014	0.0470

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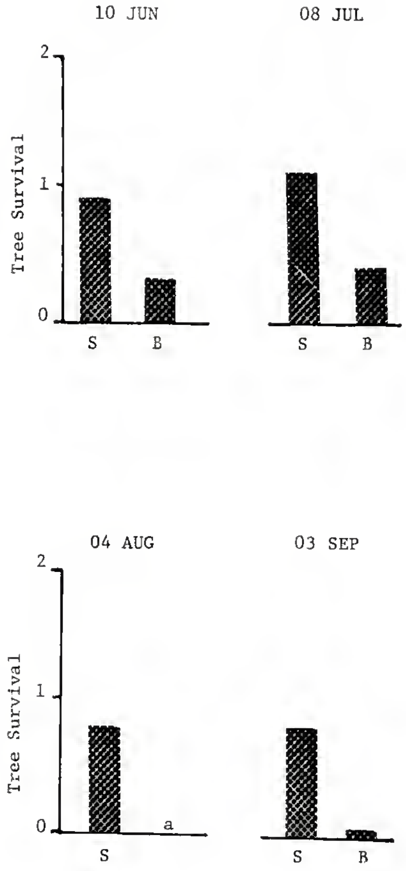
[a] insufficient bottom ash data available, analysis of scrubber sludge only

[b] not significant ($p > 0.05$)



[a]insufficient bottom ash data to complete substrate analysis

SUBSTRATES: Scrubber sludge (S), bottom ash (B)

Figure 46. Mean number of trees surviving per treatment (maximum of 3) across all treatments and species, as affected by the two test substrates, No. 1 bottom ash and scrubber sludge. Data from Phase I test plots monitored during Phase II.

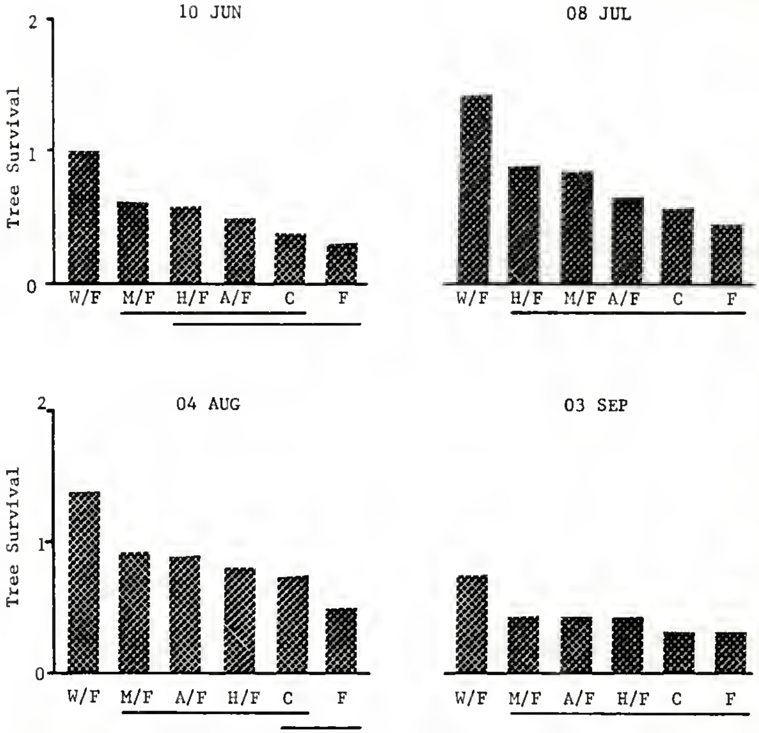
The LSD detected one treatment which consistently and significantly maintained the highest tree survival, that being woodchips plus fertilizer (Fig. 47). There was little or no significance to the differences found between the remaining five treatments at any date measured.

As per 1982 when Phase I plots were first planted and monitored, cottonwood exhibited significantly higher survival through the summer, with red cedar the second best species (Fig. 48). These two were statistically equal on 8 July, but cottonwood was significantly different at the other monthly determinations. The four remaining species were statistically indistinguishable during June and July, but during the latter half of the season black locust was identified as significantly superior to both maples and the European alder.

Monthly Substrate Analysis

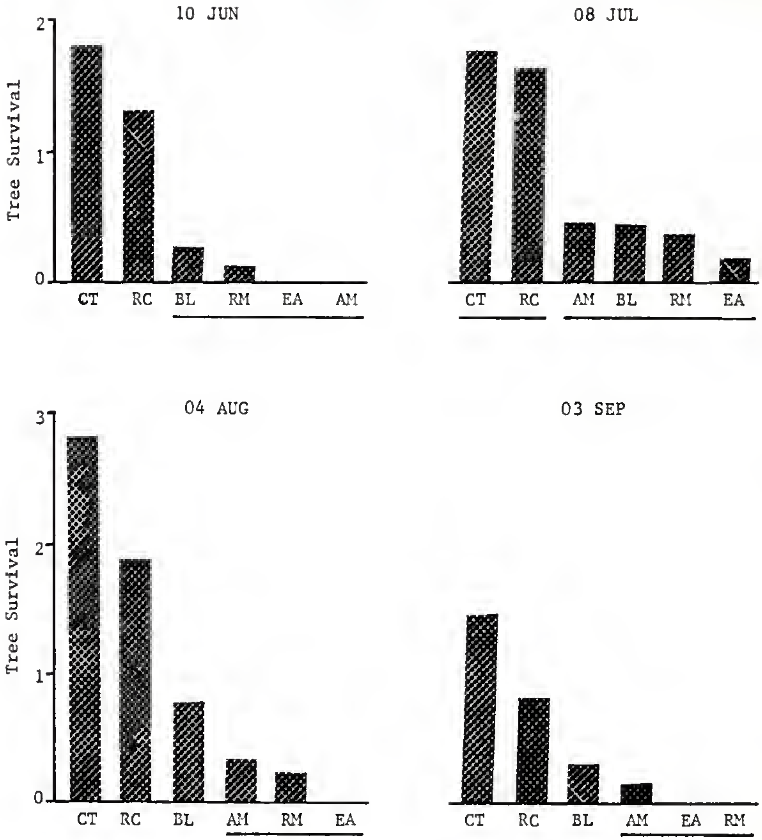
The substrates comprising the plot mixed with Unit No. 1 and Unit No. 2 bottom ash and the Unit No. 2 bottom ash plot were fairly basic, averaging approximately pH 9.5 for each (Table 29). The mixed bottom ash plot contained higher amounts of both P (3.2 vs. 1.8 kg/ha) and K (56.9 vs. 39.4 kg/ha) than did the plot containing only No. 2 ash. Phosphorus level determinations were somewhat reduced due to readings of 0.0 for both plots for the final two analyses, August and September (Appendix, Table 5). Organic matter was slightly higher in the mixed bottom ash plot, but the difference was very minor. Nitrogen levels determined for No. 2 bottom ash averaged 9.4 ppm compared with 6.7 ppm for the mixed bottom ash plot.

Both scrubber sludge plots 9 and 10 were understandably similar in substrate characteristics, located on the same substrate within 50 m of one another. They were somewhat basic, averaging approximately pH 8.2, with P concentrations at approximately 4.5 kg/ha (Table 29). There is a difference in K levels between these plots, with smaller plot 9 containing



TREATMENTS: Woodchips plus fertilizer (W/F), manure plus fertilizer (M/F), ash mix plus fertilizer (A/F), hay plus fertilizer (H/F), fertilizer only (F), and control (C)

Figure 47. Mean number of trees surviving per treatment (maximum of 3.0) across both substrates and all species; as affected by the various treatments. Data from Phase I test plots monitored during Phase II. Bars underscored by the same are not significantly different ($p > 0.05$).



SPECIES: Cottonwood (CT), red cedar (RC), black locust (BL), amur maple (AM), red maple (RM), European alder (EA)

Figure 48. Mean number of trees surviving per treatment (maximum of 3.0), across all treatments and substrates, of each species planted in Phase I test plots. Data from continued monitoring during Phase II. Bars underscored by the same line are not significantly different ($p > 0.05$).

Table 29. Characteristics of the substrates within each Phase II test plot, determined from analysis of samples taken monthly throughout the summer of 1983. Values are expressed as means (± S.D.)

Element	Plot 7[a]	Plot 8[b]	Plot 9[c]	Plot 10[d]	Plot 11[e]
pH	9.5(±0.3)	9.6(±0.2)	8.3(±0.3)	8.2(+0.2)	7.2(±0.1)
N (ppm)	6.7(±7.6)	9.4(±14.8)	9.3(±9.3)	10.4(±4.5)	26.8(±17.7)
P (kg/ha)	3.2(±3.3)	1.8(±2.9)	4.1(±4.1)	4.7(±4.6)	22.1(±2.3)
K (kg/ha)	56.9(±29.4)	39.4(±21.8)	752.6(±136.4)	476.1(±258.6)	263.3(±23.2)
P. M. (%)	1.1(±0.6)	0.8(±0.4)	1.7(±0.5)	1.4(±0.4)	3.6(±0.2)

[a] Unit No. 1/No. 2 bottom ash

[b] Unit No. 2 bottom ash

[c] Scrubber sludge, small plot

[d] Scrubber sludge, large plot

[e] Soil

one and one-half times the amount determined for plot 10. Organic matter content averaged 1.7 and 1.4 percent for these plots, with N averaging 9.3 and 10.4 ppm.

The substrate on which the soil plot was located was nearly neutral, averaging pH 7.1 (Table 29). Phosphorus (22.1 kg/ha) and organic matter (3.6%) were both at much higher concentrations when those determined for any ash substrate, while K content (163.3 kg/ha) was intermediate between the bottom ashes and scrubber sludge. Nitrogen content was much higher in soil than any other substrate, but exhibited considerable monthly variation as did all 1983 plots (Appendix, Table 5).

The analyses of substrate samples taken across all treatments were compared to determine treatment effects on substrate characteristics. Because of the similarity of substrate, the two bottom ash plots can readily be compared (Table 30). For all analyses presented, lowering of pH was considered a desirable effect, while a higher level of all other characteristics was considered beneficial. Comparing each characteristic across the range of treatments for both plots, manure plus fertilizer ranks as the best mulch treatment on both dates for six out of the 10 possible combinations, and ranks at least the second most beneficial on both dates for three of the remaining four. Scrubber sludge ash mix plus fertilizer generally tended to be the next best treatment in terms of improving fertility. Three treatments all were very similar in their overall effects: woodchips plus fertilizer, Milorganite plus fertilizer, and double fertilizer. Prairie hay seemed somewhat less beneficial than these, yet considerably more desirable than single fertilizer, with the control predictably exhibiting the lowest beneficial change.

Using this same ranking of effects, manure plus fertilizer was also the most desirable treatment on scrubber sludge plot 9 (Table 31).

Table 30. Characteristics of the substrate as affected by each treatment within Unit No. 1/No. 2 bottom ash (plot 7) and Unit No. 2 bottom ash (plot 8), determined from samples taken in early and late summer, 1983.

PLOT 7	pH		N (ppm)		O (kg/ha)		K (kg/ha)		O. M. (%)	
Treatment	June	Sept	June	Sept	June	Sept	June	Sept	June	Sept
Manure/Fert	8.5	8.1	34.5	63.8	9.0	6.8	427.5	618.8	1.6	1.2
Hay/Fert	9.5	8.9	1.5	7.2	1.1	0.0	67.5	78.8	0.9	0.7
Chips/Fert	9.1	8.7	1.0	5.2	9.0	1.1	180.0	236.3	1.4	0.6
Ash/Fert	9.0	8.4	41.4	48.6	4.5	0.0	258.8	270.0	1.7	1.1
Milorg/Fert	9.5	9.0	6.3	12.7	3.4	0.0	56.3	112.5	1.2	0.3
Double Fert	9.7	8.2	1.0	9.0	1.1	1.1	56.3	78.8	1.4	1.5
Single Fert	9.6	9.0	0.5	9.1	3.4	6.8	33.8	101.3	0.9	0.4
Control	9.6	9.1	0.5	9.3	3.4	0.0	33.8	90.0	1.0	0.5
PLOT 8										
Manure/Fert	9.0	8.7	54.7	51.6	4.5	1.1	945.0	618.8	2.1	0.8
Hay/Fert	9.7	9.3	1.7	8.5	4.5	0.0	56.3	101.3	1.2	0.8
Chips/Fert	9.4	8.7	3.8	7.0	2.3	1.1	112.5	90.0	1.2	0.3
Ash/Fert	9.4	9.0	29.5	20.4	6.8	0.0	225.0	281.3	1.7	1.3
Milorg/Fert	9.5	9.4	4.5	14.9	2.3	0.0	90.0	135.0	1.4	0.4
Double Fert	9.6	9.3	1.1	11.5	3.4	0.0	45.0	123.8	1.6	1.0
Single Fert	9.9	9.3	0.5	9.8	2.3	1.1	45.0	123.8	1.2	0.8
Control	9.8	9.5	0.4	5.6	2.3	0.0	22.5	56.3	1.1	0.2

Table 31. Characteristics of the substrate as affected by each treatment within scrubber sludge (plot 9) and soil (plot 11), determined from samples taken in early and late summer, 1983.

PLOT 9	pH		N (ppm)		P (kg/ha)		K (kg/ha)		O. M. (%)	
Treatment	June	Sept	June	Sept	June	Sept	June	Sept	June	Sept
Manure/Fert	8.3	8.2	106.3	57.1	7.9	1.1	1800.0	1642.5	3.4	2.4
Hay/Fert	8.2	8.1	21.9	15.8	7.9	0.0	810.0	843.8	1.8	1.2
Chips/Fert	8.3	8.2	9.5	16.0	9.0	1.1	641.3	113.8	2.4	1.3
Ash/Fert	8.2	8.2	21.0	17.6	10.1	1.1	360.0	630.0	1.4	1.2
Milorg/Fert	8.2	8.2	15.7	23.6	10.1	0.0	877.5	956.3	2.8	0.9
Double Fert	8.1	8.1	47.2	16.5	6.8	0.0	1091.3	866.3	2.0	1.3
Single Fert	8.2	8.1	25.8	28.8	10.1	0.0	652.5	641.3	1.8	0.9
Control	8.2	8.2	10.4	13.9	7.9	0.0	776.3	900.0	1.8	0.9
PLOT 11										
Manure/Fert	7.1	6.9	50.0	38.9	27.0	75.4	416.3	686.3	4.0	3.6
Hay/Fert	6.9	7.1	99.2	50.2	39.4	37.1	270.0	427.5	2.9	3.3
Chips/Fert	6.8	6.8	39.4	25.8	23.6	52.8	270.0	427.5	3.1	2.9
Ash/Fert	7.3	7.4	36.8	526.0	23.6	127.1	337.5	1080.0	3.9	2.6
Milorg/Fert	6.8	7.0	79.0	71.0	21.4	36.0	292.5	303.8	3.5	3.8
Double Fert	7.0	7.0	112.3	150.2	42.8	64.1	382.5	450.0	4.2	4.3
Single Fert	7.0	7.0	58.8	104.5	31.5	38.3	315.0	393.8	3.9	4.1
Control	7.1	7.2	28.8	54.3	20.3	25.9	258.8	218.3	3.5	3.5

Providing approximately equal benefit were the Milorganite plus fertilizer and the double fertilizer treatments, followed by single fertilizer, woodchips plus fertilizer, and hay plus fertilizer. Bottom ash plus fertilizer was only slightly more beneficial than was the control, again the poorest treatment as perceived by this ranking.

Double fertilizer application produced by far the best combination of desirable effects within the soil plot (Table 31). Manure plus fertilizer was the next best treatment, followed closely by single fertilizer. Ash mix and Milorganite were very similar in effects, followed by hay and woodchips. The control section was by far the least beneficial of any treatment on soil.

The large scrubber sludge plot exhibited a pattern of ranked benefits in descending order through the treatments listed (Table 32). Manure plus fertilizer was easily the best treatment, followed by manure only and then double fertilizer. Single fertilizer was somewhat less beneficial than this, with the control again ranking the poorest.

Analysis of Additional Substrate Samples

Analysis of samples of all four test substrates, collected in June and September, indicated that scrubber sludge and both bottom ash substrates contained considerably higher concentrations of each element tested than did soil (Table 33). Beyond Se, which was below the detection limit for each substrate, Mo exhibited the greatest degree of uniformity across all substrates, but was still lower in soil. No single substrate was determined to contain higher levels of all elements than all other substrates. The only element which changed dramatically in concentration from June to September was SO_4-S on the bottom ashes. It more than doubled on the Unit No. 1 and No. 2 ash mix and nearly tripled on No. 2 bottom ash.

Table 32. Characteristics of the substrate as affected by each treatment within scrubber sludge plot 10, determined from samples taken in early and late summer, 1983.

PLOT 10	pH		N (ppm)		P (kg/ha)		K (kg/ha)		O. M. (%)	
Treatment	June	Sept	June	Sept	June	Sept	June	Sept	June	Sept
Manure/Fert	8.1	8.2	44.5	27.0	5.6	3.4	990.0	1350.0	1.9	1.6
Manure	8.2	8.2	29.5	18.0	9.0	0.0	922.5	855.0	2.0	1.1
Double Fert	8.2	8.1	34.7	24.3	10.1	0.0	641.3	551.3	1.3	1.0
Single Fert	8.2	8.2	17.0	25.0	10.1	0.0	573.8	663.8	1.2	0.9
Control	8.3	8.1	9.5	16.5	9.0	0.0	663.8	495.0	1.3	0.8

Table 33. Concentrations of certain potentially toxic characteristics in the four test substrates, sampled in June and September 1983.

	SUBSTRATE CHARACTERISTICS											
	Soluble Salts (mnhos/cm)		SO_4-S (ppm)		Molybedenum (ppm)		Selenium (ppm)		Boron (ppm)		Sulfur (ppm)	
Substrate	June	Sept	June	Sept	June	Sept	June	Sept	June	Sept	June	Sept
Scrubber Sludge	2.30	2.50	4800	4300	9.86	16.99	<38.1	<38.1	86.82	64.82	68300	71610
Unit No. 1/No. 2 Bottom Ash	1.60	3.50	2700	8000	13.78	17.67	<38.1	<38.1	442.70	189.30	9090	5750
Unit No. 2 Bottom Ash	1.45	1.20	4500	13000	15.98	18.90	<38.1	<38.1	455.50	435.90	7970	7990
Soil	0.37	0.50	110	270	7.27	8.23	<38.1	<38.1	11.02	10.48	520	390

This element, along with B and S, are at concentrations in all three non-soil substrates which could be considered excessive (E. E. Schulte, Director, Wisconsin Soil & Plant Analysis Laboratory, personal communication). Yet the success of scrubber sludge compared with soil for supporting vegetation tends to discount the role these elements may actually be playing in this situation.

The four core samples collected in October along a transect extending westward across the sludge pond surface were each segregated into four subsamples representing depth increments of 2.5 cm. Results of toxicity analyses on these samples reveal sufficient variability to preclude the establishment of firm location-related trends (Table 34). Boron was the only element exhibiting generally higher concentrations with increasing distance from the bottom ash bank.

In comparing the various 2.5-cm depth analyzed the variability increases further. A slight decline in concentration with increased depth was noted for B and for soluble salts at 30, 60, and 120 m, while a slight increase with depth was noted for S and salts at 90 m. Both Mo and SO_4-S were quite variable in relation to depth, while Se was consistently at concentrations below the limits of detection.

Identification of Naturally Invading Vegetation

Identification of plants naturally occurring on the test site was conducted in order to characterize the invaders and to make comparisons with 1982 vegetation. The scrubber sludge pond yielded not only the greatest number but also the greatest variety of species (Table 35). Plants were located visually while walking through the vegetation on each area, as per 1982, making an effort to collect samples of each species present. Approximately half the plants taken from scrubber sludge were

Table 34. Concentrations of certain characteristics considered potentially toxic to plants; from four 10-cm scrubber sludge samples divided into four 2.5-cm-depth increments.

	SUBSTRATE CHARACTERISTICS					
Distance From Bottom Ash Bank	Soluble Salts (mmhos/cm)	SO_4-S (ppm)	Molybdenum (ppm)	Selenium (ppm)	Boron (ppm)	Sulfur (ppm)
30 m A	2.80	3800	15.68	<38.1	61.94	34473
B	2.25	4100	12.93	<38.1	49.69	43171
C	2.20	3900	12.91	<38.1	37.08	58038
D	2.15	3700	13.76	<38.1	34.07	62722
60 m A	3.00	4100	15.61	<38.1	78.04	36683
B	2.40	3800	13.34	<38.1	51.26	41673
C	2.20	3800	14.15	<38.1	37.82	52698
D	2.00	3800	12.22	<38.1	44.33	65544
90 m A	2.00	3900	12.64	<38.1	81.75	26357
B	2.30	3900	10.81	<38.1	60.29	22733
C	2.40	3800	13.57	<38.1	52.54	46698
D	2.30	3700	13.28	<38.1	39.39	60322
120 m A	2.70	4100	18.32	<38.1	95.78	36513
B	2.80	4000	13.51	<38.1	68.24	36154
C	2.50	4100	12.31	<38.1	49.48	43860
D	2.20	3700	9.303	<38.1	39.88	66357

A = 0-2.5 cm depth

B = 2.5-5.0 cm depth

C = 5.0-7.5 cm depth

D = 7.5-10.0 cm depth

Table 35. Plant species collected from vegetation naturally occurring on the LaCygne waste disposal areas and test site in 1983.

Location	Common Name	Scientific Name
No. 1 Scrubber Sludge	Pigweed[a]	*Amaranthus rudis* Sauer
	Common ragweed	*Ambrosia artemisifolia* L.
	Lamb's quarters	*Chenopodium album* L.
	Goosefoot[ab]	*Chenopodium bushianum* Aellen
	Pasture thistle[ab]	*Cirsium altissimum* (L.) Spreng.
	Nutsedge	*Cyperus odoratus* L.
	Barnyard grass[a]	*Echinochloa crusgalli* (l.) Beauv.
	Horse weed[b]	*Conyza canadensis* (L.) Cronq.
	Annual sunflower	*Helianthus annuus* L.
	Prickly lettuce	*Lactuca serriola* L.
	Pokeweed[a]	*Phytolacca americana* L.
	Smartweed, knotweed	*Polygonum* sp.
No. 1 Bottom Ash Bank Between Test Plot Sites	Lamb's quarters	*Chenopodium album* L.
	Annual sunflower	*Helianthus annuus* L.
	Tall goldenrod	*Solidago canadensis* L.
	Narrow-leaved cattail	*Typha angustifolia* L.
	Riverbank grape[b]	*Vitis riparia* Michx.
	Cocklebur	*Xanthium strumarium* L.
Soil Plot Control Area	Hemp dogbane[b]	*Apocynum cannabinium* L.
	Wooly croton[b]	*Croton capitatus* Michx.
	Flower-of-an-hour	*Hisbiscus trionum* L.
	Compass plant[b]	*Silphium laciniatum* L.
No. 1 Scrubber Sludge Manure Mulch	Jimson weed[b]	*Datura stramonium* L.
	Buffalo bur[b]	*Solanum rostratum* Donal.

[a] Plants collected 3 September, all others collected 22 July.

[b] Species not recorded in 1982 collections.

collected in late July, as were all plants from the other areas. The remainder were collected from scrubber sludge in early September.

Of the 22 species of plants identified, nine (41%) were species not recorded in 1982 collections. One of these, jimson weed (Datura stramonium L.), collected as a single individual growing in manure mulch on scrubber sludge plot 9, was identified in 1982 as a single plant on bottom ash plot 1, but was not collected. Both jimson weed and buffalo bur (Solanum rostratum Donal.) were collected from plot 9 because they were different from other species present, even though they may not have been 'natural' invaders. One quarter of the scrubber sludge plants identified were different than those from 1982, with only one new plant collected from bottom ash. Three of the four species taken from the soil plot were previously uncollected, with flower-of-an-hour (Hibiscus trionum L.), representing the only repeat as well as the dominant soil plant in terms of numbers. The only recording of this Hisbiscus in 1982 was from Unit No. 2 bottom ash; no soil collections were made at that time.

The results of the vegetation collections made in late September at predetermined established sampling locations across the scrubber sludge site indicate the abundance of pigweed (Amaranthus rudis Sauer) at this point in the season (Table 36). These collections were made only at the 16 sludge locations sampled previously for substrate analysis (Fig. 49). Half the 16 locations produced plants within the 15-cm sampling radius, with pigweed present at each. Sedge (Cyperus sp.) and barnyard grass (Echinochloa crugalli (L.) Beauv.) were each present at two (12%) of the points; smartweed (Polygonum lapathafolium L.) was collected at only one location (6%). Due to the late date of this collection, many species which had been present earlier, including quite abundant species such as sunflower (Helianthus annuus L.), were no longer a significant component of the vegetation.

Table 36. Plant species collected on 24 September 1983, from established sampling locations on the scrubber sludge pond (see Figure 49).

Sample No.	Common Name	Scientific Name
1	Pigweed	*Amaranthus rudis* Sauer
	Sedge	*Cyperus* sp.
2	Pigweed	*Amaranthus rudis* Sauer
	Barnyard grass	*Echinochloa crusgalli* (L.) Beauv.
3	Pigweed	*Amaranthus rudis* Sauer
	Barnyard grass	*Echinochloa crusgalli* (L.) Beauv.
5	Pigweed	*Amaranthus rudis* Sauer
7	Pigweed	*Amaranthus rudis* Sauer
	Sedge	*Cyperus* sp.
	Smartweed	*Polygonum lapathafolium* L.
8	Pigweed	*Amaranthus rudis* Sauer
9	Pigweed	*Amaranthus rudis* Sauer
13	Pigweed	*Amaranthus rudis* Sauer

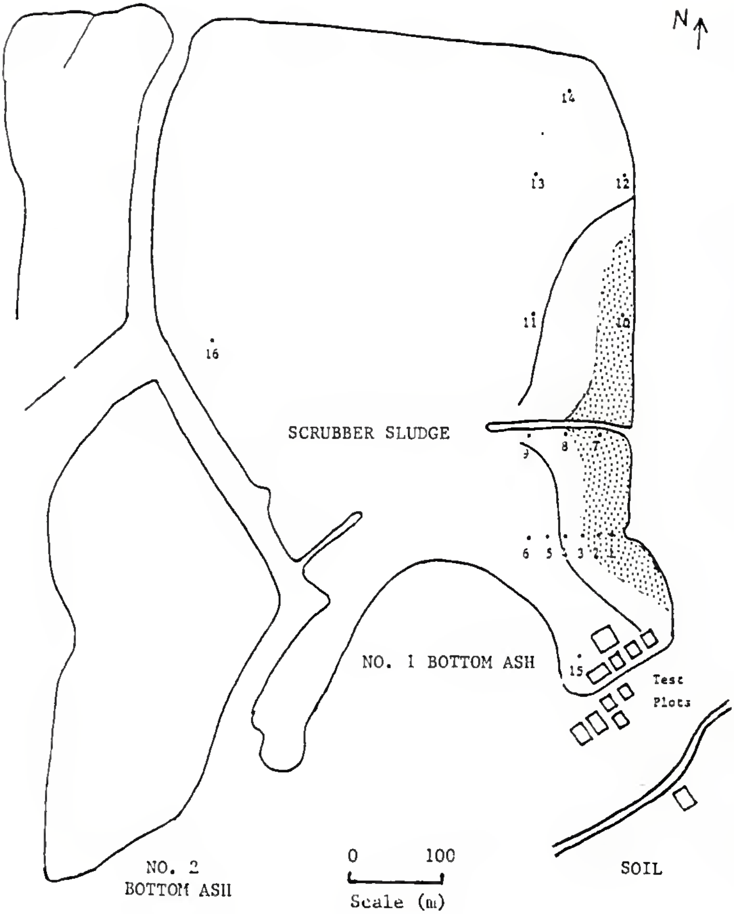


Figure 49. Disposal areas at the LaCygne station, indicating 16 scrubber sludge locations from which invading vegetation was sampled. Solid line indicates the increase in 1983 vegetative concentrations beyond those observed in 1982 (signified by stippled areas).

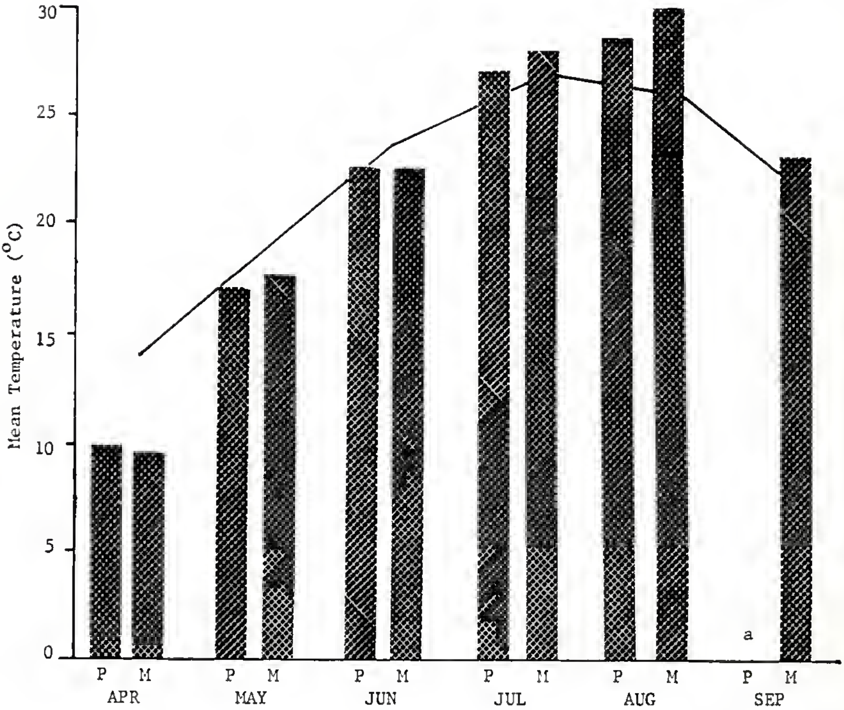
Temperature and Precipitation of the LaCygne Area

Monthly temperature means determined for Paola and Mound City during 1983 reflect the similarities of the two stations (Appendix, Table 6). A comparison of mean data for the April-September growing season indicates a steady increase in temperature from April through August, peaking at over 28° C, declining approximately 5° C in September (Fig. 50).

A comparison of 1983 mean monthly temperatures at Mound City with those representing the normal average reveals 1983 as a relatively typical year for the period April-September (Fig. 50). The greatest deviation occurred in August, when 1983 temperature peaked at just under 30° C, 4° C higher than average. All other months exhibited very slight departures from normal, the spring months averaging cooler and the summer months averaging warmer than normal.

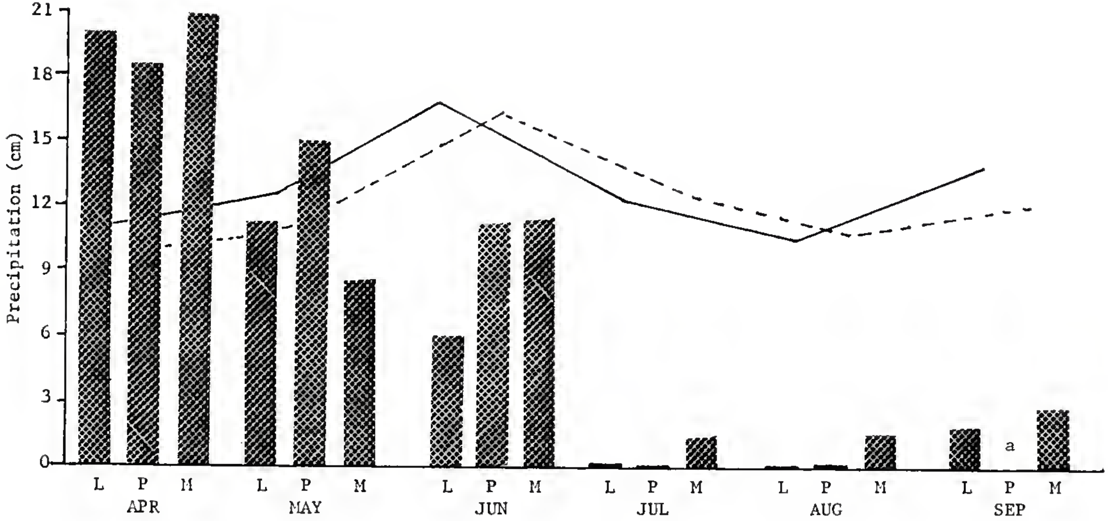
Annual precipitation records for LaCygne, Paola, and Mound City indicate only slight variations between these stations (Appendix, Table 7). A display of monthly precipitation for the growing season demonstrates a striking pattern of spring rains followed by a summer drought (Fig. 51). There was nearly a 20-cm decline in monthly precipitation from April to July, with July and August averaging almost no precipitation at all.

Monthly precipitation values at LaCygne and Paola, compared with those of the 30-year average, indicate a much greater degree of variation than was observed for temperature (Fig. 51). Both stations reported above-average precipitation for April, continuing in May at Paola while LaCygne was nearly normal. Both stations reported below normal for June, LaCygne averaging only one-third normal rainfall. The summer months of July, August, and September show a striking difference, averaging nearly zero rainfall during any of these months, while normal precipitation should have averaged approximately 10 cm/month or more. This is a graphic testimony to the severity of the drought experienced in 1983 by the study area.



^{a}missing data

Figure 50. Mean monthly temperatures recorded at Paola (P) and Mound City (M), Kansas during the period April-September, 1983. Curved line represents normal temperatures recorded at Mound City, determined from a 30-year average.



[a]missing data

Figure 51. Mean monthly precipitation recorded at LaCygne (L), Paola (P), and Mound City (M), Kansas during the period April-September, 1983. Solid line represents LaCygne normal precipitation, dashed line represents Paola normal values, determined from a 30-year average.

PHASE II

1 April 1983 - 31 March 1984

DISCUSSION

Growth of Phase II Vegetation on Four Test Substrates

Germination and growth of all Phase II test species were extremely poor on both Unit No. 1 and 2 bottom ash mix and on Unit No. 2 bottom ash alone. Vegetative failure was severe enough that growth measurements provided insufficient bottom ash data for statistical analysis beyond 10 June. For the remainder of the season, analyses incorporated only data collected from scrubber sludge and soil. Although statistical comparisons between substrates were not possible due to lack of test plot replications, scrubber sludge was observed to average somewhat higher values than soil for most variables measured.

Unit No. 2 bottom ash was reportedly finer-grained than Unit No. 1 bottom ash, and for this reason a mixture of the two was expected to produce better plant growth than Unit No. 1 ash alone. Yet despite the textural differences, the two substrates contained essentially the same principle elements: SiO_2, CaO, Al_2O_3, and Fe_2O_3 (Woodward-Clyde Consultants, 1981b). Furthermore, to state that Unit No. 2 ash is equally unsuited as a growth substrate, based upon data from Phase II, may not be entirely valid. Phase II was characterized by a summer drought considerably worse than that recorded during Phase I, with July and August each averaging less than 1 cm of rainfall, coincident with peak ambient temperatures. These conditions quite obviously put a tremendous stress on vegetation growing on any substrate, and make comparisons between the two years difficult.

The adverse weather conditions are believed responsible for the beter plant growth on scrubber sludge than on soil. The obvious subsurface moisture differences noted between substrates during Phase I were again apparent in Phase II, scrubber sludge retaining water long after none was detected even in the soil plot. The vegetation on scrubber sludge therefore was more likely able to obtain water readily during the drought months, providing opportunity for continued growth. Soil, however, was not devastated as was bottom ash, with vegetative growth at least adequate for measurements on most dates.

Herbaceous Species Survival and Growth

Six of the 13 herbaceous species exhibited increased growth characteristics on scrubber sludge and soil in 1983: tall fescue, tall wheatgrass, yellow sweetclover, Japanese millet, and annual and perennial ryegrass. Perennial ryegrass was the only one of four species added during Phase II to produce any significant growth, responding quite similarly to annual ryegrass. The other species among this list were the same ones determined the most successful from Phase I results, and have also been documented by other investigators (Adams et al., 1971; 1972; Furr et al., 1975; U. S. Environmental Protection Agency, 1976; Martin et al., 1951).

Showy sunflower was among the tallest species during the first two months of the 1983 season, then declined significantly. As per 1982, it produced very low density and ground cover throughout the season. Common reedgrass, nodding smartweed, and Korean lespedeza all exhibited extremely poor growth, repeating results from Phase I. Three newly tested species, little bluestem, western wheatgrass, and switchgrass, also were characterized by very low growth measurements, although in some instances height of switchgrass was statistically indistinguishable from 'more successful' species. Germination from seed and growth of many native perennial grasses is generally believed to be quite slow, possibly requiring 2-3 years for stand establishment (T. Swan, Kansas Fish & Game Commission, personal communication). Given the adverse weather conditions of 1983, these results should not be considered abnormal.

Tall wheatgrass and tall fescue generally produced the better ground cover across all treatments on large scrubber sludge plot 10. Differences in growth of the wheatgrass/fescue mixture planted with different equipment may be explained by mechanics. Seeds of these species flowed freely through the cyclone spreader, while they tended to be retained much more in the drop spreader. More passes were required to sow an equal quantity of seed with this spreader, and therefore more surface area was subject to compaction, which could have hindered seed germination. There was a slight difference between the two millet/sweetclover mixtures, again possibly due to mechanics. These smaller seeds flowed too quickly through the cyclone seeder, with seed deposited unevenly. Vegetation then germinated in more dense clumps, leaving open spaces which depressed the average ranking values.

No significant differences were detected between treatments for either height or density throughout the summer, and were observed only twice for ground cover ranking. This was reflective of the poor growth of most species across all treatments. Treatments receiving the highest ground cover rankings in July and August were manure plus fertilizer, Milorganite plus fertilizer, and single fertilizer. Yet the lack of overall superior growth by even the better species, coupled with the addition of two new treatments for analysis, reduced the variability from one treatment to another.

Nonstatistical differences between treatments on large scrubber sludge plot 10 indicated manure and manure plus fertilizer were the superior treatments, as had been expected based on Phase I data. The equality of mean cover rankings reported for vegetation on single and double fertilizer suggest that doubling the rate of fertilizer application is unwarranted for increasing ground cover of fescue, wheatgrass, millet, and sweetclover on scrubber sludge.

Second Year Growth and Survival of Phase I Vegetation

Herbaceous species. Scrubber sludge averaged significantly higher second year vegetative ground cover rankings than did bottom ash, with a September average ranking value of 2.4 compared with less than 0.1 for bottom ash. Not only were differences significant, but average growth on scrubber sludge was much better than on any Phase II test plots. This presumably was because vegetation was already established and able to make use of abundant early spring rainfall and milder temperatures.

Manure plus fertilizer averaged significantly higher ranking values than all other treatments, with hay and woodchips averaging higher rankings than the two inorganic treatments or the control. These results agree with those of Phase I data analysis, and with other reports of the effectiveness of organic additives (Smith et al., 1980; Lund and Doss, 1980; Sarles and Emanuel, 1977; Henry et al., 1981; Stephenson and Schuster, 1945; Hopkins, 1954).

Tall wheatgrass, fescue, millet, sweetclover, and annual ryegrass were recorded as superior species in terms of ground cover ranking. One interesting note is that while sweetclover ranked very well, almost no sweetclover plants survived on any second year plot. In its place grew an assortment of other grasses and forbs, resulting in a favorable 'sweetclover' ranking. These results suggest the value of sweetclover as a nurse crop for enriching the substrate.

Tree species. Scrubber sludge also averaged significantly higher tree survival than did bottom ash, with almost complete mortality on bottom ash by the end of the summer. Woodchips plus fertilizer maintained significantly higher rates of survival for all species than did any other treatment, with all others averaging statistically equal. The few trees which survived on bottom ash were primarily found on woodchips, suggesting its value as a buffer against the heating effects of this dark substrate, as well as probable benefits from moisture availability and nutrient addition (Gartner et al., 1973).

As per 1982, cottonwood exhibited the highest survival rate of any tree species, with red cedar the second highest. By the end of the summer amur maple, red maple, and European alder had each been reduced to extremely low survival. Black locust maintained levels somewhat between these trees and the two best, cottonwood and cedar. It must be reiterated that Phase II survival rates were dependent upon Phase I responses. Each treatment or species block began its 1983 survival just as it had been left at the end of 1982, with all inequalities intact. Therefore these rates can be viewed as merely extensions of Phase I monitoring.

Substrate Temperature and Moisture

Although significant differences between any variables were quite infrequent, manure plus fertilizer was generally observed to produce lower substrate temperatures than either the control or double fertilizer treatments. Significant differences between four species monitored on four test plots were moderate and also infrequent. Tall wheatgrass was indicated as producing the highest substrate temperature at a depth of 15 cm, yet the LSD was unable to clearly separate all four temperature responses.

Although Hopkins (1954) reported decreased substrate temperatures with use of organic mulches, species differences were the only significant effects observed when data from eight species were analyzed across three test plots. Tall wheatgrass and perennial ryegrass were identified as producing highest temperatures at 15 cm, with Korean lespedeza the lowest. This suggests a tendency toward increased substrate temperature with increased vegetative growth, just the opposite result from that reported by Buckman and Brady (1969). However, the results of statistical tests do not allow clear-cut separations due to the poor growth of most species.

The lack of apparent differences between substrate temperatures was somewhat surprising. Yet even though growth was superior on scrubber sludge and soil, having failed completely on Unit No. 2 bottom ash, it was likely not sufficient to produce significant temperature fluctuations. The similar coloration of all three substrates (unlike black Unit No. 1 bottom ash) would have reduced the effect of radiant heating as a factor of difference.

Poor growth may also have been partially responsible for the lack of any significant effects of substrate moisture content. Although Buckman and Brady (1969) did not include vegetative cover in their list of important factors influencing available soil moisture, organic matter content has been determined a positive factor. Organic amendments at LaCygne were expected to benefit through increased moisture retention, as reported by Hopkins (1954). Yet, as has been discussed, poor vegetative growth reduced the significance of most treatment-related differences.

A nonstatistical comparison of mean substrate content revealed both scrubber sludge plots to contain much more moisture than either Unit No. 2 bottom ash or soil, reinforcing the empirical observations made previously.

These differences appeared almost solely the result of the actual physical characteristics of the substrates themselves, and had little if anything to do with vegetative cover.

Substrate Characteristics

The alkaline conditions of both the mixed bottom ash and the Unit No. 2 bottom ash plots may have contributed to restrictions on plant growth, yet even these pH levels above 9.0 are not necessarily excessive (Moore, 1974). Levels in these plots of N, P, and organic matter were all lower than those observed in either scrubber sludge or soil, but not dramatically so. The most extreme difference was in K levels. Bottom ash substrates averaged 40-60 kg/ha K, scrubber sludge averaged 476-753 kg/ha, and soil averaged 263 kg/ha; yet these all are still well below mineral soil levels reported by Buckman and Brady (1969). It is believed that physical qualities of the substrates probably contributed more to their effectiveness as growth medium than did elemental composition.

Of all treatment combinations tested on these plots, manure generally tended to produce the most desirable combination of effects among the characteristics analyzed. Woodchips, Milorganite, and double fertilizer each produced very similar effects, yet each treatment varied widely in its effects from one substrate to another. It must be pointed out that comparisons merely indicate changes in specific substrate characteristics with use of different treatments. This in no way was a guarantee that a perceived beneficial change would result in an equally superior growth of vegetation on that treatment, as determined from previous analysis of growth data.

Analysis of samples of all four test substrates collected in June and September indicated that three potentially toxic elements (B, S, and SO_4-S) were at elevated levels in both bottom ash plots as well as the scrubber sludge plot. Boron and SO_4-S were both higher on either bottom ash than on scrubber sludge, with S much higher on sludge. These various levels may indeed provide some explanations for different growth responses. Yet scrubber sludge exhibited the most superior plant growth of any substrate, despite extreme S concentrations and much higher levels of most elements tested than were present in soil. This again suggests that other factors are at least as equally important as elemental composition for determining plant growth.

As per 1982, analysis of four scrubber sludge samples collected to help pinpoint differences differences in elemental composition with increasing distance from the edge of the sludge pond failed to provide this information. Neither distance-related nor depth-related differences were readily apparent, with surprisingly little variation between samples analyzed for the same elements.

One must be somewhat guarded when attempting to draw conclusions from these toxic analyses. These ash and sludge samples react differently than does soil under chemical analysis. Proper dilutions were very difficult to produce, and resulting compositional values were affected by the foreign nature of the substrates (E. E. Schulte, Director, Wisconsin Soil & Plant Analysis Laboratory, personal communication). It was hoped that any error or bias in the analysis was at least constant throughout, yet it should be understood that no comparisons should be realistically attempted between these results and those produced from analysis of other similar substrate samples.

Naturally Occurring Vegetation

The differences in species composition of the disposal areas from one year to the next are difficult to explain. While there were only four new species in 1983 from both bottom ash and scrubber sludge areas, there were eight species collected in 1982 which were not found the following year. The nature of the sampling technique no doubt lent itself to some error, being somewhat nonsystematic. The more physically conspicuous or numerically dense a particular species was, the greater the likelihood of being collected. However, it was believed that morphology alone was definitely less a factor in determining plant location. Every effort was made to locate even the smaller and less obvious species.

There were great differences in relative abundances of the various species. Some were present in great numbers (e.g., Amaranthus) while others were quite scarce (e.g., Cirsium). There may have been species present in such low densities that they were overlooked one year or the other. There may well have been species which were not collected either year. Scarcity of numbers would be a major factor contributing to this, although plant morphology could also affect detection (i.e., a single sunflower in bloom would be more easily located than a single nutsedge). If collections were continued for a period years, these species differences between areas may be seen as merely normal deviations with the primary dominant vegetation remaining relatively stable.

The continued abundance of plants on scrubber sludge compared with bottom ash areas was quite obvious. I believe the continued expansion of this vegetation along the bottom ash boundary lends support for the seed deposition theory discussed during Phase I, which was based on particle-flow data from Nelson (1981) and Grace (1977).

PHASE II

1 April 1983 - 31 March 1984

SUMMARY AND CONCLUSIONS

As a continuation of experimental efforts to vegetate waste disposal areas at KCP&L'S LaCygne Generating Station, five test plots were established to measure the effectiveness of a variety of plant species and substrate treatments. One plot each was established on scrubber sludge, Unit No. 2 bottom ash, a 50:50 mixture of Unit No. 1 and 2 bottom ash, and soil. One additional plot was established on scrubber sludge to evaluate the most successful species and treatments based on data from Phase I.

Vegetative growth was monitored biweekly, recording plant height, density, and ground cover. Six test plots established during Phase I were also continuously monitored, recording vegetative cover ranking and tree survival. Each substrate was analyzed monthly for pH, organic matter, and macronutrients, with periodic analyses for toxic characteristics. Specimens of naturally invading vegetation were collected and identified to determine species composition. Substrate temperature and moisture were monitored throughout the summer, to identify different physical effects of species or treatments. At the end of the year, temperature and precipitation records were obtained for the LaCygne area, for comparison with normal conditions represented by an average of 30-year records.

Data collected during this investigation support the following conclusions:

1. Although not confirmed statistically, scrubber sludge tended to produce vegetative growth superior to both bottom ash substrates and even to soil. Substrate analyses offered no explanations for this difference, with physical characteristics believed to be more important.

2. Manure tended to stimulate vegetative growth more than other treatments, yet significant differences were infrequent owing to poor relative growth throughout the abnormally dry summer. Manure was significantly better for stimulating second year growth of Phase I vegetation, with both prairie hay and woodchips averaging well.

3. Perennial ryegrass was the only new Phase II species tested which exhibited significant growth, joining tall wheatgrass, tall fescue, Japanese millet, yellow sweetclover, and annual ryegrass among the most successful herbaceous species.

4. Cottonwood and eastern red cedar continued to exhibit significantly higher rates of survival than other woody species during their second year of growth on Phase I plots.

5. Substrate temperature tended to decrease with additional treatment application, and seemed to increase with increased plant growth. However, significant differences were too infrequent to justify firm conclusions. Substrate moisture was much higher in scrubber sludge than either bottom ash or soil. No significant treatment or species differences were detected.

6. The Phase II growing season was characterized by a drought during the summer months of July, August, and September. Although temperatures were only moderately above normal, they coincided with periods of almost total lack of precipitation.

OVERALL PROJECT DISCUSSION

The demand for coal as an energy source may be expected to increase in the U.S. in the coming years, as oil and gas become less available. Along with accelerated coal consumption will come an increase in the environmental problems which accompany it. One of the primary problems is that of deterioration of air quality, especially in the immediate vicinity of the particular generating station. This degradation may manifest itself as elevated atmospheric particulate loads, health risks and potential economic losses to humans and livestock, and acid rain. In order to alleviate these negative effects, utility companies will be continually required to maintain and upgrade air quality control features on all coal-burning facilities.

The FGD wet scrubber system at LaCygne is an example of the type of technology which will be relied upon for the removal of sulfur and various particulates from smokestack emissions. The result of this will be an increase in the amount of scrubber sludge and other solid wastes produced, creating more disposal problems similar to that addressed in this report. The utility industry will be called upon to comply with various state and federal requirements regarding handling of such solid wastes. The methods employed must provide for storage or disposal in a manner which is environmentally sound and yet economically feasible.

The two years of research completed at the LaCygne Generating Station have demonstrated that scrubber sludge ponds can be successfully vegetated without the use of a topsoil cover layer. Reductions in both costs and in environmental disturbances may be realized by implementation of these methods on a larger scale. Data from this study strongly suggest that some form of organic substrate amendment is highly desirable for producing a more acceptable vegetative cover, with manure, prairie hay, and woodchips all exhibiting favorable results. Cost and availability may well determine which of these are more widely utilized.

Species used for reclamation of scrubber sludge areas should be tolerant of slightly alkaline substrates, though conditions at LaCygne were certainly not excessive. A variety of cool-season species, mainly grasses, were determined to be well suited for this type of reclamation project, producing thick cover which was self-maintaining at least to the second year. Preliminary observations in May 1984 indicate several of these same species are growing quite well in their third year, particularly tall fescue and tall wheatgrass. Yellow sweetclover, one of the species naturally invading scrubber sludge, also provided abundant substrate cover when planted in test plots.

The planting of trees was discontinued after the first year, on the assumption that more valuable information could be gained from continued monitoring of existing trees than from annual planting of new seedlings. Survival data from two growing seasons identify cottonwood and eastern red cedar as the best species to plant on LaCygne scrubber sludge. Yet in terms of producing accelerated growth leading to formation of an eventual canopy cover, cottonwood is by far the superior tree.

Observations of invading vegetation suggest that, if left undisturbed, the scrubber sludge surface would eventually be reclaimed by natural processes. But these take many years, with possibly a decade or more required to achieve an acceptable level of surface cover, whereas direct planting can speed these results considerably. Using techniques discovered during this study, the entire 54 ha of the presently available scrubber sludge surface area could probably be reclaimed in 1-3 years.

None of the methods evaluated during the two phases of this research were successful at maintaining vegetative growth on bottom ash, yet a solution may still be available. If bottom ash does require complete burial beneath an amending cover in order to establish vegetation, scrubber sludge should be considered as an alternative to soil for use as the cover material. Its availability should reduce many of the costs involved with using soil, and in this way KCP&L could effectively reclaim two solid waste products in the same process.

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Dan Mulhern

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EXPERIMENTAL VEGETATION OF BOTTOM ASH AND SCRUBBER SLUDGE AT KANSAS CITY POWER & LIGHT COMPANY'S LACYGNE GENERATING STATION

APPENDIX

Appendix, Table 1. Characteristics of bottom ash (plots 1, 2, and 3) and scrubber sludge (plots 4, 5, and 6) samples collected from the LaCygne experimental site during summer, 1982.

	Bottom Ash Experimental Site																	
	Plot 1						Plot 2						Plot 3					
	May	July	Aug	Sep	October		May	July	Aug	Sep	October		May	July	Aug	Sep	October	
pH	7.8	6.7	6.3	6.7	6.9	6.9	8.3	7.3	6.8	8.0	7.6	8.1	7.4	6.9	6.2	7.0	6.7	6.4
N (ppm)	a	a	1.5	0.2	0.0	0.5	a	a	0.0	0.1	0.2	0.2	a	a	0.4	0.1	0.0	0.0
P (kg/ha)	29.3	9.0	6.8	5.6	3.4	5.6	14.6	16.9	18.0	18.0	11.3	20.3	5.6	7.9	4.5	5.6	4.5	2.3
K (kg/ha)	95.6	483.8	24.8	34.9	30.4	21.4	38.3	563.0	24.6	31.5	16.9	20.3	37.1	297.0	15.8	29.3	25.9	23.6
O.M. (%)	1.1	0.6	0.5	0.3	0.5	0.1	0.8	0.3	0.2	0.6	0.3	0.4	2.0	0.3	0.0	1.0	0.7	0.5
	Fly Ash Experimental Site																	
	Plot 4						Plot 5						Plot 6					
	May	July	Aug	Sep	October		May	July	Aug	Sep	October		May	July	Aug	Sep	October	
pH	8.4	7.7	7.6	8.2	8.1	8.2	8.4	7.8	7.9	8.2	8.3	b	8.5	7.9	7.8	8.1	8.1	8.1
N (ppm)	a	a	1.9	1.0	12.0	0.0	a	a	1.3	2.3	12.0	b	a	a	0.6	0.5	0.0	0.0
P (kg/ha)	10.1	4.5	10.1	3.4	0.0	1.1	9.0	4.5	10.1	11.3	0.0	b	19.1	9.0	6.8	7.9	0.0	1.1
K (kg/ha)	256	563	563	563	563	563	227	563	563	563	563	b	138	563	383	430	383	298
O.M. (%)	1.7	2.4	2.2	1.4	1.5	2.1	1.2	2.6	1.7	1.1	1.9	b	1.6	2.0	1.4	1.0	1.0	1.3

[a] No analysis performed.

[b] Sample lost during analysis.

Appendix, Table 2. Mean monthly ambient temperatures recorded at Paola and Mound City, Kansas during 1982.

LOCATION	TEMPERATURE (°C)											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Paola	-3.8	-0.6	8.3	12.1	18.1	20.6	25.9	24.1	19.9	14.1	7.8	4.0
Mound City	-2.7	0.4	9.0	12.2	19.8	21.2	26.9	26.1	21.2	14.6	8.2	4.7
normal[a]	-1.1	2.2	7.2	14.0	19.1	23.9	26.7	25.8	21.2	15.2	7.5	1.9

[a] Normal Mound City temperatures determined from a 30-year average, 1951-1980

Appendix, Table 3. Monthly precipitation recorded at LaCygne, Paola, and Mound City, Kansas during 1982.

LOCATION	PRECIPITATION (cm)											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LaCygne	8.44	3.26	7.64	6.97	20.38	9.26	4.46	17.21	1.77	9.00	6.15	9.03
normal[a]	3.49	3.08	6.54	10.82	12.48	16.31	12.43	10.52	13.82	8.72	4.23	3.98
Paola	6.87	1.58	6.44	7.51	22.72	20.85	9.79	13.08	3.31	6.92	4.05	8.69
normal[a]	3.43	3.25	6.75	10.51	11.75	16.03	12.79	10.72	11.98	9.18	3.97	3.92
Mound City	7.87	2.51	6.77	5.26	22.10	11.90	3.74	18.97	2.85	8.03	5.64	10.33

[a] Normal LaCygne and Paola precipitation determined from a 30-year average, 1951-1980

Appendix, Table 4. Mean ground cover ranking for each species or combination across all treatments and for each treatment across all species on large scrubber sludge plot #10, tabulated for each date recorded in 1983.

	GROUND COVER RANK ($\bar{X}$)							
SPECIES	11JUN	25JUN	09JUL	22JUL	04AUG	19AUG	03SEP	24SEP
Clover	1.0	1.0	1.2	1.5	2.0	2.2	2.2	2.2
Wheatgrass	1.3	1.7	1.4	2.3	2.1	2.4	2.2	2.3
Fescue	1.2	1.7	1.5	2.0	2.0	2.2	2.0	2.2
Millet	1.0	1.0	1.0	1.2	1.4	2.0	1.6	2.0
Millet/sweetclover	1.0	1.0	1.2	1.6	1.7	2.4	2.2	2.6
Millet/sweetclover[a]	1.0	1.0	1.0	1.2	1.6	2.2	1.9	2.3
Wheatgrass/fescue	1.3	1.8	1.3	1.8	1.6	2.0	1.9	2.1
Wheatgrass/fescue[a]	1.2	1.6	1.6	2.2	2.0	2.5	2.2	2.6
TREATMENT								
Manure/Fert	1.3	1.9	1.8	2.8	3.1	3.8	3.6	3.9
Manure	1.3	1.7	1.6	2.6	2.8	3.8	3.4	3.8
Double Fert	1.1	1.1	1.0	1.2	1.1	1.4	1.1	1.3
Single Fert	1.0	1.1	1.0	1.8	1.1	1.1	1.1	1.4
Control	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[a] Planted with a cyclone seeder, all others with a drop seeder

Appendix, Table 5. Characteristics of substrate samples collected from the LaCygne experimental site during summer field work, 1983.

	Plot 7					Plot 8				
	10May	27Jun	22Jul	18Aug	24Sep	10May	27Jun	22Jul	18Aug	24Sep
pH	9.9	9.6	9.3	9.4	9.1	9.9	9.8	9.3	9.5	9.5
N (ppm)	3.0	0.5	1.8	18.9	9.3	3.0	0.4	2.3	35.7	5.6
P (kg/ha)	4.5	3.4	7.9	0.0	0.0	0.0	2.3	6.8	0.0	0.0
K (kg/ha)	22.5	33.8	56.3	82.1	90.0	11.3	22.5	45.0	61.9	56.3
O.M. (%)	1.0	1.0	2.2	0.8	0.5	0.6	1.1	1.0	1.1	0.1

	Plot 9					Plot 10					Plot 11				
	10May	27Jun	22Jul	18Aug	24Sep	10May	27Jun	22Jul	18Aug	24Sep	13Jun	27Jun	22Jul	18Aug	10Sep
pH	8.9	8.2	8.2	8.2	8.2	8.6	8.3	8.0	8.1	8.1	7.2	7.1	7.3	7.0	7.2
N (ppm)	4.0	10.4	9.3	9.1	13.9	4.0	9.5	10.5	10.5	16.5	7.0	28.8	16.5	27.3	54.3
P (kg/ha)	2.3	7.9	9.0	1.1	0.0	3.4	9.0	10.1	1.1	0.0	20.3	20.3	22.5	21.4	25.9
K (kg/ha)	585.0	776.3	641.3	860.6	900.0	33.8	663.8	518.8	659.3	495.0	292.5	258.8	236.6	247.5	281.3
P.M. (%)	2.0	1.8	2.0	1.8	0.9	1.4	1.3	1.8	1.5	0.8	4.0	3.5	3.5	3.5	3.5

Appendix, Table 6. Mean monthly ambient temperature recorded at Paola and Mound City, Kansas during 1983.

	Temperature (°C)											
Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Paola	0.7	3.3	7.7	9.8	17.2	22.6	27.1	28.4	[b]	14.1	6.9	-9.3
Mound City	0.8	3.6	7.5	9.7	17.6	22.8	27.9	29.8	23.0	16.0	9.0	-7.4
normal[a]	-1.1	2.2	7.2	14.0	19.1	23.9	26.7	25.8	21.2	15.2	7.5	1.9

[a] Normal Mound City temperatures determined from a 30-year average, 1951-1980

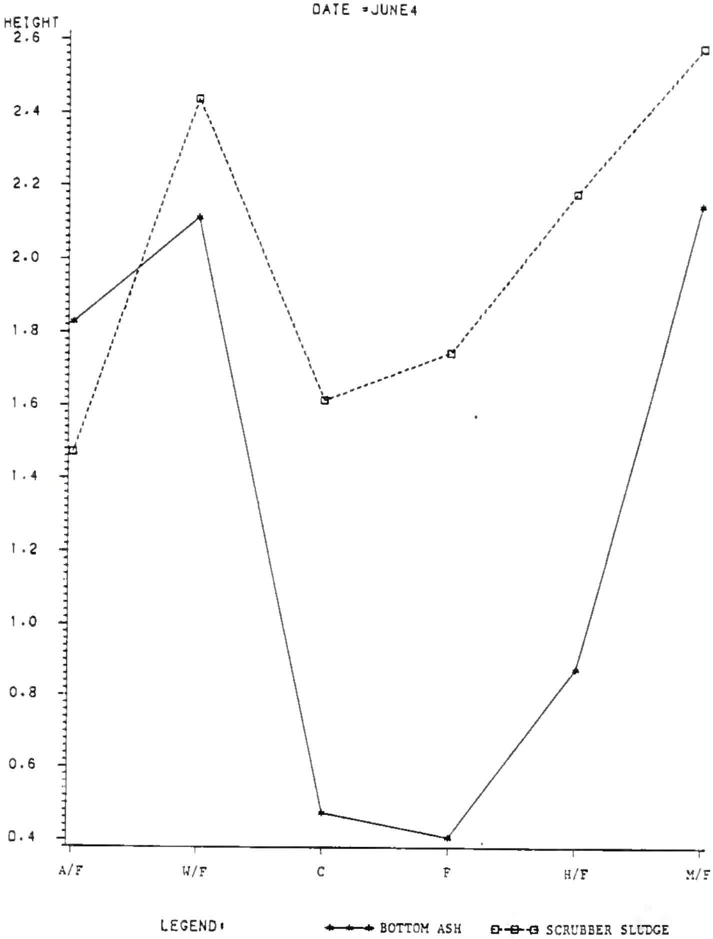
[b] Data missing

Appendix, Table 7. Monthly precipitation recorded at LaCygne, Paola, and Mound City, Kansas during 1983.

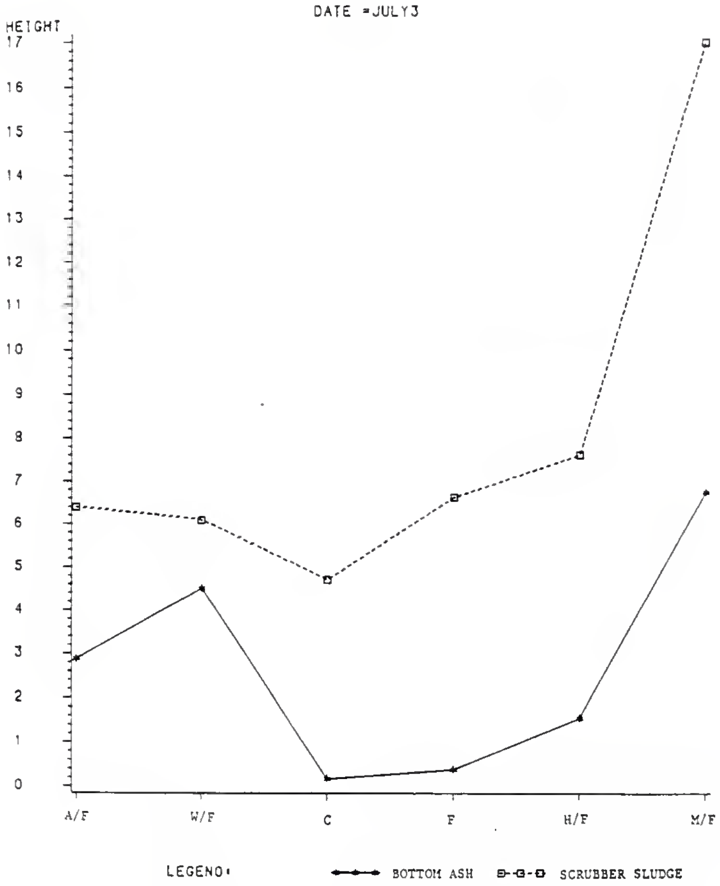
	Precipitation (cm)											
Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LaCygne	2.18	3.08	10.46	19.89	11.26	5.74	0.58	0.13	1.87	12.15	4.33	1.27
normal[a]	3.49	3.08	6.54	10.82	12.48	16.31	12.43	10.52	13.82	8.72	4.23	3.98
Paola	2.21	0.18	8.41	18.67	15.28	11.13	0.48	0.53	b	16.54	5.22	1.10
normal[a]	3.43	3.25	6.75	10.52	11.75	16.03	12.79	10.72	11.98	9.18	3.97	3.92
Mound City	2.56	4.85	11.64	20.85	8.69	11.59	1.17	1.66	2.72	17.74	4.91	2.20

[a] Normal LaCygne and Paola precipitation determined from a 30-year average, 1951-1980

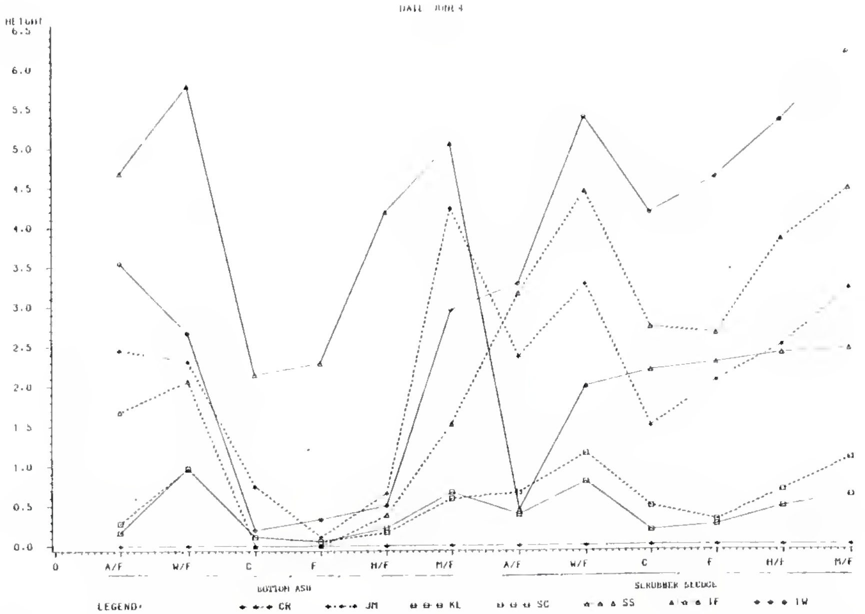
[b] Data missing



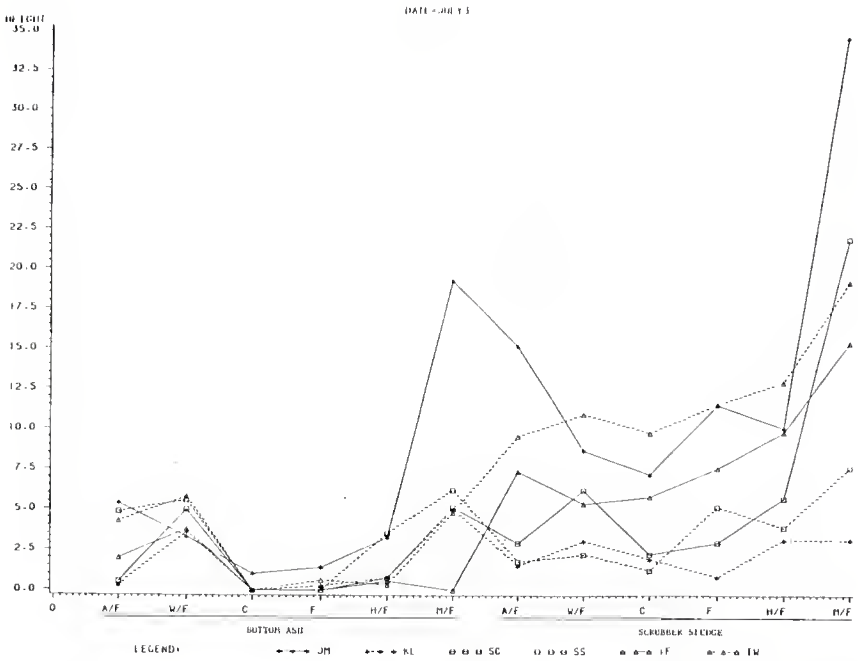
Appendix, Figure 1. Mean plant height (cm) of vegetation on each treatment, measured on 4 June on bottom ash and scrubber sludge.



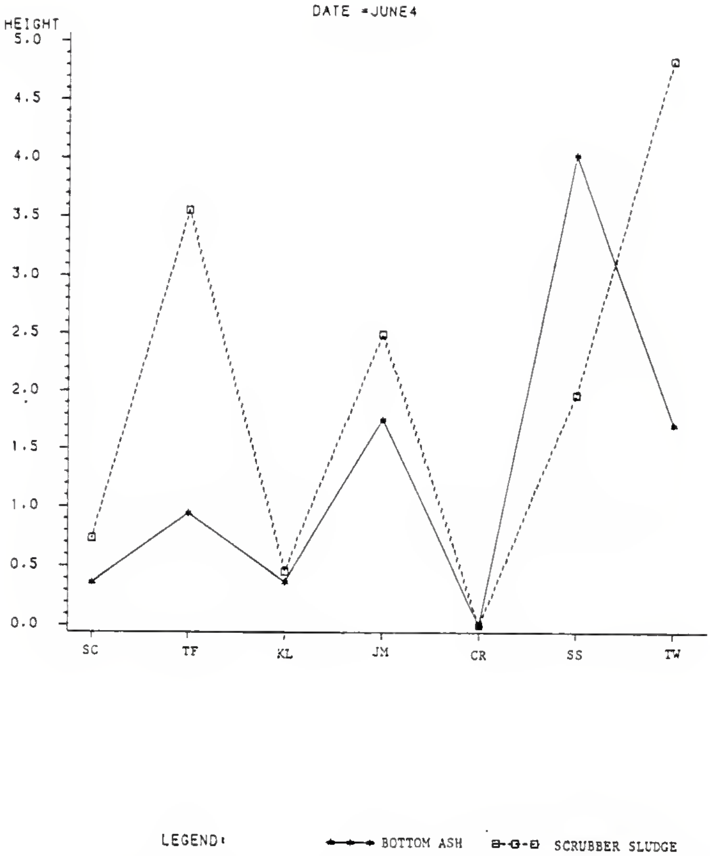
Appendix, Figure 2. Mean plant height (cm) of herbaceous vegetation on each treatment, measured on 3 July on bottom ash and scrubber sludge.



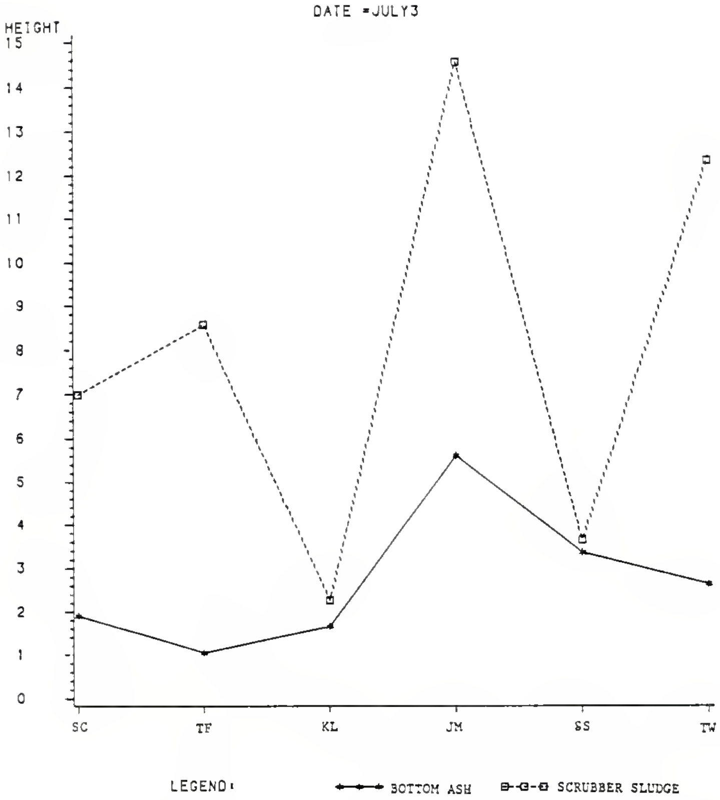
Appendix, Figure 3. Mean plant height (cm) of test species as affected by the six treatments on each substrate, measured on 4 June.



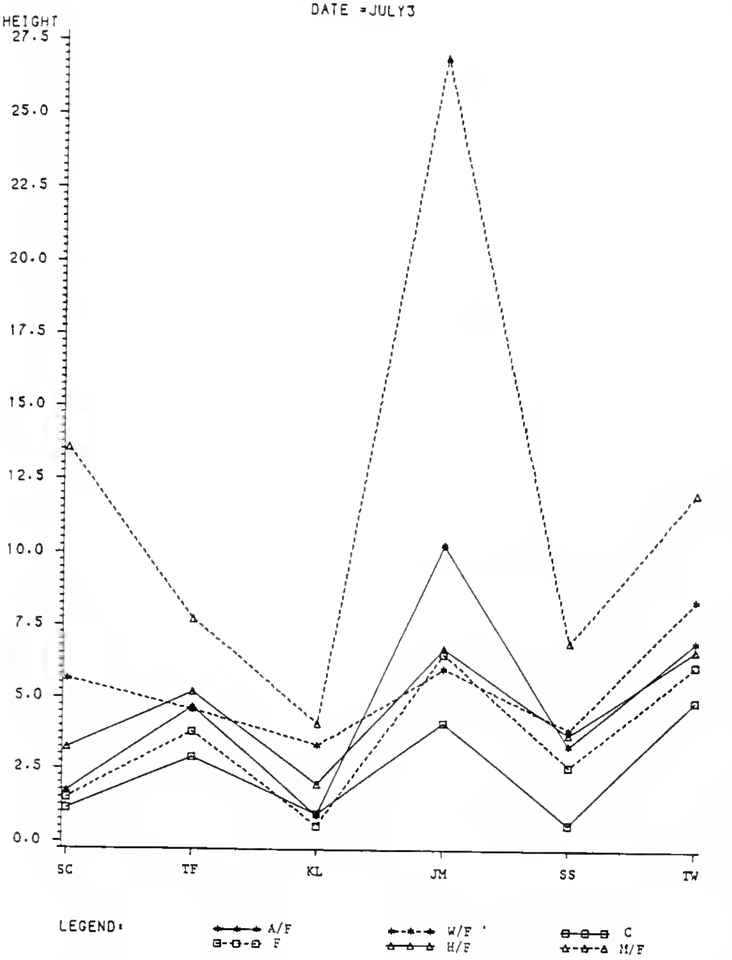
Appendix, Figure 4. Mean plant height (cm) of test species as affected by the six treatments on each substrate, measured on 3 July.



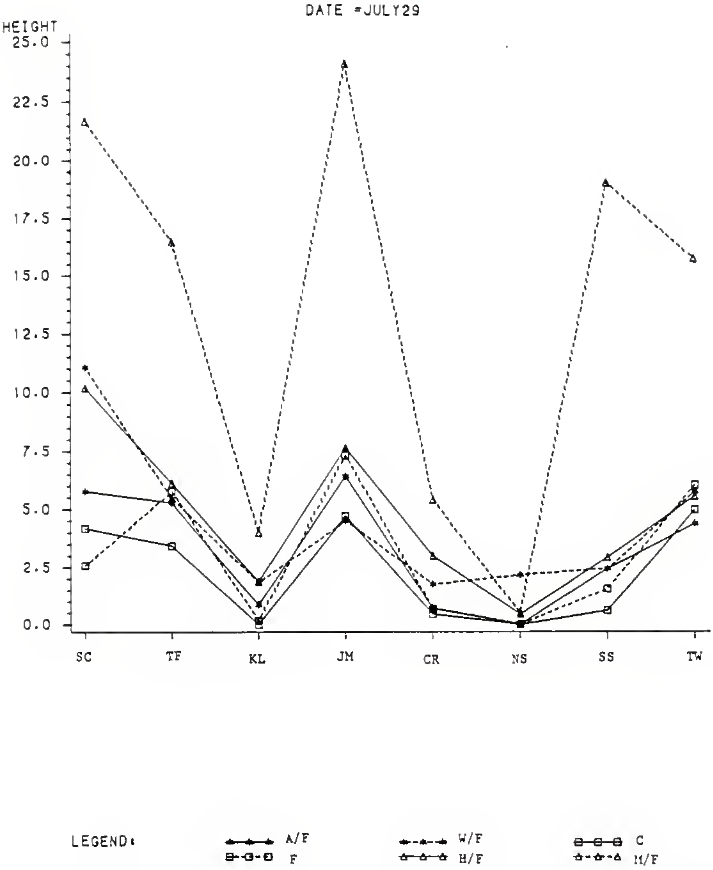
Appendix, Figure 5. Mean plant height (cm) of test species across all treatments, measured on 4 June on bottom ash and scrubber sludge. .



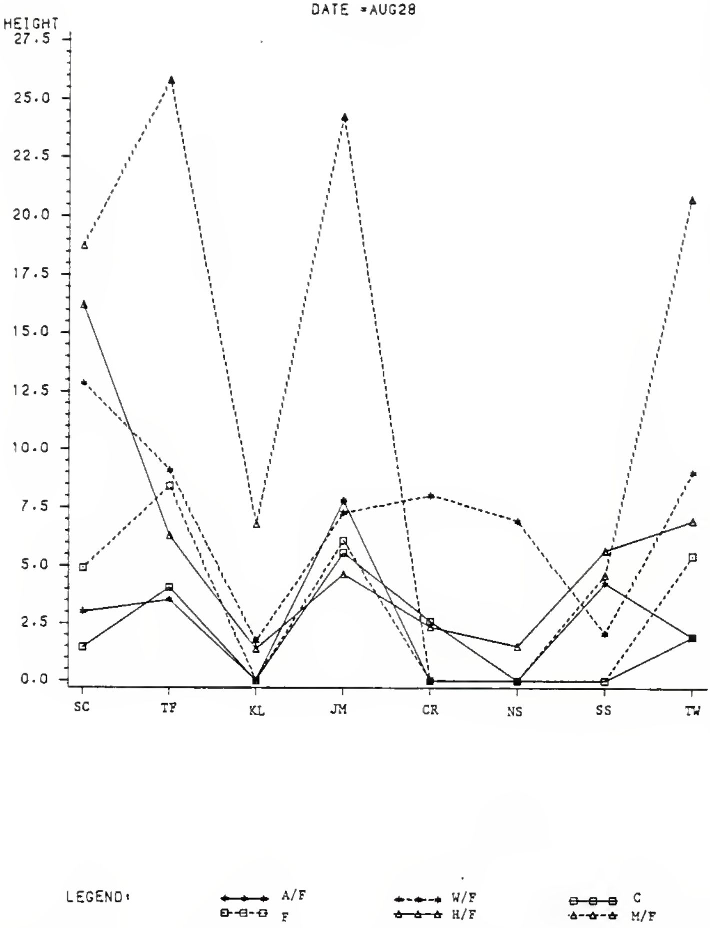
Appendix, Figure 6. Mean plant height (cm) of test species across all treatments, measured on 3 July on bottom ash and scrubber sludge.



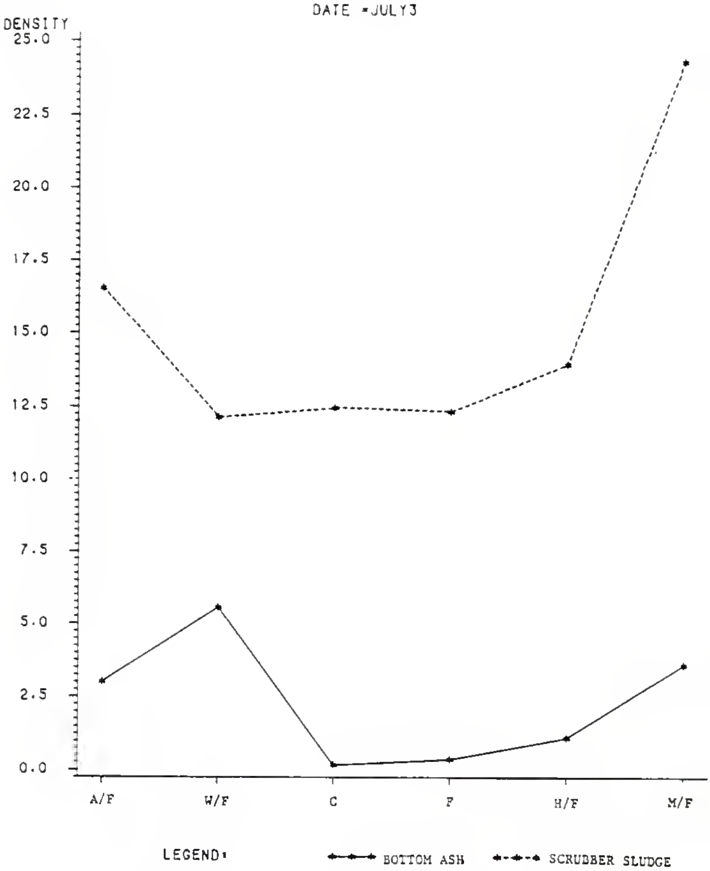
Appendix, Figure 7. Mean plant height (cm) of test species as affected by the six treatments across both substrates, measured on 3 July.



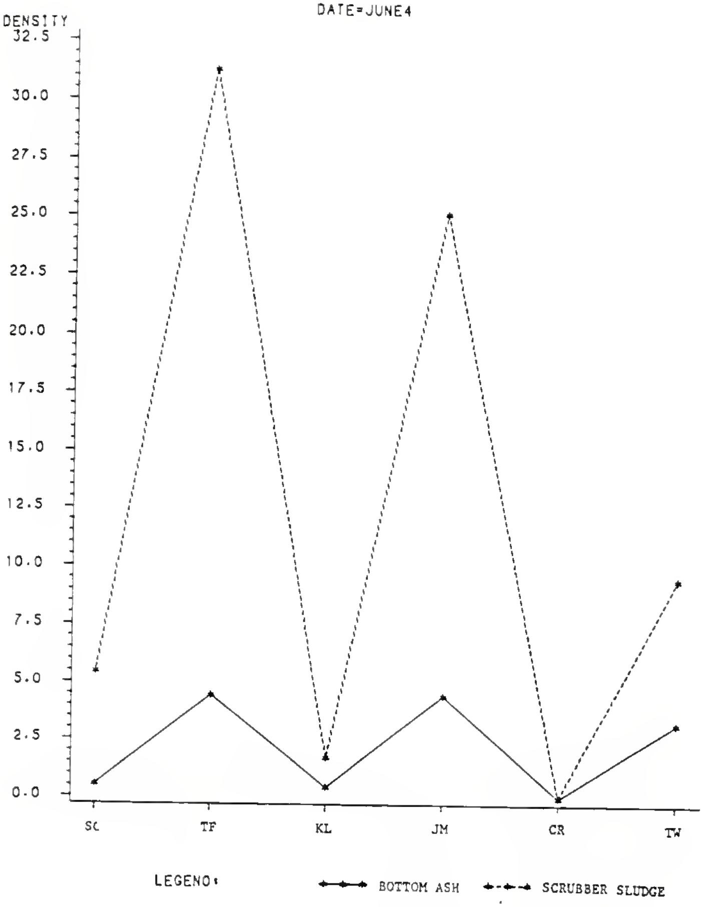
Appendix, Figure 8. Mean plant height (cm) of test species as affected by the six treatments on scrubber sludge, measured on 29 July.



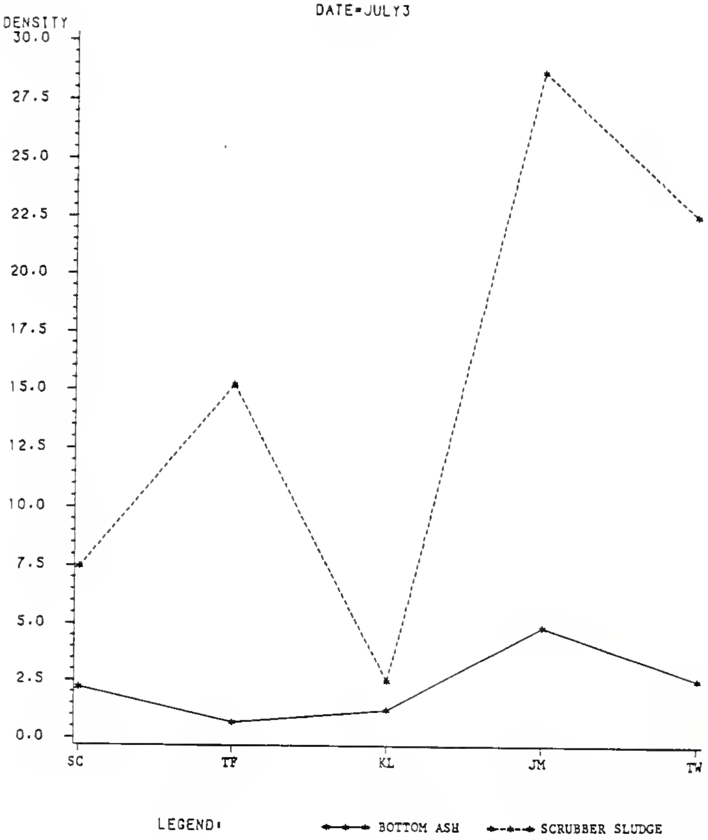
Appendix, Figure 9. Mean plant height (cm) of test species as affected by the six treatments on scrubber sludge, measured on 28 August.



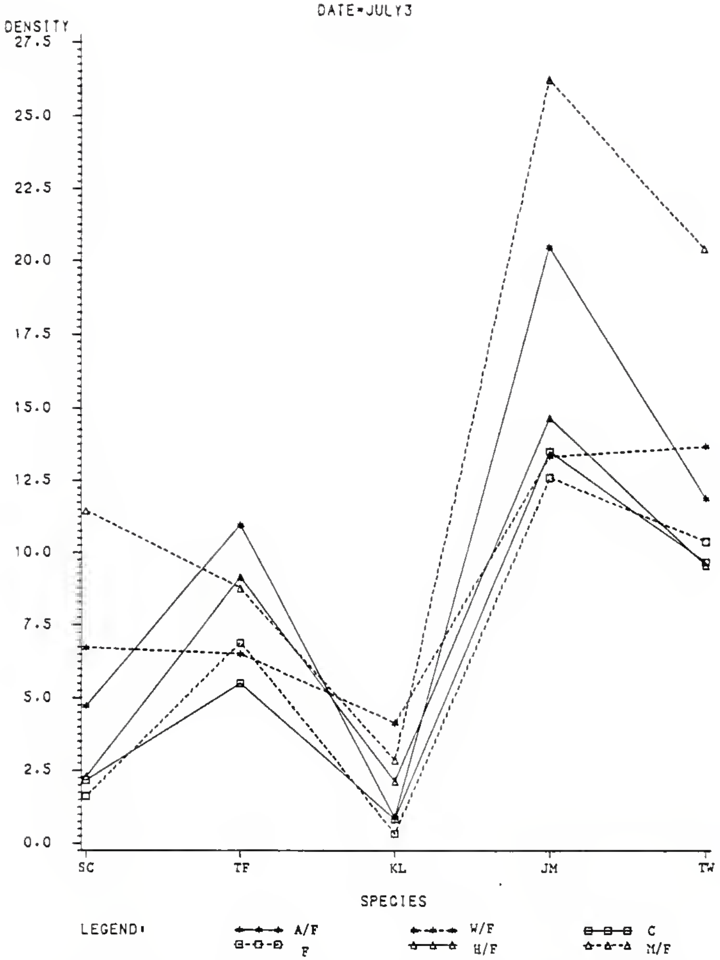
Appendix, Figure 10. Mean plant density (plants/100 cm^2) of herbaceous vegetation on each treatment, measured on 3 July on bottom ash and scrubber sludge.



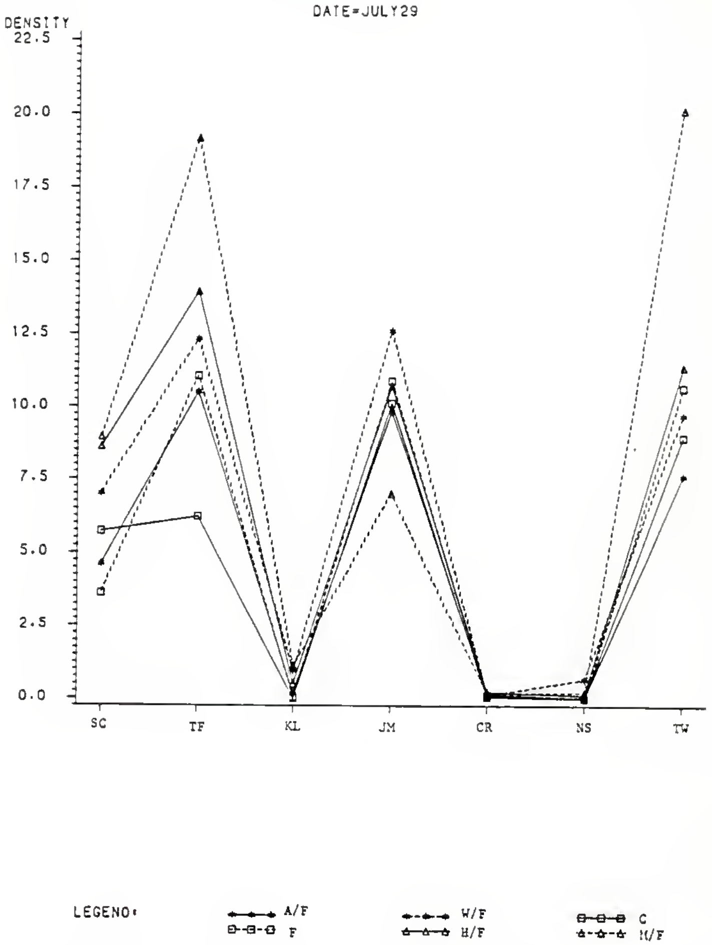
Appendix, Figure 11. Mean plant density (plants/100 cm^2) of test species across all treatments, measured on 4 June on bottom ash and scrubber sludge.



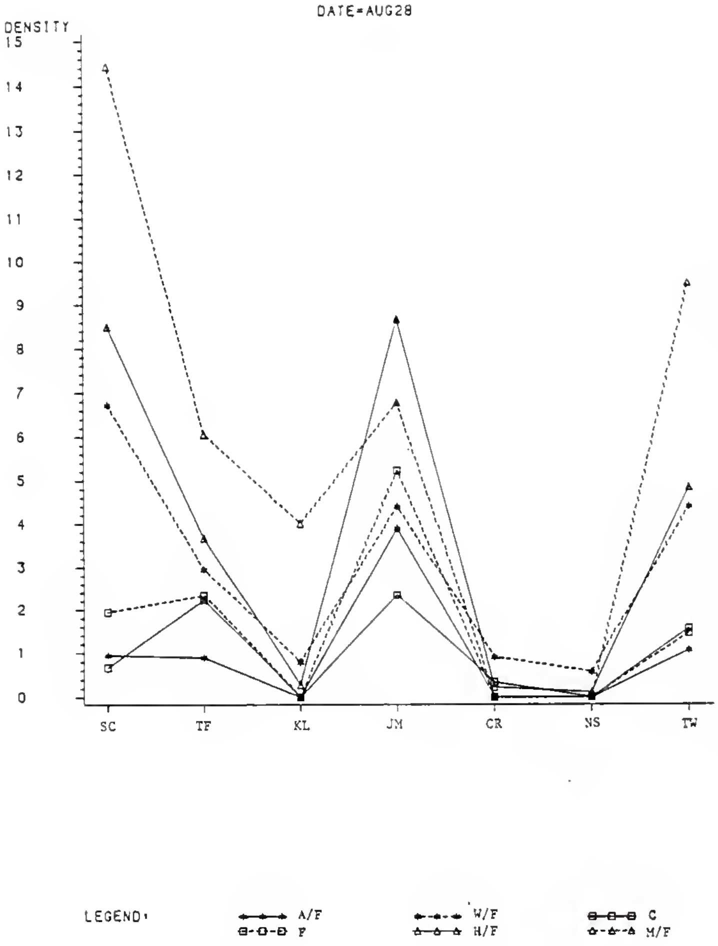
Appendix, Figure 12. Mean plant density (plants/100 cm^2) of test species across all treatments, measured on 3 July on bottom ash and scrubber sludge.



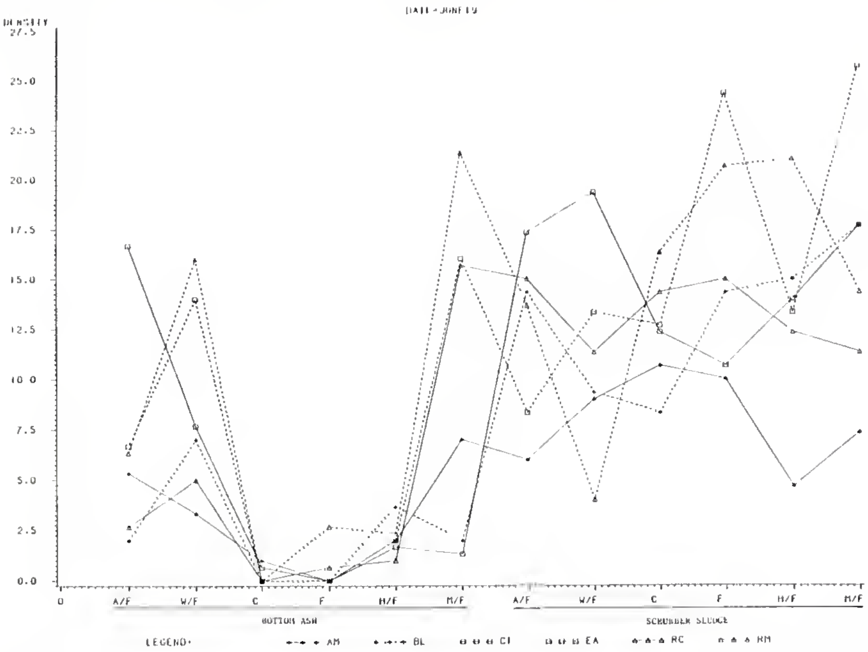
Appendix, Figure 13. Mean plant density (plants/100 cm^2) of test·species as affected by six treatments across both substrates, measured on 3 July.



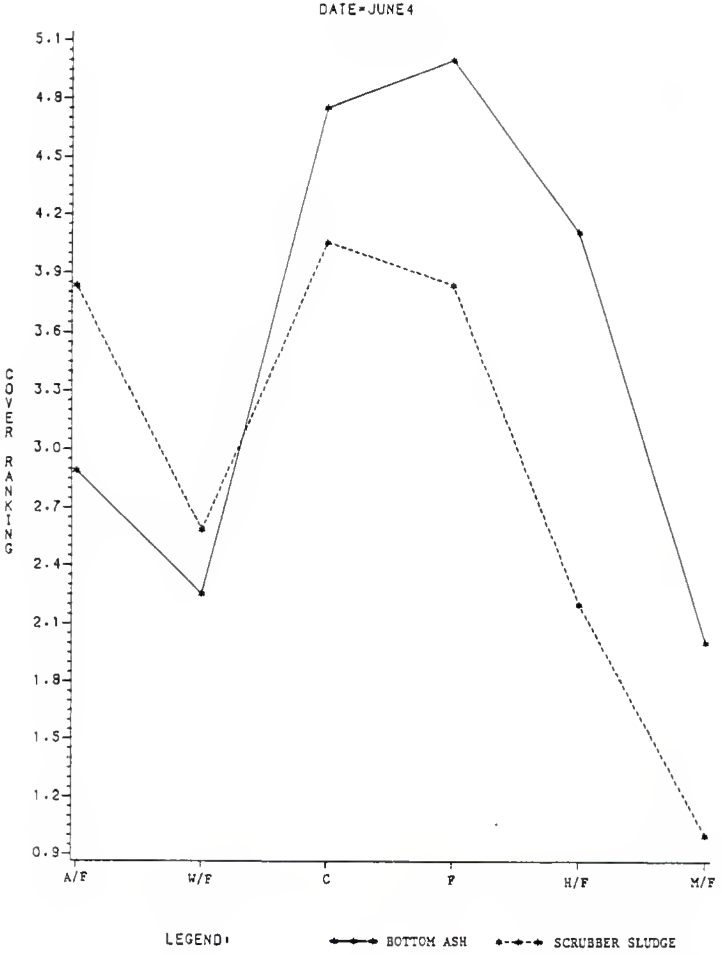
Appendix, Figure 14. Mean plant density (plants/100 cm^2) of test species as affected by the six treatments on scrubber sludge, measured on 29 July.



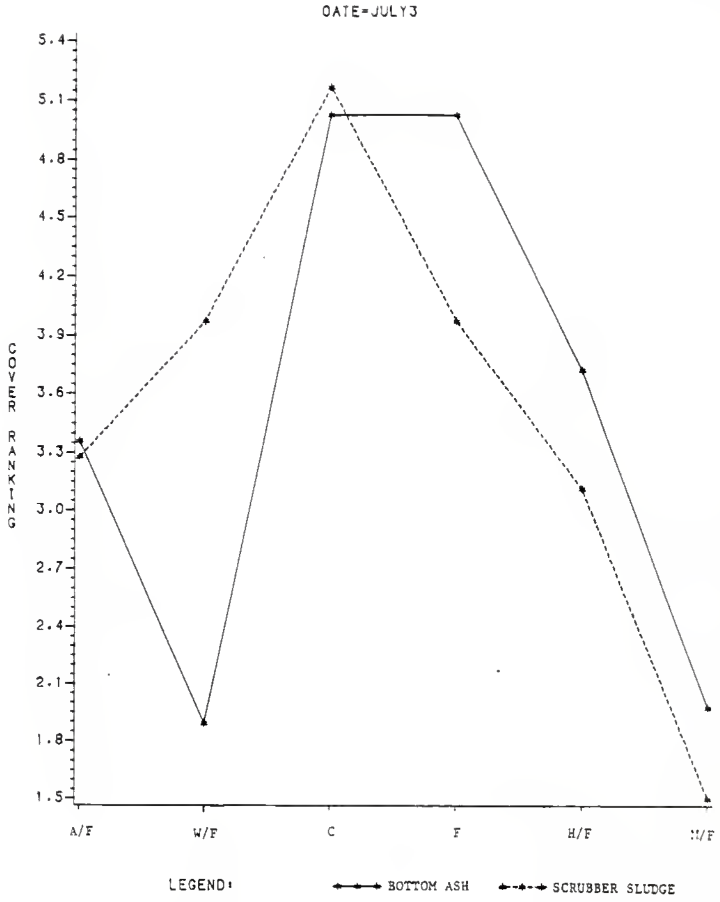
Appendix, Figure 15. Mean plant density (plants/100 cm^2) of test species as affected by the six treatments on scrubber sludge, measured on 28 August.



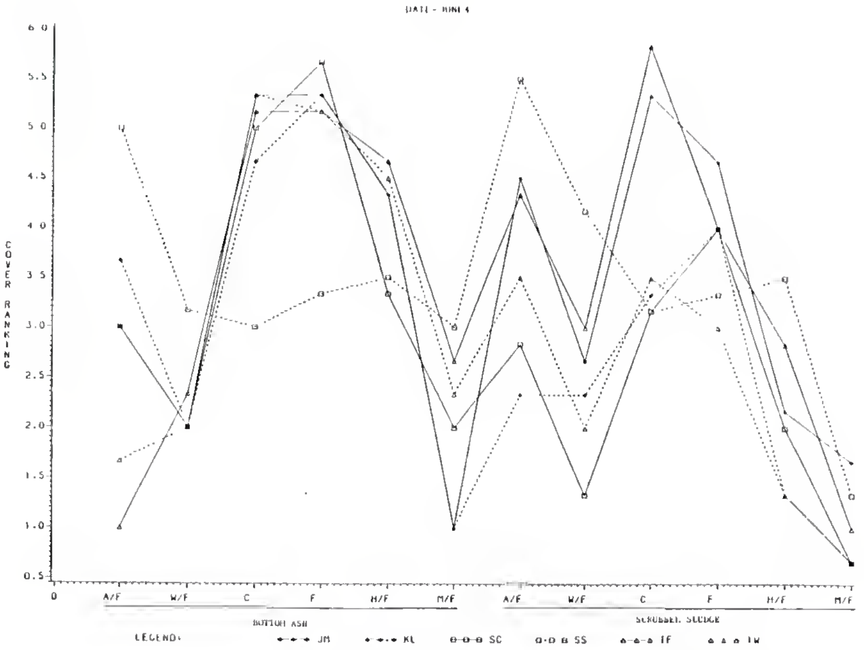
Appendix, Figure 16. Mean plant density (plants/100 cm^2) of test species as affected by the six treatments on each substrate, measured on 19 June.



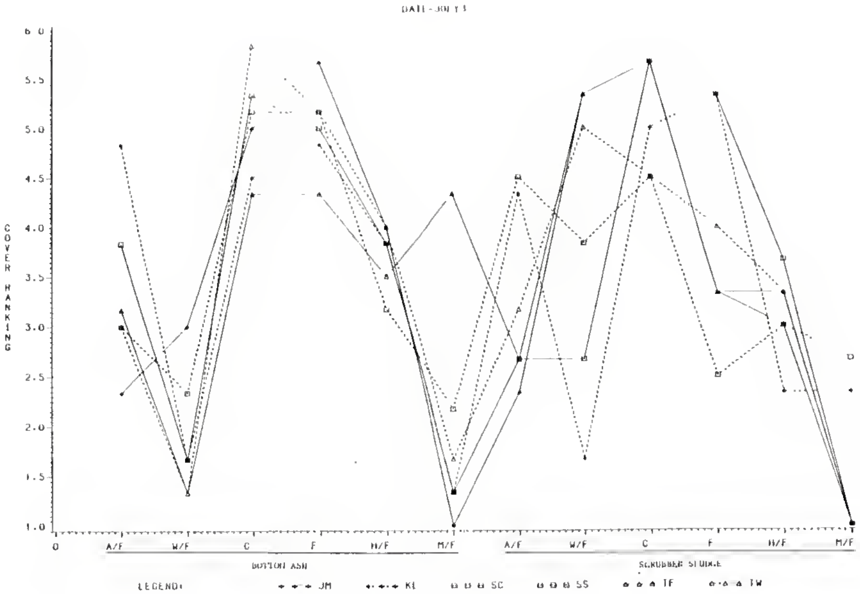
Appendix, Figure 17. Mean ground cover ranking of herbaceous vegetation on each treatment, measured on 4 June on bottom ash and scrubber sludge.



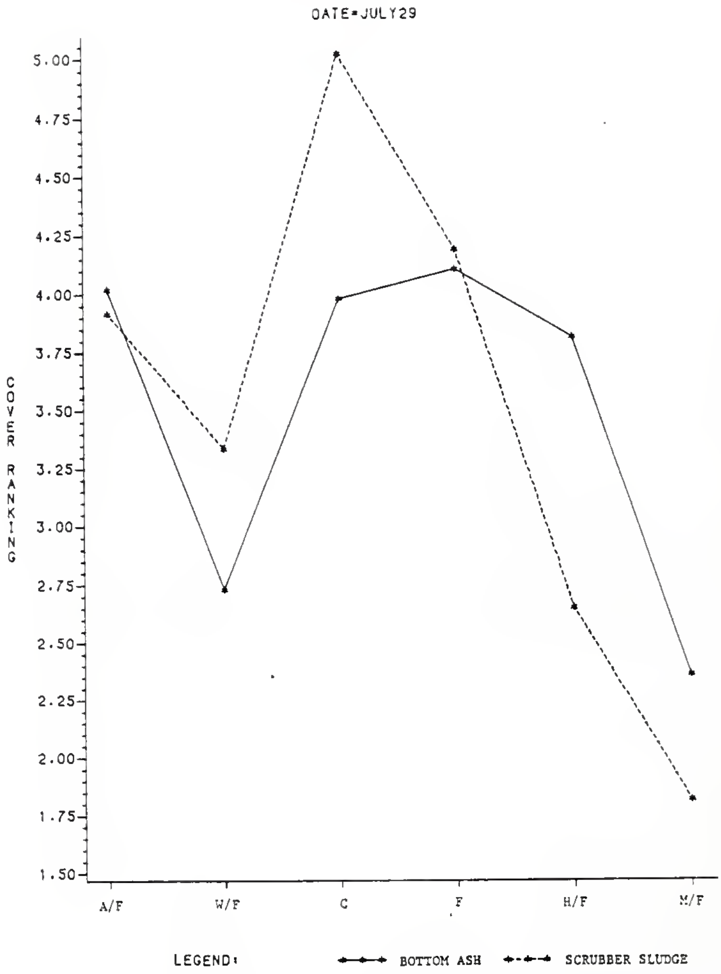
Appendix, Figure 18. Mean ground cover ranking of herbaceous vegetation on each treatment, measured on 3 July on bottom ash and scrubber sludge.



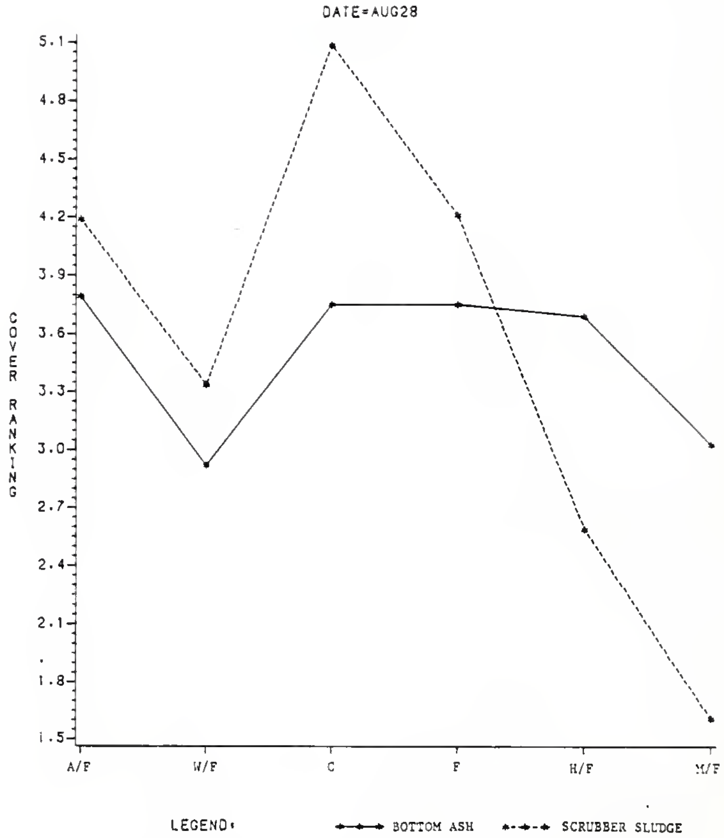
Appendix, Figure 19. Mean ground cover ranking of test species as affected by the six treatments on each substrate, measured on 4 June.



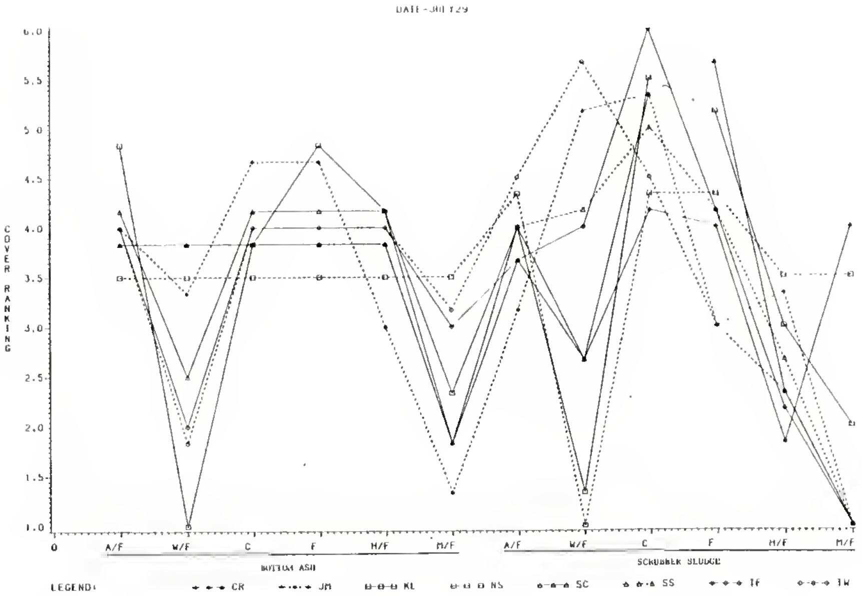
Appendix, Figure 20. Mean ground cover ranking of test species as affected by the six treatments on each substrate, measured on 3 July.



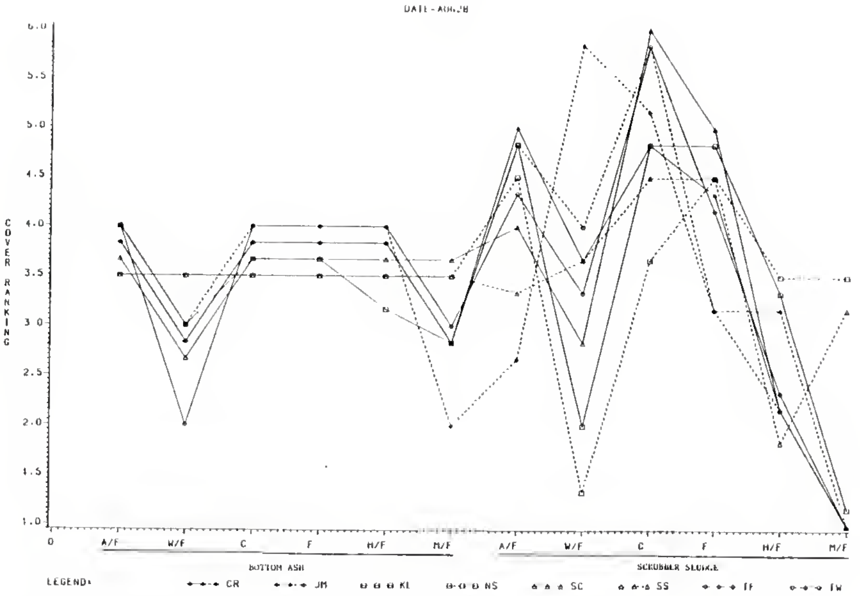
Appendix, Figure 21. Mean ground cover ranking of herbaceous vegetation on each treatment, measured on 29 July on bottom ash and scrubber sludge.



Appendix, Figure 22. Mean ground cover ranking of herbaceous vegetation on each treatment, measured on 28 August on bottom ash and scrubber sludge.



Appendix, Figure 23. Mean ground cover ranking of test species as affected by the six treatments on each substrate, measured on 29 July.



Appendix, Figure 24. Mean ground cover ranking of test species as affected by the six treatments on each substrate, measured on 28 August.

EXPERIMENTAL VEGETATION OF BOTTOM ASH AND SCRUBBER SLUDGE AT KANSAS CITY POWER & LIGHT COMPANY'S LACYGNE GENERATING STATION

by

DANIEL WAYNE MULHERN

B. S., Kansas State University, 1980

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

Division of Biology

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Manhattan, Kansas

1984

Kansas City Power & Light Company (KCP&L) operates a double-unit electricity generating station near LaCygne, Kansas, which produces bottom ash, fly ash, and scrubber sludge waste products from the combustion of both Kansas (Unit No. 1) and Wyoming (Unit No. 2) coal. Disposal of these wastes typically involves covering with soil material before planting to vegetation. In order to circumvent this costly procedure, a 3-phase study was conducted to investigate the potential for vegetative reclamation of these areas without using topsoil. This report presents the results of the first two phases of this research.

During Phase I, six test plots were established on disposal areas at the LaCygne station, three each on Unit No. 1 bottom ash and scrubber sludge. These plots were designed to test differences between the two substrates as well as the effects of six planting treatments on nine herbaceous and six woody species, with growth characteristics monitored biweekly. Each substrate was analyzed monthly for pH, organic matter, and macronutrients, and surveys were conducted to characterize the vegetation naturally invading the study sites. Ambient temperature and precipitation was recorded for the LaCygne area, comparing 1982 with normal conditions represented by a 30-year average.

To continue during Phase II, five new test plots were established to evaluate the same herbaceous species and treatments, including four additional species and two additional treatments. One plot each was established on scrubber sludge, a mixture of Unit No. 1 and Unit No. 2 bottom ash, Unit No. 2 bottom ash alone, and soil. A fifth plot on scrubber sludge was designed to further test the most successful species and treatments from Phase I. Monitoring of the six Phase I test plots was renewed during Phase II. Substrate temperature and moisture were monitored throughout the summer, and substate characteristics, invading vegetation, and ambient temperature and precipitation were recorded, as per 1982.

Due to much drier weather conditions during Phase II, comparisons between Phase I and Phase II are somewhat tenuous. Extremely poor plant growth on all substrates during Phase II resulted in nonsignificance of many analyses. Yet scrubber sludge in 1983 was identified as supporting vegetative growth superior to either bottom ash substrate or to the soil plot. Increased moisture availability was believed a primary advantage of vegetation on scrubber sludge.

Organic substrate amendments produced significantly higher growth measurements than did inorganic treatments or a control. Most species grown on manure plus fertilizer produced consistently higher values of growth measurements, with those on woodchips and hay also averaging quite high.

Six herbaceous species identified as the most successful of 13 evaluated during the two years included tall wheatgrass (Agropyron elongatum), tall fescue (Festuca arundinacea), yellow sweetclover (Melilotus officinalis), Japanese millet (Echinochloa crusgalli), annual ryegrass (Lolium multiflorum), and perennial rygrass (L. perenne). Two of the six tree species, cottonwood (Populus deltoides) and eastern red cedar (Juniperus virginiana), exhibited the highest rates of survival over a 2-year period. Cottonwood also produced significantly greater increases in growth than any other woody species.

Substrate moisture content averaged much higher in scrubber sludge than any other substrate, yet no treatment or species effects could be detected. Substrate temperature values yielded mixed results, with no clear indications of precise variable effects. Although Phase I and II were characterized by temperatures only moderately above normal during the growing season, lack of percipitation was a problem both years, particularly during Phase II.