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ASH BASIN RECLAMATION WITH FOREST TREES

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by

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ABSTRACT

An ash basin at the Savannah River Plant, Aiken, South Carolina is growing trees as well as, and with some species better than, a local soil. The basin contains ashes from a stoker-fed boiler and was last used about 12 years before the trees were planted. The concentrations of 24 chemical elements were measured in ashes, soil, and trees. The concentrations of most of the chemical elements were higher in ashes than in soil; however, with a few exceptions, these elements were less available to the trees on ashes than to the trees on soil. The trees do not show any toxicity or deficiency symptoms, but the concentration of manganese in sycamore growing on ashes indicates a possible deficiency. No concentration of an element in trees appears to be high enough to be toxic to the trees. A longer period of study will be required to determine whether the ashes can produce commercial timber, but trees can be used to stabilize ash basins and improve their appearance.

This report was submitted in fulfillment of ERDA/EPA Interagency Agreement EPA-IAGD5-B681 (Subagreement 78BCC). Work was completed as of September 30, 1977.

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INTRODUCTION

The disposal of coal ashes in the United States has consumed many hectares of land and removed it from the production of food and fiber. Although ashes have possible economic value as construction materials, their use has been very limited[1] and the land area covered by them continues to grow. Some studies have indicated that they are valuable as fertilizer for field crops,[2,3,4] but no effort was made to compare the cost of transporting the ashes and the cost of buying chemical elements in a more concentrated form. From the composition of ashes that has been reported,[5] it would seem that as a fertilizer their value is less than the cost of transporting them. Also, where ashes are sluiced from powerhouses into earthen basins, excavating a new basin may be less expensive than removing ashes from a filled basin.

Because of the scarcity of arable land in England, reclamation studies of ash basins were begun two decades ago.[5] Those studies demonstrated that with a thin soil cover some tolerant crops could be grown on pulverized fly ash. One large Savannah River Plant ash basin filled with ashes sluiced from a stoker-fed boiler has been abandoned since 1964. In 1976, a few scattered pines and willow trees were observed growing on the ashes, and most of them appeared to be healthy. Therefore, a study was begun to determine whether trees, grasses, or legumes could be grown on these ashes with only the fertilizer applications required on local agricultural soils.

The chemical elements for this study were aluminum (Al), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), selenium (Se), silver (Ag), sodium (Na), strontium (Sr), titanium (Ti), vanadium (V), and zinc (Zn).

CONCLUSIONS

An ash basin at the Savannah River Plant, Aiken, South Carolina filled with coal ashes sluiced from a stoker-fed boiler is growing trees as well as, and with some species better than, a local soil.

Survival of tree seedlings was poor under severe droughts but was much better on ashes than on soil.

The concentrations of most of the 24 chemical elements measured were higher in the ashes than those in the local soil; however, with a few exceptions, these elements were less available to the trees on ashes than to the trees on soil.

No concentration of an element in leaves of the trees appears to be high enough to be toxic to the trees. The only likely deficiency is manganese in sycamore.

A longer period of study will be required to determine the ability of ashes to produce commercial timber, but trees can be used to stabilize ash basins and to improve their appearance.

RECOMMENDATIONS

Annual observations and height or diameter measurements of trees growing on the Savannah River Plant ash basin should be made. If nutrient deficiency or toxicity symptoms develop, further studies should be made to determine the cause.

Additional information of availability to plants and leachability of chemicals in ashes is vital in selecting the most economical method of disposal that is environmentally acceptable. These studies should include various types of ashes.

METHODS

FIELD TESTS

All experiments on ashes were duplicated on soil typical of much of the Savannah River Plant site. The soil selected was Fuquay sandy loam. The top soil is 20 to 40 cm thick and underlaid with sandy clay loam. This soil will produce large loblolly pine sawlogs within 60 years. The test site was in planted pines for about 15 years, but was clean-cut in 1972 following severe ice damage.

Experimental design for the trees consists of four replications of plots 12.8 meters long and 14.9 meters wide. Four species, longleaf pine, loblolly pine, sweetgum, and sycamore, were included, and their location in each replication was randomly selected. Trees were planted 1.1 meters apart with 2.1 meters between rows. Each plot contained 91 trees. Trees on both soil and ashes were planted January 26, 1976. No amendments were utilized on either site.

A survival count of trees in each plot was made on August 24 and 25, 1976, and again on July 21 and 22, 1977. Also on July 21 and 22, 1977, the height of ten trees in each plot was measured. On August 30 and 31 and September 1, 1976, seven trees were excavated from each plot of loblolly pine, sweetgum, and sycamore. Longleaf pine was not sampled because of low survival. Leaves, stems, and roots were separated. Roots were washed in water until visually clean and then in a 1-to-10 dilution of nitric acid for 1 minute immediately followed by a thorough washing in deionized water. All samples were dried overnight in a forced-air oven at 110°C. The dried samples were weighed to determine yields and then ground to pass a 1-mm screen in preparation for chemical analyses.

A sample of soil or ashes was collected during the excavation of each tree. These samples were composited for each plot and dried overnight in a forced-air oven at 110°C. They were then sieved with a 2-mm sieve in preparation for chemical analyses.

Plots of Pensacola Bahia grass, Bermuda grass, Dallis grass, Korean lespedeza, bi-color lespedeza, serecia lespedeza, and millet were seeded on both soil and ashes on April 6 and 7, 1976. Before seeding, the sites were limed (soil only), fertilized, and disked. Good stands of all but Dallis grass had been obtained on both soil and ashes by May 20, 1976; then very unfavorable weather destroyed the stands in nearly all plots. The grass and legume experiment could not be completed.

CHEMICAL ANALYSES

Various analytical methods were required to measure the elements of interest in the different types of samples. The methods included plasma source emission spectrometry, conventional atomic absorption spectrometry, and conventional spectrophotometric methods. These methods and their applicability to the various types of samples are described below.

Plasma Source Emission Spectrometry

In plasma source emission spectrometry, an inductively coupled plasma torch provides an ultra-stable heat source for the vaporization and excitation of metallic elements in aqueous solution. Excited atoms of the respective elements subsequently emit their excitation energy as discrete wavelengths of electromagnetic radiation (light) characteristic of the emitting atom. The emitted light enters the spectrometer through a narrow slit and is separated into its component wavelengths by a diffraction grating. The diffracted light is brought to focus at the focal plane of the optical system and is detected and measured by photocells. Samples of vegetation, soil, and ashes were completely dissolved before analysis with an acid digestion bomb which provides for rapid dissolution at increased pressures. The digestion solution used in the bomb was $HF\text{-}HClO_4\text{-}HNO_3$.

Plasma source emission spectrometry analyses were provided by Barringer Research of Ontario, Canada. The following elements were determined in all samples: Ag, Al, B, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Sr, Ti, V, and Zn.

Atomic Absorption Spectrometry

In atomic absorption spectrometry, characteristic radiation of the element to be determined is produced by a hollow cathode or other type of vapor discharge lamp. Light from the lamp is passed through a flame and into a monochromator where particular wavelengths of interest are isolated and focused onto a photodetector. Metallic elements in solution are injected into the flame where they are vaporized and their compounds are dissociated into atoms. Free unexcited atoms in the flame absorb the characteristic radiation from the vapor discharge lamp and attenuate its intensity. The degree of attenuation is a function of the concentration of the element in solution.

All atomic absorption analyses were performed by Barringer Research. Samples were dissolved by the acid digestion bomb described earlier in this report, and atomic absorption analyses were made for Cd, Mo, Pb, and Se.

Conventional Spectrophotometry

In conventional spectrophotometry, the concentration of a constituent in solution is determined by measuring the relative absorbance or transmittance of light of a definite wavelength through a solution containing the constituent. At Barringer Research, arsenic was measured by a spectrophotometric procedure based on the red complex formed when arsenic is reduced to arsine. This arsenic complex is subsequently absorbed in a solution of silver diethyldithiocarbamate and pyridene.

STATISTICAL ANALYSES

The analysis of variance was used to determine significant differences between all comparisons made in this study. When a significant difference existed, a least significant difference (LSD) at the 0.05 level of significance was calculated.

RESULTS

SURVIVAL AND GROWTH OF TREES

Survival counts of trees were made twice. The first count was on August 24 and 25, 1976; the second was on July 21 and 22, 1977. Results are shown in Table 1. Survival of longleaf pine was poor on both soil and ashes. This was probably due to variation in planting depth which is critical for the species. None of the trees survived as well on soil as on ashes. Survival and growth would almost certainly have been better on all plots if rainfall had been more normal. During the 17 months that the test was in progress, three prolonged droughts occurred. The first was during February, March, and April 1976; the second during July and August 1976; and the third during April, May, June, and July 1977.

Comparative growth rates on ashes and soil were determined by weighing trees harvested during August and September 1976 for chemical analyses and by measuring the height of trees in July 1977. These results are shown in Tables 2 and 3. When a significant difference existed, a least significant difference (LSD) at the 0.05 level of significance was calculated. There was no significant difference (NSD) between the weight of trees on ashes and the weight on soil when harvested in 1976, but sweetgum and sycamore were significantly taller on ashes than on soil when measured in 1977.

Table 1. SURVIVAL OF TREE SEEDLINGS ON SOIL AND ON ASHES[a]

	Number of trees surviving per plot			
	Aug. 24-25, 1976		*July 21-11, 1977*	
Species	*Ashes*	*Soil*	*Ashes*	*Soil*
Loblolly pine	83	53	71	34
Longleaf pine	23	5	19	3
Sweetgum	71	34	63	21
Sycamore	82	55	74	31
LSD	15		14	

a. 91 seedlings were planted per plot on Jan. 26, 1976. On Aug. 30-31 and Sept. 9, 1976, seven loblolly pine, sweetgum, and sycamore were removed per plot for chemical analyses.

Table 2. WEIGHT OF TREES ON SOIL AND ON ASHES[a]

Species	*Average weight per tree, g*[b]	
	Ashes	*Soil*
Loblolly pine	5.5	4.0
Sweetgum	22.7	18.9
Sycamore	29.8	30.8
LSD	7.4	

a. Trees were harvested on Aug. 30-31 and Sept. 1, 1976. Dried overnight at 110°C.

b. Total dry weight of leaves, stems, and roots.

Table 3. HEIGHT OF TREES ON SOIL AND ON ASHES[a]

Species	*Height, cm*	
	Ashes	*Soil*
Loblolly pine	41	45
Sweetgum	52	34
Sycamore	106	75
LSD	11	

a. Measurements were made on July 22, 1977.

CHEMICAL ELEMENTS IN ASHES AND IN SOIL

As shown in Table 4, twenty-four chemical elements were measured in both ashes and soil. The concentrations of all these were higher in ashes than in soil except for Ag and Mn. Thus, the quantity of these elements in ashes is more than adequate for plant growth if these elements are available to plants. Mn is a possible exception; Ag is not essential to plant growth.[6] Some of the elements may be toxic to plants. Availability of the elements will determine whether deficiencies or toxicities exist.

Table 4. CHEMICAL ELEMENTS IN ASHES AND IN SOIL (ppm)

Element	*Ashes*	*Soil*	*LSD*
Al	30,200	13,600	2,500
Ag	1.5	1.7	0.07
As	11.5	2.0	2.3
B	86	9	17
Ba	410	80	75
Be	3.64	0.44	0.04
Ca	10,500	330	2,300
Cd	<0.1	<0.1	NSD
Co	12	8	1.4
Cu	29.0	6.3	3.8
Cr	39	25	4
Fe	14,000	4,700	900
K	9,800	7,300	970
Mg	2,400	270	195
Mn	90	270	68
Mo	6.5	2.0	0.7
Na	990	320	160
Ni	18	9	2.4
P	310	250	30
Pb	20.2	5.8	5.6
Se	3.0	1.1	1.6
Sr	250	6	29
Ti	1,650	4,000	660
V	44	20	3
Zn	19	16	3

AVAILABILITY TO TREES OF THE CHEMICAL ELEMENTS IN ASHES AND IN SOIL

There is no universally accepted method for determining the availability to plants of chemical elements in soil. All methods have limitations, and some methods are more applicable to certain elements than to others. Because of these limitations, this study assumes that the concentration of a chemical element in plants is proportional to the available concentration in soil in which the plants grow. Therefore, the concentration factor (concentration in tree organ/concentration in ashes or soil) for each element by each tree organ (leaves, stems, and roots) was calculated. A complete list of the concentration factors is given in Appendix A. There were significant differences between the organs of trees and species of trees. Detailed results are given in Appendix A. In general, except for Ag and Ti, chemical elements in ashes are less available to plants than are the same chemical elements in soil. Thus, the possibility that toxic concentrations of chemical elements will exist in the trees growing on ashes is reduced, but the possibility that deficiencies will occur is increased.

CONCENTRATION OF CHEMICAL ELEMENTS IN TREES

Twenty-four chemical elements were measured in leaves, stems, and roots of loblolly pine, sweetgum, and sycamore trees growing on ashes and on soil. These elements were Al, Ag, B, Ba, Be, Ca, Cd, Co, Cu, Cr, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Sr, Ti, V, and Zn. All results are summarized in Appendix B. There were significant differences in the concentrations of many elements in the different organs, species, and the same species of trees growing on soil or on ashes. All of these are reported in Appendix B. For our study, the most important purpose of these data is to determine whether chemical deficiencies or toxicities exist in trees growing on ashes.

CHEMICAL DEFICIENCIES OR TOXICITIES IN TREES GROWING ON ASHES

To determine whether deficiencies or toxicities exist in trees growing on ashes, only the concentrations in leaves will be considered because most deficient or toxic concentrations reported in the literature are for leaves. Also the concentrations of elements in trees growing on soil are assumed to be neither deficient nor toxic. Of the 24 chemical elements measured in trees, 10 are essential for plant growth.[6] As shown in Table 5, these chemical elements are B, Ca, Cu, Fe, K, Mg, Mn, Mo, P, and Zn. The concentration of Mn in leaves of loblolly pine, sweetgum, and sycamore, P in leaves of loblolly pine, and Mg in leaves of sycamore growing on ashes were lower than the concentrations in leaves of the same species of trees growing on soil. Thus, the concentrations of these elements may be deficient in trees growing on ashes. The concentrations of these elements that cause deficiency symptoms in loblolly pine, sweetgum, and sycamore trees are not available. Most results reported in the literature are for trees that bear edible fruit or nuts.[6] These concentrations are compared with the possible deficient concentrations in leaves of trees growing on ashes (Table 6). The most likely deficiency is Mn in sycamore trees whose leaves contained 14 ppm. This concentration is similar to deficient concentrations reported in the literature for most trees.

Table 5. CHEMICAL ELEMENTS ESSENTIAL TO PLANT GROWTH (ppm)

Element	*Needles of loblolly pine* Ashes	Soil		*Possible Deficiency*	*Leaves of sweetgum* Ashes	Soil		*Possible Deficiency*
B	25	27			48	30		
Ca	6,060	2,070	*		7,350	5,430	*	
Cu	2.1	3.0			2.0	1.9		
Fe	64	234			50	65		
K	6,650	4,900	*		6,180	6,280		
Mg	1,360	1,060			2,980	3,030		
Mn	139	681	*	X	49	567	*	X
Mo	0.69	0.63			0.31	0.35		
P	770	1,310	*	X	790	870		
Zn	25	35			8.5	13.2		

Element	*Leaves of sycamore* Ashes	Soil		*Possible Deficiency*
B	35	28	*	
Ca	13,980	5,850	*	
Cu	4.0	2.6	*	
Fe	28	48		
K	8,930	5,200	*	
Mg	1,620	1,990	*	X
Mn	14	135	*	X
Mo	1.25	0.35	*	
P	980	910		
Zn	10.1	8.4		

* Significant difference at 0.05 level of significance.

Table 6. POSSIBLE DEFICIENT CONCENTRATIONS OF CHEMICAL ELEMENTS IN TREES GROWING ON ASHES

	Experiments on ashes		*Reported in literature*		
Element	*Species*	*Conc, ppm*	*Species*	*Conc, ppm*	*Ref*
Mn	Loblolly pine	139	Apple	2-25	7
	Sweetgum	49	Apricot	9-14	
	Sycamore	14	Lemon	9-13	
			Currant	15	
			Peach	5-19	
			Pear	5-25	
			Plum	15	
			Tung	27-55	
			Walnut	5-25	
P	Loblolly pine	770	Apple	750-1000	8
			Grapefruit	400-2000	
			Lemon	600-1100	
			Orange	500-1500	
			Peach	1100	
			Tung	800	
			Walnut	650-900	
Mg	Sycamore	1620	Apple	400-500	9
			Birch	600	
			Grapefruit	130-3400	
			Orange	250-2500	
			Olive	600-3700	
			Peach	1300-3900	
			Pecan	400-1200	
			Pine	780-950	
			Plum	1400	
			Tung	500-2000	

Of the 24 elements measured in the trees, 14 could be toxic to plant growth if present in sufficient concentrations.[6] As shown in Table 7, these are Ag, Al, B, Cr, Co, Cu, Fe, Mn, Mo, Ni, Pb, Se, V, and Zn. Of these, the concentrations of Ni in leaves of loblolly pine, Cr and V in leaves of sweetgum, and Ag, B, Co, and Cu in leaves of sycamore growing on ashes are higher than the concentrations in the leaves of the same species growing on soil. Thus, the concentrations of these elements may be toxic in trees growing on ashes. Most of the concentrations in tree leaves reported to produce toxicity symptoms are for trees which produce edible fruits or nuts.[6] These concentrations are compared with possible toxic concentrations in the leaves of trees growing on ashes (Table 8). None of these elements appear to be in concentrations sufficient to be toxic.

Table 7. CHEMICAL ELEMENTS THAT CAN BE TOXIC TO PLANTS (ppm)

Element	*Needles of loblolly pine*			*Possible*	*Leaves of sweetgum*			*Possible*
	Ashes	*Soil*		*Toxicity*	*Ashes*	*Soil*		*Toxicity*
Ag	0.23	0.22			0.21	0.25		
Al	525	2,770	*		475	1,795	*	
B	25	27			48	30	*	X
Cr	4.0	4.1			6.2	4.4	*	X
Co	0.53	0.40			0.75	0.73		
Cu	2.1	3.0			2.0	1.9		
Fe	64	234			50	65		
Mn	139	681	*		49	567	*	
Ni	4.4	3.0	*	X	1.8	4.1	*	
Pb	1.5	1.8			2.0	2.6		
Se	2.3	1.3			1.5	2.5		
V	0.55	0.48			1.30	0.51	*	X
Zn	25	35			8.5	13.2		

Element	*Leaves of sycamore*			*Possible*
	Ashes	*Soil*		*Toxicity*
Ag	0.27	0.12	*	X
Al	144	308		
B	35	28	*	X
Cr	3.9	3.7		
Co	1.20	0.45	*	X
Cu	4.0	2.6	*	X
Fe	28	48		
Mn	14	135	*	
Ni	1.9	1.4		
Pb	3.4	2.8		
Se	2.5	1.8		
V	0.65	0.42		
Zn	10.1	8.4		

* Significant difference at 0.05 level of significance.

Table 8. POSSIBLE TOXIC CONCENTRATIONS OF CHEMICAL ELEMENTS IN TREES GROWING ON ASHES

	Experiments on ashes		*Reported in literature*		
Element	*Species*	*Conc, ppm*	*Species*	*Conc, ppm*	*Ref*
Ni	Loblolly pine	4.4	Citrus	55-140	10
Cr	Sweetgum	6.2	None reported for trees but 10.0 does not produce toxicity symptoms in orange.		11
V	Sweetgum	1.3	No data reported for trees, but 2.3 in soybean leaves is toxic while 1.05 in corn leaves is not.		12
Ag	Sycamore	0.27	None reported for trees but 0.7 to 1.0 does not produce toxicity symptoms in citrus.		13
B	Sycamore	35	Apricot	82	14
			Cherry	167-182	
			Grapefruit	747-1522	
			Lemon	266-1400	
			Orange	262-1679	
			Pecan	457-823	
			Plum	176	
			Prune	54-61	
			Walnut	302-1088	
Co	Sycamore	1.2	None reported in literature, but 845 does not produce toxicity symptoms in black gum.		15
Cu	Sycamore	4.0	Orange	>23	16
			Peaches	>30	

DISCUSSION

A much longer period of observation will be necessary to determine the ability of the ashes to produce marketable timber or pulpwood. As the trees become larger, several possible problems may exist.[17,18] Nitrogen may be insufficient for rapid growth. Reduced growth rates because of droughts during this study may have prevented a nitrogen deficiency. The ashes may not have sufficient cohesion to prevent large trees from falling during strong wind. Hardpans due to chemical precipitation may exist in the ashes and prevent root penetration. These hardpans could cause reduced growth and/or increase the possibility of windthrow.

The superior survival of tree seedlings on ashes as compared to soil may be due to factors that influence available moisture. Trees on ashes had almost no competition from weeds, but the soil test site was almost completely covered with weeds. Fly ash from pulverized coal has very favorable water retention characteristics.[17,18] The same may be true for ashes from stoker-fired boilers. Also, the chemical precipitation or filtration of fines may have sealed the soil below the ashes and thus produced a perched water table from which water rises by capillarity during droughts.

The apparent reduced availability to plants of chemical elements in ashes may be due to incorporation of the elements in an insoluble matrix or to high pH of the ashes.[17,18] pH of the ashes ranged between 8.9 to 9.2 as compared with 5.1 to 5.4 for the soil. These pH differences influence the availability of chemical elements to plants. The possibility of a manganese deficiency in sycamore trees growing on ashes may be due to the high pH. As weathering reduces pH of the ashes, manganese and other elements such as aluminum and boron may become available in concentrations sufficient to be toxic.[17]

From the information gained in this experiment, trees present a minimum cost means of stabilizing ash basins that have been sufficiently leached of toxic elements. No fertilizer was applied, and the only expense was tree seedlings and the planting of them.

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APPENDIX A

CONCENTRATION FACTORS FOR CHEMICAL ELEMENTS IN THE ORGANS OF TREES GROWING ON ASHES OR SOIL

This study assumes that the concentration of a chemical element in plants is proportional to the available concentration in soil in which the plants grow. The concentration factor (concentration in tree organ/concentration in ashes or soil) for each element by each tree organ (leaves, stems, and roots) was calculated as an indication of the availability of the element.

The analysis of variance was used to determine significant differences between concentration factors. The * indicates that there is a significant difference at the 0.05 level of significance between the concentration factor in the organ of the tree growing on ashes and the organ of the tree growing on soil. The following list of concentration factors shows that there were significant differences between the organs of trees and species of trees. The least significant difference (LSD) at the 0.05 level of significance can be used in comparing any two concentration factors.

		Conc factor for Ag			*Conc factor for Al*		
Species	*Organ*	*Ashes*		*Soil*	*Ashes*		*Soil*
Loblolly pine	Leaves	0.15		0.13	0.0044	*	0.0518
	Stems	0.16		0.14	0.0052	*	0.0318
	Roots	0.23		0.26	0.0017	*	0.0901
Sweetgum	Leaves	0.14		0.16	0.0040	*	0.0328
	Stems	0.14	*	0.09	0.0026		0.0182
	Roots	0.06		0.07	0.0065	*	0.0349
Sycamore	Leaves	0.18	*	0.07	0.0012		0.0057
	Stems	0.07		0.05	0.0013		0.0046
	Roots	0.06		0.05	0.0090		0.0252
LSD			0.05			0.0178	

Species	*Organ*	*Conc factor for B* *Ashes*		*Soil*	*Conc factor for Ba* *Ashes*		*Soil*
Loblolly pine	Leaves	0.30	*	2.87	0.048	*	0.291
	Stems	0.33	*	3.02	0.050	*	0.509
	Roots	0.26	*	3.14	0.044	*	0.648
Sweetgum	Leaves	0.56	*	3.29	0.125	*	0.549
	Stems	0.38	*	3.07	0.121	*	0.848
	Roots	0.37	*	2.66	0.071	*	0.463
Sycamore	Leaves	0.41	*	2.98	0.041	*	0.201
	Stems	0.23	*	2.33	0.033	*	0.512
	Roots	0.27	*	2.59	0.038	*	0.455
LSD			0.42			0.158	

Species	*Organ*	*Conc factor for Be* *Ashes*		*Soil*	*Conc factor for Ca* *Ashes*		*Soil*
Loblolly pine	Leaves	0.034	*	0.137	0.60		6.81
	Stems	0.027		0.120	0.41		5.44
	Roots	0.022	*	0.142	0.25		4.08
Sweetgum	Leaves	0.039	*	0.324	0.72	*	19.05
	Stems	0.058	*	0.301	1.24	*	21.95
	Roots	0.030	*	0.176	0.50	*	9.87
Sycamore	Leaves	0.071	*	0.330	1.37	*	20.38
	Stems	0.020		0.120	0.27	*	7.36
	Roots	0.023		0.125	0.27	*	5.70
LSD			0.103			6.42	

		Conc factor for Co			Conc factor for Cu		
Species	*Organ*	*Ashes*		*Soil*	*Ashes*		*Soil*
Loblolly pine	Leaves	0.43	*	0.50	0.071	*	0.483
	Stems	0.49		0.50	0.090	*	0.571
	Roots	0.39	*	0.65	0.184	*	0.867
Sweetgum	Leaves	0.61	*	0.88	0.070	*	0.301
	Stems	0.64	*	0.69	0.074	*	0.408
	Roots	0.33	*	0.66	0.069	*	0.318
Sycamore	Leaves	0.99	*	0.56	0.138	*	0.412
	Stems	0.45	*	0.50	0.124	*	0.607
	Roots	0.41	*	0.50	0.221	*	0.697
LSD			0.03			0.086	

		Conc factor for Cr			Conc factor for Fe		
Species	*Organ*	*Ashes*		*Soil*	*Ashes*		*Soil*
Loblolly pine	Leaves	0.104	*	0.169	0.0046	*	0.050
	Stems	0.096	*	0.159	0.0066	*	0.037
	Roots	0.109	*	0.183	0.0160	*	0.087
Sweetgum	Leaves	0.161		0.181	0.0035	*	0.014
	Stems	0.100	*	0.159	0.0039	*	0.024
	Roots	0.098	*	0.159	0.0073	*	0.041
Sycamore	Leaves	0.096	*	0.150	0.0021	*	0.010
	Stems	0.061	*	0.164	0.0019	*	0.012
	Roots	0.108		0.136	0.0653	*	0.026
LSD			0.037			0.022	

Species	*Organ*	*Conc factor for K*			*Conc factor for Mg*		
		Ashes		*Soil*	*Ashes*		*Soil*
Loblolly pine	Leaves	0.68		0.68	0.57	*	4.01
	Stems	0.50	*	0.65	0.28	*	2.91
	Roots	0.37		0.51	0.21	*	2.52
Sweetgum	Leaves	0.63	*	0.87	1.24	*	11.40
	Stems	0.56	*	0.73	0.67	*	5.24
	Roots	0.49		0.59	0.50	*	3.67
Sycamore	Leaves	0.91	*	0.73	0.67	*	7.52
	Stems	0.32		0.30	0.21	*	2.63
	Roots	0.43		0.42	0.53	*	4.80
LSD			0.15			0.56	

Species	*Organ*	*Conc factor for Mn*			*Conc factor for Mo*		
		Ashes		*Soil*	*Ashes*		*Soil*
Loblolly pine	Leaves	1.58	*	2.58	0.11	*	0.31
	Stems	0.40	*	1.20	0.09	*	0.28
	Roots	0.08	*	0.93	0.12	*	0.25
Sweetgum	Leaves	0.54	*	2.21	0.05	*	0.19
	Stems	0.12	*	1.14	0.08	*	0.19
	Roots	0.08	*	0.52	0.06	*	0.19
Sycamore	Leaves	0.16		0.51	0.20		0.19
	Stems	0.03		0.13	0.07	*	0.31
	Roots	0.07		0.12	0.10	*	0.29
LSD			0.42			0.11	

Species	*Organ*	*Conc factor for Na* *Ashes*		*Soil*	*Conc factor for Ni* *Ashes*		*Soil*
Loblolly pine	Leaves	0.14	*	0.35	0.26		0.33
	Stems	0.29	*	0.56	0.19		0.27
	Roots	0.45	*	1.41	0.15	*	0.28
Sweetgum	Leaves	0.14	*	0.35	0.11	*	0.46
	Stems	0.14	*	0.31	0.23	*	0.44
	Roots	0.15	*	0.32	0.18		0.29
Sycamore	Leaves	0.11	*	0.24	0.11		0.16
	Stems	0.09	*	0.22	0.06		0.09
	Roots	0.10	*	0.32	0.07		0.14
LSD			0.09			0.13	

Species	*Organ*	*Conc factor for P* *Ashes*		*Soil*	*Conc factor for Pb* *Ashes*		*Soil*
Loblolly pine	Leaves	2.47	*	5.29	0.075	*	0.320
	Stems	1.73	*	3.78	0.112	*	0.385
	Roots	1.55	*	3.63	0.031	*	0.262
Sweetgum	Leaves	2.57	*	3.50	0.096	*	0.456
	Stems	1.09	*	2.01	0.048	*	0.165
	Roots	1.29		1.77	0.025		0.094
Sycamore	Leaves	3.15		3.66	0.170	*	0.499
	Stems	1.78	*	2.83	0.113	*	0.335
	Roots	4.72	*	5.79	0.039		0.112
LSD			0.76			0.105	

Species	*Organ*	*Conc factor for Se* *Ashes*		*Soil*	*Conc factor for Sr* *Ashes*		*Soil*
Loblolly pine	Leaves	0.72		1.88	0.230		0.595
	Stems	0.73	*	2.91	0.143	*	1.041
	Roots	0.49		2.13	0.129	*	1.166
Sweetgum	Leaves	0.50	*	3.96	0.236	*	1.929
	Stems	0.61	*	2.79	0.515	*	3.774
	Roots	0.52	*	3.79	0.220	*	1.774
Sycamore	Leaves	0.83	*	2.88	0.462	*	3.345
	Stems	0.50		1.63	0.133	*	1.929
	Roots	0.64	*	2.67	0.135	*	1.851
LSD			1.86			0.468	

Species	*Organ*	*Conc factor for Ti* *Ashes*		*Soil*	*Conc factor for V* *Ashes*		*Soil*
Loblolly pine	Leaves	0.0013	*	0.0005	0.013	*	0.025
	Stems	0.0015	*	0.0007	0.013	*	0.028
	Roots	0.0027	*	0.0018	0.061		0.052
Sweetgum	Leaves	0.0007		0.0003	0.030		0.028
	Stems	0.0007		0.0005	0.016		0.024
	Roots	0.0025		0.0020	0.016		0.026
Sycamore	Leaves	0.0005		0.0003	0.015		0.022
	Stems	0.0003		0.0001	0.007		0.012
	Roots	0.0024	*	0.0002	0.022		0.028
LSD			0.0006			0.012	

		Conc factor for Zn		
Species	*Organ*	*Ashes*		*Soil*
Loblolly pine	Leaves	1.35	*	2.26
	Stems	0.96	*	3.17
	Roots	0.89	*	1.94
Sweetgum	Leaves	0.46		0.84
	Stems	0.49		0.64
	Roots	0.33		0.41
Sycamore	Leaves	0.54		0.54
	Stems	0.35		1.23
	Roots	0.48	*	0.72
LSD			0.72	

APPENDIX B

CHEMICAL ELEMENTS IN THE ORGANS OF TREES GROWING ON ASHES OR SOIL

This appendix lists the concentration of each chemical element in leaves, stems, and roots of each specie of trees growing on ashes and on soil. Also, listed is the concentration of each chemical element in soil and in ashes.

The analysis of variance was used to determine significant differences. The * indicates that there is a significant difference at the 0.05 level of significance between the concentration of a chemical element in an organ of a tree growing on ashes and the same organ of the same specie of tree growing on soil.

There were significant differences between the concentration of a chemical element in the different organs of trees and different species of trees. The least significant difference (LSD) at the 0.05 level of significance can be used to compare any two concentrations of a chemical element in tree organs.

		Al, ppm			*Ag, ppm*		
Species	*Organ*	*Ashes*		*Soil*	*Ashes*		*Soil*
Loblolly pine	Leaves	525	*	2,773	0.23		0.22
	Stems	617	*	1,714	0.24		0.24
	Roots	2,030	*	4,735	0.35		0.42
Sweetgum	Leaves	475	*	1,795	0.21		0.25
	Stems	309	*	976	0.21		0.15
	Roots	781	*	1,816	0.10		0.12
Sycamore	Leaves	144		308	0.27	*	0.12
	Stems	155		243	0.10		0.08
	Roots	1,091	*	1,370	0.10		0.08
LSD			204			0.08	
Ashes or soil		30,200	*	13,600	1.52	*	1.65

Species	*Organ*	*B, ppm* *Ashes*		*Soil*	*Ba, ppm* *Ashes*		*Soil*
Loblolly	Leaves	25		27	20		22
pine	Stems	27		28	21	*	39
	Roots	22	*	29	13	*	50
Sweetgum	Leaves	48	*	30	50		43
	Stems	32		28	49	*	66
	Roots	31	*	25	29		36
Sycamore	Leaves	35	*	28	17		16
	Stems	19		22	14	*	39
	Roots	22		24	15	*	34
LSD			5			10	
Ashes or soil		86	*	9	410	*	80

Species	*Organ*	*Be, ppm* *Ashes*		*Soil*	*Ca, ppm* *Ashes*		*Soil*
Loblolly	Leaves	0.13	*	0.06	6,060	*	2,070
pine	Stems	0.10	*	0.05	4,200	*	1,620
	Roots	0.08		0.06	2,560		1,230
Sweetgum	Leaves	0.14		0.14	7,350	*	5,430
	Stems	0.21	*	0.13	12,480	*	6,480
	Roots	0.11		0.08	5,080	*	2,750
Sycamore	Leaves	0.26	*	0.15	13,980	*	5,850
	Stems	0.07		0.05	2,870		2,100
	Roots	0.08		0.06	2,750		1,680
LSD			0.04			1880	
Ashes or soil		3.64		0.44	10,500	*	330

Species	*Organ*	*Cd, ppm* *Ashes*		*Soil*	*Co, ppm* *Ashes*		*Soil*
Loblolly pine	Leaves	0.053	*	0.219	0.53		0.40
	Stems	0.100	*	0.569	0.60		0.40
	Roots	0.125	*	0.531	0.48		0.53
Sweetgum	Leaves	0.031		0.031	0.75		0.73
	Stems	0.063		0.094	0.78		0.55
	Roots	0.044		0.056	0.40		0.53
Sycamore	Leaves	0.025		0.025	1.20	*	0.45
	Stems	0.025		0.044	0.55		0.40
	Roots	0.031		0.031	0.50		0.40
LSD			0.073			0.27	
Ashes or soil		<0.1		<0.1	12.3	*	8.1

Species	*Organ*	*Cr, ppm* *Ashes*		*Soil*	*Cu, ppm* *Ashes*		*Soil*
Loblolly pine	Leaves	4.0		4.1	2.1		3.0
	Stems	3.7		3.9	2.6		3.6
	Roots	5.3		4.5	5.4		5.5
Sweetgum	Leaves	6.2	*	4.4	2.0		1.9
	Stems	3.9		3.9	2.1		2.6
	Roots	3.8		3.9	2.0		2.0
Sycamore	Leaves	3.9		3.7	4.0	*	2.6
	Stems	2.6	*	3.9	3.7		3.8
	Roots	4.2		3.4	6.3	*	4.4
LSD			0.9			1.3	
Ashes or soil		39	*	25	29.0	*	6.3

Species	*Organ*	*Fe, ppm* *Ashes*		*Soil*	*K, ppm* *Ashes*		*Soil*
Loblolly	Leaves	64		234	6,650	*	4,900
pine	Stems	91		174	4,900		4,680
	Roots	223		405	3,600		3,700
Sweetgum	Leaves	50		65	6,180		6,280
	Stems	54		113	5,530		5,230
	Roots	102		188	4,780		4,230
Sycamore	Leaves	28		48	8,930	*	5,200
	Stems	26		57	3,150		2,200
	Roots	614	*	120	4,150	*	3,030
LSD			208			1010	
Ashes or soil		10,900		4,700	7,500		7,300

Species	*Organ*	*Mg, ppm* *Ashes*		*Soil*	*Mn, ppm* *Ashes*		*Soil*
Loblolly	Leaves	1,360	*	1,060	139	*	681
pine	Stems	650		770	35	*	314
	Roots	510		670	8	*	245
Sweetgum	Leaves	2,980		3,030	49	*	567
	Stems	1,620		1,390	10	*	292
	Roots	1,200		980	7	*	135
Sycamore	Leaves	1,620	*	1,990	14	*	135
	Stems	500		700	2		34
	Roots	1,270		1,280	5		32
LSD			300			64	
Ashes or soil		2,400	*	270	90	*	270

Species	*Organ*	*Mo, ppm* *Ashes*		*Soil*	*Ni, ppm* *Ashes*		*Soil*
Loblolly	Leaves	0.69		0.63	4.4		3.0
pine	Stems	0.56		0.56	3.3		2.4
	Roots	0.75	*	0.50	2.6		2.5
Sweetgum	Leaves	0.31		0.35	1.8	*	4.1
	Stems	0.50	*	0.35	3.9		3.8
	Roots	0.35		0.35	3.1		2.6
Sycamore	Leaves	1.25	*	0.35	1.9		1.4
	Stems	0.44	*	0.63	1.0		0.8
	Roots	0.63		0.56	1.1		1.2
LSD			0.11			1.3	
Ashes or soil		6.5	*	2.0	17.6	*	9.2

Species	*Organ*	*P, ppm* *Ashes*		*Soil*	*Pb, ppm* *Ashes*		*Soil*
Loblobbly	Leaves	770	*	1,310	1.5		1.8
pine	Stems	540	*	940	2.2		2.2
	Roots	480	*	900	0.6	*	1.4
Sweetgum	Leaves	790		870	2.0		2.6
	Stems	340		500	0.9		0.9
	Roots	400		440	0.5		0.6
Sycamore	Leaves	980		910	3.4		2.8
	Stems	560		700	2.2		1.9
	Roots	1,460		1,440	0.8		0.6
LSD			220			0.7	
Ashes or soil		310	*	250	20.2	*	5.8

Species	*Organ*	*Na, ppm* *Ashes*		*Soil*	*Se, ppm* *Ashes*		*Soil*
Loblolly	Leaves	138		113	2.3		1.3
pine	Stems	283	*	178	2.1		1.9
	Roots	445		455	1.5		1.4
Sweetgum	Leaves	138		110	1.5		2.5
	Stems	143		100	1.8		1.5
	Roots	145		103	1.6		2.6
Sycamore	Leaves	113	*	38	2.5		1.8
	Stems	90		70	1.4		1.1
	Roots	100		103	1.9		1.8
LSD			46				
Ashes or soil		780		320	3.0	*	1.1

Species	*Organ*	*Sr, ppm* *Ashes*		*Soil*	*Ti, ppm* *Ashes*		*Soil*
Loblolly	Leaves	56	*	4	2.1		1.9
pine	Stems	35	*	6	2.5		2.7
	Roots	32	*	7	4.5	*	7.2
Sweetgum	Leaves	58	*	12	1.2		1.3
	Stems	126	*	24	1.2		2.1
	Roots	54	*	11	4.2	*	8.2
Sycamore	Leaves	115	*	21	0.8		1.0
	Stems	33	*	12	0.6		0.5
	Roots	33	*	12	3.9	*	0.7
LSD			15			2.2	
Ashes or soil		250	*	6	1650	*	3990

Species	*Organ*	*V, ppm* Ashes		*Soil*	*Zn, ppm* Ashes		*Soil*
Loblolly pine	Leaves	0.55		0.48	25.0		35.4
	Stems	0.57		0.52	18.1	*	50.2
	Roots	2.64	*	1.02	16.7	*	30.3
Sweetgum	Leaves	1.30	*	0.51	8.5		13.2
	Stems	0.71		0.46	9.1		9.9
	Roots	0.69		0.50	6.1		6.3
Sycamore	Leaves	0.65		0.42	10.1		8.4
	Stems	0.30		0.23	6.7	*	19.3
	Roots	0.93	*	0.55	9.2		11.3
LSD			0.34			11.7	
Ashes or soil		44	*	20	19.3	*	15.7