Elemental Content of Vegetables, Grains, and Forages Field-Grown on Fly Ash Amended Soil

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Forty-one elements were determined in alfalfa, birdsfoot trefoil, brome, field corn, millet, orchard grass, sorghum, timothy, beans, cabbage, carrots, onions, potatoes, and tomatoes field-grown on soil amended with 50 tons/acre of fly ash. Arsenic, boron, magnesium, and selenium were greater in concentration in crops grown on the fly ash amended soil than control crops grown on soil alone.

Fly ash is trapped by electrostatic precipitators as pulverized coal is burned in electric power generating stations. From an estimated production of 29 million tons of the material in the United States in 1975 (Brackett, 1970), the annual yield of fly ash will expectedly increase rapidly with the rising use of coal.

Most fly ash produced in this country is disposed of in landfills. A small percentage of this total is used in concrete and ceramics (Buttermore et al., 1972), as a base material in roadbeds (National Ash Association, 1969), and as an alkaline amendment to coal mine spoils, refuse banks, and other wasteland areas to facilitate their reclamation for growing cover crops to prevent erosion (Adams et al., 1972) or forage and pasture crops (Barber, 1974). The subject of the reclamation of soils with fly ash has been reviewed by Plank and Martens (1973).

Fly ashes typically contain a broad spectrum of elements, both essential and toxic (Davison et al., 1974; von Lehmden et al., 1974; Furr et al., 1977). Element concentration in fly ash will depend on factors such as parent coal composition, combustion temperature, and trapping efficiency of the electrostatic precipitator. Owing to the large quantities of fly ash available and its content of nutrient elements, it has been investigated as a possible soil amendment in agriculture. It has been added to soils as a fertilizer source of B, Mo, P, K, and Zn for plants (Doran and Martens, 1972; Martens, 1971; Martens et al., 1970; Schnappinger et al., 1975). In a recent study, Furr et al. (1976a) determined 42 elements in a variety of vegetables and millet grown in potted soils containing fly ash. Arsenic, B, Ca, Cu, Fe, Hg, I, K, Mg, Mo, Ni, and Sb were higher in concentration in several of the crops grown on fly ash amended soil as compared to controls. Interestingly, Se concentrations in all crops grown on fly ash–soil mixtures were higher than in control crops. Furthermore, Se concentrations in the plants were approximately proportional to the rate of application of fly ash. Among other elements Se and Rb were found markedly elevated in the tissues of Guinea pigs fed yellow sweet clover grown on fly ash as 45% of their ration for 90 days as compared to control animals fed clover grown on soil (Furr et al., 1975).

In the work reported, a variety of vegetables, grains, and forage crops were grown in the field on soil which was amended with fly ash. The objective of the study was to learn the extent of absorption of a large number of essential and toxic elements by a range of field-grown edible crops when fly ash was present or absent in the plant root zone.

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EXPERIMENTAL SECTION

In June, 1976, two plots each with dimensions of 3.05 × 6.1 m were selected for plant growth studies in Ithaca, New York. The soil was an Arkport fine sandy loam (coarse-loamy, mixed mesic Psammetic hapludalfs), pH 6.0, and with a cation-exchange capacity of 13.5 mequiv/100 g. The soil contained 75% sand, 20% silt, 3% clay, and 2% organic matter. Fly ash was obtained as freshly produced material by Milliken Station, a coal-burning electric power-generating plant located in Lansing, New York, about 32.2 km north of Ithaca on the eastern shore of Cayuga Lake. This power plant burns about 2270 metric tons of coal/day, yielding about 454 metric tons of fly ash daily. The pH of the fly ash was 5.0. The fly ash produced by this power plant results from combustion of about 80 to 90% Pennsylvania, 10% West Virginia, and 1% each of Maryland and Ohio coal. Five percent (w/w) fly ash was spread and thoroughly mixed into the soil of one of the plots with a rotary cultivator. This was equivalent to 45.4 metric tons dry weight of fly ash applied per acre using the standard agronomic estimate of 909 091 kg dry weight of soil in an acre furrow slice. The pH of the resulting fly ash–soil mixture was 5.9. The other plot, untreated with fly ash, served as the control. Each plot was fertilized by thoroughly mixing 4.54 kg of 15–15–15% N–P_2O_5–K_2O into the soil at the time of plot preparation and cultivation.

The crops planted were: "Tendercrop" bush bean (*Phaseolis vulgaris*), "Golden Acre" cabbage (*Brassica oleracea* var. *capitata*), "Scarlet Nantes" carrot (*Daucus carota* var. *sativa*), "Cornell 110" field corn (*Zea mays*), Japanese millet (*Echinochloa crusgalli* var. *frumentacea*), "1620 Pedro" onion (*Illium cepa*), "Katahdin" potato (*Solanum tuberosum*), "Sudax" Sudan grass (*Sorghum sudanense*)–sorghum (*Sorghum bicolor*) hybrid, and "Supersonic" tomato (*Lycopersicon esculentum*). The crops were seeded (cabbage, onions, and tomatoes were planted as transplants) in rows 3.05 m long and cultivated as necessary. Rainfall from the time of plot preparation through harvest of all crops totalled 49 cm. No supplemental irrigation was necessary.

At maturity the crops were totally harvested. Only the edible portions of the vegetables were taken for analysis. With corn, millet, and sorghum, the plants were separated into grain as one sample and combined stems and leaves as the other. All crops were thoroughly rinsed with water to remove adhering dust. Carrots, onions, and potatoes were brushed, rinsed, and peeled. The respective plant portions from the entire yield of each crop were then combined, subdivided by homogenizing in a blender, chopping in a food cutter, or milling in the case of dry material. The crop material was mixed by quartering on plastic, subsampled, freeze-dried in polystyrene containers,

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Table I. Elemental Analysis of Soil and Fly Ash

Element	Element concn, ppm, dry weight	
	Soil	Fly ash
Al	39960	93890
As	8.8	23
Au		0.08
B	10	14
Ba	336	599
Br	2.6	1.7
Ca	4200	23670
Cd	0.2	0.4
Ce	62	178
Cl	10220	2481
Co	7.3	33
Cr	37	125
Cs	1.7	9.9
Cu	1727	395
Eu	1.0	2.6
Fe	21080	68770
Hf	12	5.4
Hg	0.5	1.3
I	1.2	1.4
K	20090	25100
La	21	63
Lu	0.3	1.1
Mg	10610	64510
Mn	410	219
Mo	2.2	2.9
Na	7161	1933
Rb	78	158
Sb	0.7	4.3
Sc	4.5	17
Se	1.5	5.1
Sm	17.1	60
Sn	575	29
Sr		2100
Ta	0.5	1.2
Th	11	33
Ti	1884	7453
U	2.8	5.9
V	70	170
W	1.3	4.1
Yb	2.0	3.8
Zn	38	118

and again subsampled for analysis. Prior to soil application the total fly ash amendment was mixed by quartering and subsampled. The soil was sampled from 30 stations selected at random in the plots. These portions of soil were mixed and subsampled for analysis.

Following fall harvest the field plots were again tilled and five grass and legume forage crops were planted. The crops were "Honeyoye" alfalfa (*Medicago sativa*), "Empire" birdsfoot trefoil (*Lotus corniculatus*), brome (*Bromus* cv. "*Saratoga*"), "Penn Mead" orchard grass (*Dactylis glomerata*), and "Climax" timothy (*Phleum praetense*). Each crop was planted in an area with dimensions of 0.91 × 3.05 m in each of the plots. At maturity the following summer, the crops were harvested, dried, milled, mixed, and subsampled for analysis.

Thirty-nine elements were determined in the nine crops (vegetables, corn, millet, and sorghum) first grown on the plots using nondestructive neutron activation analysis as previously described (Furr et al., 1976b).

Selenium was determined by a modification of the method of Olson (1969) employing wet digestion of the sample and measurement of the fluorescence of piazselenol resulting from the reaction of selenium with 2,3-diaminonaphthalene. Boron was determined by the curcumin spectrophotometric procedure (Greweling, 1966). Arsenic was determined by dry ashing (Evans and Bandemer, 1954) the samples, distilling arsine, and analysis using the silver diethyldithiocarbamate spectrophotometric procedure (Fisher Scientific Co., 1960). Only arsenic, boron, and selenium were determined in the five grass and legume crops grown. Soil reaction (pH) was determined by the method of Peech et al. (1953).

RESULTS AND DISCUSSION

Table I lists the results of total elemental analysis of the soil and fly ash. Thirty-three elements were higher in total concentration in the fly ash than in the soil. The growth of plants on the fly ash treated and control plots appeared comparable and was excellent. In Table II are given the concentrations of those elements (As, B, Mg, and Se) which were found most consistently elevated in the crops grown on the fly ash amended soil as compared to the control crops. Wilcoxon's signed rank test (Steel and Torrie, 1960) for detecting real differences between paired treatments showed the concentrations of As, B, Mg, and Se to be significantly higher (As, B, and Se ($p < 0.01$); Mg ($p < 0.02$)) in the fly ash grown crops than the corresponding controls. Arsenic, B, Mg, and Se were also found at higher concentrations in vegetables grown on potted soil amended with fly ash as compared to soil (fine sandy loam) alone (Furr et al., 1976a). Arsenic, B, and Se were found higher

Table II. Element Concentrations (Parts per Million Dry Weight) in Edible Portions of Crops Field-Grown on Soil Amended with 50 Tons/Acre of Coal Fly Ash and on Soil Alone (Control)

Crop	Arsenic[a]		Boron[a]		Magnesium[a]		Selenium[a]	
	Control	Fly ash	Control	Fly ash	Control	Fly ash	Control	Fly ash
Alfalfa	0.6	0.4	34	40			0.07	0.13
Birdsfoot trefoil	0.2	0.8	35	37			0.09	0.22
Brome	0.2	0.4	14	18			0.12	0.28
Corn (grain)	0.1	0.2	0.7	0.2	1258	1511	0.02	0.05
Corn (foliage)	0.4	0.5	11	9.5	1041	899	0.03	0.07
Millet (grain)	0.03	0.1	3.0	3.0	2164	2149	0.05	0.16
Millet (foliage)	0.2	0.5	8.7	11	4263	4950	0.04	0.13
Orchard grass	0.2	1.0	9.0	25			0.11	0.50
Sorghum (grain)	0.1	0.3	8.2	8.2	1778	1900	0.06	0.08
Sorghum (foliage)	0.1	0.5	8.7	7.7	1790	2636	0.03	0.04
Timothy	0.2	0.4	14	24			0.08	0.27
Bean	0.1	0.03	22	26	1762	2271	0.02	0.07
Cabbage	0.2	0.3	27	44	2469	2859	0.07	0.20
Carrot	0.05	0.2	15	20	1203	1446	0.02	0.06
Onion	0.1	0.3	18	20	835	941	0.02	0.21
Potato	0.1	0.1	4.2	4.5	1053	1055	0.02	0.03
Tomato	0.03	0.1	8.7	12	1856	1940	0.01	0.02

[a] Differences were highly significant for As, B, Se ($p < 0.01$) and Mg ($p < 0.02$) using Wilcoxon's signed rank test.

in cabbage grown on a silt loam soil amended at 7% (w/w) with fly ashes from any of 16 different states (Furr et al., 1977).

The question of whether fly ash can ever be recommended as a beneficial soil amendment in agriculture deserves discussion. On the positive side, fly ash which is presently in abundant supply can be used to increase the concentration of certain desirable elements in plants if the composition of the fly ash is known and the rate of application is controlled. Boron and selenium, essential elements for plants and animals, respectively, are deficient in many soils. As illustrated in this study, amending soil with fly ash can result in raising the boron and selenium concentration in plants. Certain alkaline fly ashes can be used to neutralize and reclaim acid soils (Adams et al., 1972). Based on human and animal toxicity of arsenic compounds (U.S. Department Health, Education and Welfare, 1976), the increase in the arsenic content of plants (up to about 0.1 ppm As on a fresh weight basis) due to the fly ash amendment in this study would appear to be below a toxicologically significant level.

On the negative side fly ashes vary greatly in elemental composition and acidity. Their pH may range from 4 to 11 (Furr et al., 1977). Amending soils with highly alkaline fly ashes could raise the soil pH sufficiently to cause a deficiency of elements such as iron, copper, zinc, and manganese in plants. High rates of application of fly ash can also result in boron toxicity to sensitive plants (Barber, 1974). Furthermore, although fly ash amendments may not affect the physical properties of certain soils (Jones and Amos, 1976), a pronounced cementing effect resulted from the addition of fly ash to the soil in this study, probably accentuated by the low content of soil organic matter. Finally, owing to its bulk density the cost of hauling fly ash would be considerable if distances were great.

In conclusion, the successful agricultural use of fly ash would require careful analytical monitoring of its composition and subsequent controlled rate of application to soil. The effect of fly ashes of varying chemical composition applied once or successively on different soil types as regards element uptake by plants, effects on soil physical properties, and chemical composition of soil leachates remains to be determined.

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