DIRECT REVEGETATION OF FLY ASH--A GREENHOUSE STUDY[1]

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Abstract: Two greenhouse experiments were conducted on fly ash to determine if such material could be vegetated without covering it with soil, in anticipation of a field research study. Corn was used as a test crop in both studies. In the first study, very poor growth was obtained. In spite of high soil test levels for P, plants exhibited extreme P deficiencies. This was intensified when K was applied. Plants appeared normal for the first 3 weeks, then rapidly exhibited deficiency symptoms with total P often <0.1 ppm. In the second experiment, the same fly ash source was mixed with either sewage sludge or soil or both and three rates of each soil and sewage sludge were used with a fly ash control. Unlike the first experiment, only one rate of P and K was used. The plants of the control were similar to those in the first experiment; however, both sewage sludge and soil amendments produced significantly greater yields as well as reduced P deficiency symptoms. After the second crop, K was applied to all pots because plant tissue levels were approaching deficient levels. By the fourth crop, plants began to exhibit low P levels and were approaching a critical level in spite of the fact soil test levels remained high. It is apparent that the soil tests were extracting greater levels of P than were available to the corn test crop.

Additional Key Words: phosphorus, soil test, Bray-1P, Mehlich III-P.

Introduction

Environmentally acceptable, cost-effective disposal of large quantities of fly ash produced by coal-burning power plants poses a significant challenge, especially in view of changes in the regulations associated with landfills. When landfill closure requires a 4-ft soil cover, removal of adjacent soils may cause significant environmental problems, with impacts approaching those of the landfill itself.

Direct revegetation of fly ash disposal sites would reduce land disturbances, provided suitable methods can be developed. Significant amounts of information are available in the literature that indicate direct seeding of fly ash may offer a successful alternative to current and proposed practices.

As a result, a demonstration study was conducted on a fly ash disposal site by East Kentucky Power Cooperative (EKPC). Questions were raised concerning the obvious P deficiency symptoms observed for some plant species in spite of the very high soil test levels for this element. In an attempt to answer this question, a greenhouse study was initiated. This first experiment had two main objectives: determining (1) if the P soil tests were valid, and (2) if the apparent differences could be corrected by adding P fertilizers, in spite of high soil test levels.

Literature Review

A feasibility study conducted in 1976 by the U.S. Environmental Protection Agency (Dougherty and Holzen) concluded pulverized fuel fly ash could be used effectively to produce a soil cover capable of sustaining grasses and legumes on regraded acidic surface mine spoils. Such reclamation was found effective in producing usable land and in improving water quality.

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[1]Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

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Proceedings America Society of Mining and Reclamation, 1994 pp 159-165
DOI: 10.21000/JASMR94030159

https://doi.org/10.21000/JASMR94030159

Wendell et al. (1992) conducted a 3-year study to examine the suitability of lime-stabilized fly ash scrubber sludge (FASS) in surface mine reclamation. The primary concern of using FASS in row crop production was the effect of B concentrations on plants that could reach toxicity levels with subsequent yield reduction.

In an associated study using the same FASS, Zhang et al. (1992) evaluated the impact of this soil amendment upon the growth of legumes and grasses. An addition of 2.5% to 5.0% FASS by weight to an acidic topsoil produced an increase in soil pH and salt level, and an associated increase in yield for alfalfa, birdsfoot trefoil, and tall fescue. FASS was contributed to improved soil water retention, supplied supplemental Ca, S, Cl, B, Mo, and Mn, neutralization of acidity, and increased plant yields.

Growth and elemental analysis studies were conducted on trees growing on abandoned coal fly ash basins (Carlson and Adriano 1991). Trees found to contain the greatest trace element concentrations also attained the greatest height and diameter growth. Size differences between trees grown in soil and fly ashes were attributed to increased water-holding capacity in the fly ash substrate. Raw fly ash from bituminous coal-fired power plants was used by Adams et al. (1971) in the reclamation of coal surface-mined lands. Fly ash amendment was found to increase pH and improve soil texture and available water-holding capacity. Of the grasses and legumes planted, Kentucky 31 tall fescue, rye, and red top grasses, and birdsfoot trefoil survived the best.

Fly ashes have been applied in the reclamation of abandoned mine spoils to produce agricultural crops (Ghazi et al. 1987). Excellent yields of alfalfa were produced when as much as 350 t/a of fly ash had been applied, as long as adequate P was supplied to these acidic spoils. In this case, fly ashes were serving as a liming agent as well as a source of some plant nutrients.

Usually fly ash contains virtually no N and has little plant-available P (Martens 1971, Adriano et al. 1978). Appropriate fertilizer rates to accommodate these deficiencies would be indicated.

Oyler (1989) tested the use of sewage sludge, fly ash, lime, and potash in mixtures to vegetate areas containing high concentrations of particular metals in the soil. A 1:1 ratio of sludge to fly ash was found to be most successful. The metals-tolerant herbaceous species used were switchgrass, big bluestem, tall fescue, birdsfoot trefoil, flatpea, perennial ryegrass, and intermediate wheatgrass.

Francis et al. (1985) found that ryegrass grown in unlimed and unfertilized coal gasification fly ash and soil mixtures contained very high concentrations of Al, B, Cd, Co, Mo, Ni, and Zn, many of which were considered to be phytotoxic. However, it was demonstrated that with proper liming and fertilizing practices, risk of transport of these metals through the food chain was eliminated. Similar conclusions were reported by Keefer and Singh (1985).

In a similar study, Sopper and McMahon (1988) used mixtures of sludge and fly ash to successfully aid in the establishment of grasses and legumes in soils highly contaminated from operations of a zinc smelter. A 2:1 ratio of sludge to fly ash resulted in the highest average percent vegetation cover and dry matter production. The seed mixture exhibiting the best performance was orchardgrass, tall fescue, and crown vetch.

Methods and Materials

Greenhouse Experiment I

Several kilograms of fly ash, which had been previously pumped to sediment ponds, were collected at the John Sherman Cooper Plant near Somerset, KY. At this plant, two ponds exist, and ash samples were collected from both. One pond contains old ashes and was filled to capacity at least 10 years ago. The second pond was currently receiving ashes. These two bulk samples were dried, sieved through a 2-mm screen, and mixed to provide a uniform sample.

Pots large enough to hold 2 kg each were lined with plastic. Three separate studies were conducted, two using ashes from each pond and the third using fly ash collected directly from the precipitators at the power plant. A 3 x 3 factorial design was used in each case.

Three rates of P and K were chosen, representing 0, 56, and 112 kg/ha for P, and 0, 140, and 280 kg/ha for K, assuming a furrow slice weighs 2 x 10^6 kg. For each study, three replications were used. Nitrogen was initially added to each pot at a rate equivalent to 200 kg N per hectare. The fertilizers were mixed with the ashes and placed in the pots. Midway during the growing period, week 3, an additional application equivalent to 75 kg N per hectare was applied.

Deionized water was added to raise the ashes to field capacity or about 38% water on a dry weight basis. In each pot, holes were dug 2 cm deep, six corn seeds were placed in a symmetrical pattern and covered. Corn plants were grown 6 weeks and harvested. A second cropping was started after a 100-g portion of ashes was removed from each pot for soil testing. This process was repeated two more times.

The plant tissue was dried at 60°C, ground to <10 mesh, and analyzed using standard wet-ash for P, K, Ca, Mg, and Na, and micro-Kjeldahl N tests published in American Society Agronomy (ASA) Monograph 9. The ash samples were analyzed for available P by both the Bray-1P and Mehlich III extracting solutions. Exchangeable Ca, K, Na, and Mg were also determined using methods in ASA Monograph 9. The texture, available water-holding capacity (AWC), and pH were determined by commonly used methods described in ASA Monograph 9.

Greenhouse Experiment II

In general, the procedures were the same, except in this case ashes from only the old pond were used. The main treatments were equivalent to 0, 18, and 30 Mg/ha of sewage sludge added to the following: (1) a fly ash control, (2) a 25:75 mixture of subsoil to fly ash, and (3) a 50:50 mixture of subsoil to fly ash. The subsoil was obtained from a stockpile of unknown source adjacent to the old ash pond; it is believed that it had been removed during the construction of the pond and was likely from the Pembroke soil (fine-silty, mixed, mesic Mollic Paleudalfs). If soil was to be required for covering the ash pond, it is likely that at least some of it will come from this stockpile.

Results and Discussion

Greenhouse Experiment I

Data for selected physical and chemical properties are given in table 1 for the "old" and "new" fly ashes. The "new" ashes had a lower AWC because they had a higher sand content. This is most likely a function of the location within the respective ponds from which the ashes were collected with respect to the outlet of the pipe carrying the ashes. Both fly ash and bottom ashes were pumped into both of these ponds. The "new" ashes had higher nutrient levels of P, K, Mg, and Ca. Any value for P >68 kg/ha would be considered high had this been an agricultural soil. In spite of these high P levels, the plants were experiencing severe P deficiencies. For that reason, the Mehlich III P test was used to test P availability. A large discrepancy exists between the two methods for P. In fact the Mehlich III-P was proportionally higher and exceeded the upper detection limit (224 kg/ha) without dilution of the extract. Since the Mehlich III extract was measured with an inductively coupled plasma emission spectrometer (ICP), it is unlikely that this high P value would represent soluble silica from the ashes as was originally believed to be the case for the Bray-1P measurement. For Bray-1P, an ammonium molybdate was used to determine P, under some conditions it can also react with Si to give erroneous values.

The average biomass produced in each of the four growth periods from both of the P and K treatment combinations for fly ashes from the "old" sediment pond are given in table 2. Similar trends for corn growth were obtained for all four harvest dates. The largest response was for added K, especially between the 0 and 140 kg/ha, with little if any additional yield response between 140 and 280 kg/ha. The response to K increased somewhat for each rate of applied P, with the largest values occurring for the 100 kg/ha P and 280 kg/ha K treatments three of the four harvests.

Little if any response in yield was observed for applied P at any K rate for the first harvest. However, there appeared to be some response to P for subsequent harvests, at least for those treatments that also received K. In other words, there was an interaction between P and K. Although yield responses to P and K were obtained, yields were much lower than normal (as compared with a response commonly observed for agricultural soils).

Table 1. Physical and Chemical Properties of Fly Ash Samples.

Sample	AWC[3]	Texture Sand	Silt	Clay	
	%	---------- % ----------			
Old Ashes	40.0	16.1	82.7	1.2	
New Ashes	27.7	35.9	60.3	3.8	
	Bray-1P	P[4]	K	Ca	Mg	pH

Sample	Bray-1P	P[4]	K	Ca	Mg	pH
	------------- kg/ha ------------					
Old Ashes	57.3	224+	87	683	53	6.8
New Ashes	96.3	224+	126	974	87	6.7

[3]AWC = available water-holding capacity, i.e., field capacity - wilting point.
[4] P = Mehlich III available phosphorus.

Table 2. Yield of corn (forage) in response to P and K additions to fly ash from old pond.

Treatment P	K	Harvest Date 1	2	3	4
		------ g dry wt/treatment ------			
0	0	2.92	3.00	1.76	2.47
0	140	3.99	5.33	6.45	4.32
0	280	4.03	5.16	6.93	4.90
50	0	2.96	2.80	2.39	1.85
50	140	4.12	6.77	7.70	5.99
50	280	4.38	7.37	9.87	7.83
100	0	2.88	2.93	2.15	2.24
100	140	4.24	6.46	8.17	6.88
100	280	5.02	7.06	12.30	9.04

Severe P deficiency symptoms were observed for all treatments in which K was applied. The corn plants had stopped growing the last week before harvest and by that time, most of the leaves had turned purple. The 0 K treatments had much smaller plants, as indicated by the yield values, and all plants were yellow, indicative of K deficiency. These observations were confirmed by plant tissue analyses for P and K as given in table 3.

The concentration of K was slightly below normal for the 0 K treatment, but it was within the normal range for higher K rates. The corn plants responded to applied K, and it did not appear that an interaction existed between P and K as was observed for forage yields reported in table 2.

Since few positive conclusions could be drawn from the first greenhouse study, the second experiment was developed, the data of which are given in the following section.

Greenhouse Experiment II

Data for biomass produced from this study are given in table 4. The first harvest date had the greatest biomass, especially for the 100% and 50% fly ash treatments, as compared with subsequent harvests. The biomass was about 2 times that for later harvests. There was a trend for increased biomass as a function of sewage sludge rate for the first harvest, but this did not seem to be the case for later harvests. It is unlikely that N could have been limited in any growth period.

Table 3. P and K levels of corn forage in response to P and K additions to fly ash from the old pond.

Treatment P	K	Harvest Date 1	2	3	4
		P in plant,%			
0	0	0.16	0.24	0.30	0.28
0	140	0.10	0.10	0.13	0.10
0	280	0.09	0.10	0.13	0.10
50	0	0.16	0.21	0.42	0.38
50	140	0.09	0.10	0.13	0.11
50	280	0.10	0.10	0.13	0.11
100	0	0.18	0.25	0.43	0.40
100	140	0.10	0.10	0.14	0.16
100	280	0.09	0.10	0.12	0.12
		K in plant,.%			
0	0	1.04	1.39	2.24	1.09
0	140	2.36	3.77	4.16	3.71
0	280	3.87	4.42	5.59	4.93
50	0	1.00	1.42	1.69	1.02
50	140	2.63	3.48	3.10	4.62
50	280	3.73	4.35	4.68	4.60
100	0	0.97	1.53	1.89	1.13
100	140	2.45	3.57	2.80	3.94
100	280	3.67	4.23	4.28	4.77

Table 4. Effect of adding sewage sludge to mixtures of fly ash and subsoil on biomass production of corn.

FA[5]	SS[6]	Harvest Date 1	2	3	4
%	Mg/ha	g/plant			
100	0	1.7	0.6	0.5	0.4
100	0	1.9	1.0	1.0	0.6
100	0	2.0	1.8	1.3	0.6
75	15	1.4	1.3	1.0	1.2
75	15	2.1	1.2	1.2	0.9
75	15	2.2	1.1	1.1	0.7
50	30	1.5	1.2	1.7	1.5
50	30	2.5	1.3	1.5	1.1
50	30	2.4	1.1	1.7	1.2

[5] Percent fly ash with remaining being subsoil.

[6] Sewage sludge equivalent in terms of megagrams per hectare

As the percentage of soil in the fly ash mixture increased, there was a trend for the biomass to increase for each comparable sewage sludge treatment. This effect was more pronounced between the 0% and 25% soil treatments and was observed for all four growing periods.

The effects of sewage sludge and subsoil additions on the percent P and K of corn grown on fly ash are given in table 5. The addition of sewage sludge to fly ash increased the percent P and K in the plant tissues for all harvest dates and for all fly ash and soil mixtures. The magnitude of this trend diminished with harvest date. This is in spite of the fact that extractable P was high for all mixtures. All treatments had >224 kg/ha P based on the Mehlich III soil test (data not shown).

The level of K decreased in most cases between the first and second harvest, especially for the two fly ash and soil mixtures. As a result, K fertilizer was added to each pot between the second and third growing periods. This had an effect of increasing the level of K in the plants. Although K concentrations in the plant tissue would not appear to be limiting biomass production for any of the treatments, the concentration of this element changed over time to a greater degree than all others measured. Data for Ca, Mg, N, and several trace elements are not given since none of these varied significantly as a result of any treatment.

Table 5. Effect of adding sewage sludge to mixtures of fly ash and subsoil on P and K levels of the plant tissue.

		Harvest Date			
FA	SS	1	2	3	4
%	Mg/ha	P in plant, %			
100	0	0.12	0.14	0.11	0.11
100	0	0.15	0.16	0.13	0.15
100	0	0.20	0.16	0.13	0.18
75	15	0.13	0.27	0.14	0.15
75	15	0.19	0.18	0.14	0.14
75	15	0.18	0.22	0.14	0.15
25	30	0.13	0.29	0.13	0.15
25	30	0.14	0.24	0.14	0.16
25	30	0.18	0.20	0.14	0.15
		K in plant, %			
100	0	1.35	1.78	2.35	1.88
100	0	1.57	1.69	2.34	1.70
100	0	1.81	1.89	2.14	1.99
75	15	2.00	0.87	2.30	1.55
75	15	2.11	1.42	2.42	1.58
75	15	2.09	2.11	2.46	1.83
25	30	2.35	1.06	1.42	1.36
25	30	1.86	1.26	1.40	1.55
25	30	2.34	1.61	1.82	1.56

Conclusions

Knowledge gained from the first greenhouse study indicated that P may be limited for plant uptake even when data from either Bray-1P or Mehlich III extractions would indicate adequate levels should be in the high range. A three-fold difference between these two extractants was observed. The amount of P that corn could remove from fly ashes was reduced when K was applied.

Data from the second greenhouse experiment were encouraging that fly ash could be directly vegetated. The use of sewage sludge or some other organic materials is likely to be necessary to serve as a slow release N fertilizer. It is also likely that soil will be mixed with the fly ash to provide more cation exchange capacity and plant nutrients. It appears that sewage sludge and soil has P in a more available form than that found in fly ashes.

Although corn was used as a test crop, it is highly unlikely to be grown on the site, hence other grasses such as Kentucky 31 will need to be tested. It would appear the fly ashes at this site could be directly vegetated without the 4-ft soil cover. It has been proposed that a field study be established to verify these conclusions.

Acknowledgment

This work was supported in part by funds from the U.S. Department of the Interior, Office of Surface Mining, Reclamation and Enforcement to the University of Kentucky Research Foundation under Cooperative Agreement No. G1114121.

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