VEGETATION ESTABLISHMENT ON SOIL – AMENDED WEATHERED FLY ASH[1]

by

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Abstract. A field study was conducted with the following objectives in mind: 1) to study the effect of soil addition to weathered fly ash on the establishment and survival of different grasses and legumes, 2) to identify suitable grasses and/or legume species for vegetation of fly ash, 3) to study the fertilizer N and P requirements for successful vegetation establishment on fly ash and ash-soil mixtures, 4) to examine the nutrient composition of the plant species tested, and 5) to study the plant availability of P from fly ash and ash-soil mixtures. Three rooting media were used: weathered fly ash, and 33% or 50% soil blended with the ash. Four experiments were established on each of these media to evaluate warm season grasses in pure stands, warm season grasses inter-seeded with legumes, cool season grasses, and cool season grasses inter-seeded with legumes. Soil used in this study was more acidic than the fly ash. Only the results from characterization of the rooting media, ground cover, and yield will be presented here.

Additional Key Words: Reclamation, direct revegetation, soil cover.

Introduction

Large volumes of fly ash are generated from coal-burning electric power plants. This ash is disposed of in ponds and landfills, with less than 20% put to industrial use. With coal consumption (USA) estimated to reach 1.9 Metric Tons (Adriano et al., 1980) by the year 2000, development of other fly ash disposal and utilization methods is becoming an increasing necessity. Although there exists the potential to use fly ash as a nutrient source for many plants in agriculture, its use has been limited by a concern over toxic elements, especially in unweathered or fresh ashes. Several studies (Adriano et al., 1980; Carlson and Adriano. 1993; and Martens and Beahm. 1978) have demonstrated, however, that weathered fly ash presents no environmental threat as a plant growth medium and can, with proper handling, support vegetation. Regulations require that a closed landfill be covered with 120 cm of soil and stabilized with vegetation. This presents a problem in areas where soil may be limited. In addition, reclamation costs increase with the amount of soil used, especially if it must be transported for great distances. Knowing the minimum amount of soil to achieve satisfactory vegetation establishment would greatly reduce reclamation costs.

Hodgson (1961) observed that yields of several crops were improved by mixing small layers (0, 5, and 10 cm) of soil with pulverized ash. Using a range of soil depths from 10 cm to 120 cm with different fertilizer combinations for different crops, Hodgson et al. (1963) obtained a series of yield isoquants relating soil depth and fertilizer combinations necessary to produce a given level of yield. For certain crops, maximum yields were sustained using 10 cm of soil with 1.5 times the normal fertilizer rates. For other crops, 60 cm of soil with 1.5 times the normal fertilizer rates gave 90% of the maximum yield. Adams et al., (1971) reported successful vegetation establishment on fly ash based scrubber sludge without any soil cover. Mulhern et al., (1989) also demonstrated that several herbaceous and tree species could be established on scrubber sludge without any soil cover.

Preliminary greenhouse investigations (Barnhisel, 1994) indicated, that in spite of the high soil test P, corn grown on fly ash showed signs of severe P deficiency. East Kentucky Power Cooperative (EKPC) was facing two problems, ash disposal and soil cover requirements if their ashes were to be classified in the future as being hazardous waste. Furthermore, the soils in the immediate property of EKPC are shallow. The question was proposed "Can the weathered ashes support vegetation without the need for a four-foot soil cover?" The present field study was conducted to: 1) study the

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effect of soil addition to weathered fly ash on the establishment and survival of different grasses and legumes, 2) identify suitable grasses and/or legume species for vegetation of fly ash, 3) study the fertilizer N and P requirements for successful vegetation establishment on fly ash and ash-soil mixtures, 4) examine the nutrient composition of the plant species tested, and 5) study the plant availability of P from fly ash and ash-soil mixtures.

Materials and Methods

This study was located on an old fly ash pond operated by EKPC, near Somerset, KY. At the time the present study was started, this pond had not been used for disposal for at least ten years. Because the nutrient retention capacity (CEC) is essentially zero for the fly ash, it was believed that some soil would be required to maintain growth over time, so we decided to use three rooting media: weathered fly ash, and 33% or 50% soil blended with the ash. From August to October 1994, an embankment 240 m long, 35 m wide at the base with a 20 m wide face on which the plots were to be established, was constructed on the southwestern-most section of the fly ash pond using scraper pans.

In March and April 1995, soil and fly ash to be mixed in amounts to give 33% and 50% soil were placed in the concrete spillway that was constructed for the ash pond when it was originally being used for ash deposition. The truckloads of soil, Frederick rocky silt loam (clayey, kaolinitic, mesic, Typic Paludults), and fly ash taken from the pond were placed in this spillway structure in quantities to produce the desired mixture. An end loader was used to mix these materials together by placing buckets full in a central pile. This process was repeated four times for each batch, then loaded into trucks to place the two soil-fly ash mixtures at the foot of the embankment. In the case of the 0% soil, the fly ash was trucked directly to the embankment. A bulldozer was used to push the rooting materials onto the face of the embankment providing a vainer approximately 30 cm in depth, to create three equally-sized portions of rooting media.

Four experiments, with plant species and N or P fertilizer treatments in complete factorial, were superimposed over these rooting media. Experiments were: 1) warm season grasses in pure stand, 2) warm season grasses inter-seeded with legumes, 3) cool season grasses, and 4) cool season grasses inter-seeded with legumes. Nitrogen rates were 60, 120, and 180 kg N/ha, (urea) and N was the nutrient variable studied as a part of experiment 1 and 3. Phosphorus was the nutrient variable in experiments 2 and 4 with rates of 0, 26, 52, and 78 kgP/ha, (triple super-phosphate). In addition, P was applied to experiments 1 and 3 at a rate of 52 kg P/ha, and N was applied in experiments 2 and 4 at a rate of 120 kgN/ha. Potassium was applied as muriate of potash, at 149 kg K/ha on all plots.

Each experiment within each fly ash-soil mixture was arranged as a randomized complete block design with four replications, with plots being 3x2 m in size. The initial applications of N, P, and K and all seeding was done between April and May, 1995 with either a small cyclone seeder or by hand in the case of the bermudagrass sprigs. All plots, even those which received the initial N variable, received a modest application of N (25kg/ha) was top-dressed during the summer and fall of 1995 when plants were exhibiting nitrogen stress symptoms.

Ground cover and yield were determined at different times during the experiment, depending on the plant type, i.e., warm versus cool season plants when the group had reached maturity. Plant tissue was sampled for nutrient analysis including N, P, K, Ca, and Mg; these data as well as plant nutrient levels for each species-treatment combination and a more detailed description of the field and laboratory results are not presented here, but can be found in the Dissertation of the senior author (Semalulu, 1997).

The soil and fly ash and the mixtures were characterized using standard methods found in Soil Science Society of Agronomy's Book Series 5, Parts 1 (Klute et al., 1986) and 3 (Sparks et al,. 1996). The properties analyzed for these samples included: particle size distribution, water holding capacity, organic matter, pH, exchangeable cations (Ca, Mg, K), exchangeable Al, cation exchange capacity, extractable Fe, Mehlich III P, and P fractions. The three rooting media were also characterized using the same methods, but data for only pH; Mehlich P, K, Ca, Mg, Zn; exchangeable Al and clay percentages are given here.

Results and Discussions

Initial characteristics of fly ash and soil are presented in Table 1. Soil used in this study was more acidic than the fly ash. Most of the carbon reported for the fly ash was probably due to un-burned coal rather than the of type organic matter commonly found in soils. While the soil had a low CEC of 4.38 cmol/kg, because it came from the kaolinitic Frederick soil, the fly ash had almost none, 0.05 cmol/kg. Exchangeable cations were much lower in fly ash than in soil, and Al was not detected in the fly ash. The soil was also higher in amorphous iron oxides than the fly ash. Mehlich III extractable P was much higher in the fly ash than in the soil and had a level that would not theoretically require P fertilizers to be added, whereas the soil had a very low rating as to available P. The fly ash was fractionated using the procedure of Chang and Jackson (1957), and of the three most common fractions, most fly ash P was distributed in the Fe-P fraction, with the Ca-P fraction constituting the least. For the soil, most of the P was in the Al-P fraction.

The particle size distribution indicates that the bulk of the fly ash was in the silt fraction. Typically fly ash would have a greater percentage of silt-sized particles, but EKPC deposited both fly ash and bottom ash in this pond. The texture of the Frederick soil used in this study was high in clay since the material used was predominately subsoil. The water holding capacity was twice that of the soil.

Some of the fly ash characteristics affected by soil addition are shown in Table 2. Data from only experiment 1 are presented here, but data were consistent in all four experiments. In general, adding soil to fly ash improved fly ash K, Ca, Mg, nutrient reserve, while P and Zn decreased. The higher acidity of the soil led to a decrease in pH with as associated increase in the exchangeable Al. Unfortunately, the data from the soil were not obtained until after the soil mixtures were prepared and the plots were seeded, otherwise lime would have been added to raise the pH's of the mixtures to the same level. Note that the clay content was also increased by adding soil to fly ash.

Experiment 1:

In Table 3 are data for ground cover and dry matter yield for individual warm season species, as affected by soil additions to the fly ash, experiment 1. Compared with other species in this experiment, bermudagrass had the highest ground cover and yield on fly ash (0% soil), but yield was not significantly affected by soil addition. Expected yields forage yields for soils of this area under a medium level of management is 3.70 Mg/ha; it is clear that bermudagrass yields on fly ash exceeded this value.

Switchgrass ground cover and yield were both significantly increased by addition of both 33% and 50% soil to fly ash, while the yield for Zoysia was only improved for the 50% soil treatment. Poor performance of sideoats grama, especially on the 50% soil medium, may be due to increasing acidity, but in general, this species is difficult to establish in Kentucky.

Experiment 2:

Table 4 shows that dry matter yields for grasses were lower when in mixture with legumes, than in pure stand. For example, the yield for the grass portion in the mixture was 0.47 Mg/ha, whereas for the pure stand the yield was 4.25 Mg/ha (see Table 3). However, the overall yield for the grass-legume combinations were higher in the mixtures due to the contribution of the legume, in this case the total yield was 6.96 Mg/ha. The lower yield for grasses was due to competition from legumes, for moisture, light as well as soil nutrients, with legumes being physiologically better adapted to low N environments than grasses, since they can fix their own N. Birdsfoot trefoil is a long-lived legume that withstands harsh field conditions such as those in abandoned mine lands, coal spoils (Powell, et al., 1982 a, b), and fly ash-spoil mixtures (Adams et al., 1971). Ability to fix N, coupled with its adaptation to harsh conditions, make birdsfoot trefoil a likely species to survive on fly ash.

Except for sideoats grama, the grass component of the mixtures increased with soil addition to ash, but the total yield increased for only one of the mixtures, switchgrass-sericea lespedeza. Although the overall fertility accompanying the addition of soil had increased, the pH was lower and this favored survival and growth of grasses, but caused a reduction in legume survival and growth. Table 4 shows the most affected legume to be birdsfoot trefoil where the rooting medium was 50% soil. Although capable of thriving under infertile soil conditions (Beard, 1973), sericea lespedeza did not grow as well on fly ash or ash-soil mixtures as the other legumes in this study. A possible reason could be its low N fixation and slow establishment, especially in the presence of high competition.

Clovers are important agronomic legumes that survive better on deep well drained fertile soils (Beard, 1973). Thus, while ability to fix N would make clovers suitable for survival on fly ash and ash-soil mixtures, their short-lived (2-3 yr.) nature and fertility requirements would be a limitation to survival on fly ash and ash-soil mixtures, compared to, birdsfoot trefoil, and even sericea lespedeza.

Table 1. Some characteristics of the fly ash and soil used in this study.

	Particle size distr. sand	silt	clay	WHC	OM	pH	1M $NH_4C_2H_3O_2$ extr. CEC	Ca	Mg	K	KCl extr. Al	CBD extr. Fe	Mehlich III extr. P	P fractionation Al	Fe	Ca
	-----	%	-----				-----	-----	cmol/kg	-----	-----	%	-----	mg/kg	-----	-----
Fly ash	25.8	71.2	3.0	32.6	4.99	6.4	0.05	0.67	0.10	0.10	0.00	0.71	89.0	147	215	44
Soil[1]	15.6	42.7	41.7	16.4	1.21	4.4	4.38	1.46	0.34	0.21	1.40	1.89	5.1	68	32	12

[1] Soil in this area is predominantly composed of a Fredonia (fine, mixed, mesic, ultic hapludalfs)-Frederick (clayey, kaolinitic, mesic, typic paleudults) complex, typically 50-80 cm over the bedrock.

Table 2. Composition of the rooting media as affected by soil addition

% soil	pH	Mehlich III extractable P	K	Ca	Mg	Zn	KCl extr. Al	Clay
		-----	-----	mg/kg	-----	-----	cmol/kg	%
0	6.58	90	97	431	33.7	2.88	0.00	3.5
33	5.81	96	121	774	63.2	2.11	0.13	9.1
50	5.20	48	147	714	79.0	2.05	1.02	20.3

Table 3. Effect of soil on the ground cover and dry matter yield of different grass species, Experiment 1.

Species variety & scientific name	% soil	Ground cover, % 9/95	Ground cover, % 6/96	Total yield, Mg/ha
Common bermudagrass	0	89.4	62.5	4.25
(Cynodon dactylon)	33	82.1	67.3	4.74
	50	85.8	67.7	4.98
Sprigged bermudagrass	0	84.8	82.3	4.51
(Cynodon dactylon)	33	80.6	77.1	5.62
	50	78.8	77.7	5.10
Blackwell Switchgrass	0	15.0	34.4	1.74
(Panicum virgatum)	33	55.8	69.0	5.22
	50	56.0	75.8	6.20
El Reno Sideoats Grama	0	42.3	27.7	1.87
(Bouteloua curtipendula)	33	33.1	28.1	2.40
	50	64.6	1.9	0.84
Sunrise Zoysia grass	0	56.0	58.5	2.20
(Zoysia matrella)	33	68.3	63.1	1.98
	50	64.6	72.9	3.78

Experiment 3:

Table 5 shows that compared to other cool season species in this experiment, 'Forager' and 'KY 31' tall fescue had the highest dry matter yields on fly ash. However, these yields were about 50% lower than those of common bermudagrass and switchgrass. Fescue yields were not significantly affected by the addition of soil, although they generally increased. Forager and KY 31 tall fescue are known to adapt to a wide range of climatic and soil conditions; being long-lived, deep-rooted, tolerant to drought, acid (pH 4.7-8.5), and infertile soil conditions (Beard, 1973) make them especially suitable for revegetation of mine spoils, abandoned mined lands (Powell, et al., 1982 a, b), and fly ash-spoil mixtures (Adams et al., 1971). Yields for orchardgrass, KY bluegrass, and hard fescue were positively affected by soil addition to fly ash. While all five species/varieties yielded nearly the same on the 33% soil medium, orchardgrass, and bluegrass yields were higher than those of Forager or KY 31 tall fescue on the 50% soil medium. Hard fescue and KY bluegrass are shallow rooted species that survive best on fertile soils (Beard, 1973), and this could explain their poor survival on fly ash. Orchardgrass tolerates a wide range of soil conditions, but has poor drought tolerance (Beard, 1973), consequently, drought conditions experienced at various periods during the course of this study (Semalulu, 1997) could have affected its performance.

Experiment 4:

Table 6 shows that in mixture with legumes, the dry matter yields of cool season grass components were lower than in pure stand (see Table 5), due to competition from legumes. However, the total yield of the grass-legume combination was higher when grown as a mixture. As for warm season species, soil addition to fly ash favored the cool season grass component at the expense of legumes. In general, bluegrass portions of the yields were higher than those of KY 31 and Forager tall fescue on both the 33 and 50% soil media. This was due to the rather minor competition from Korean lespedeza at the time of sampling (May 1996). Korean lespedeza is a summer annual legume that is favored by warm summer temperatures, and at the time of the first forage sampling it did not have enough time to produce as much growth as the other legumes. Early cutting, in turn, affected its performance later in the summer, which could easily be seen in the remainder of the plot not harvested. On the other hand, birdsfoot trefoil thrives best under cool temperatures, and therefore, posed serious competition to KY 31 tall fescue, especially on the 0 and 33% soil media.

Table 4. Effect of soil on the ground cover and dry matter yield of different grass and legume species, Experiment 2

Species variety & scientific name		% soil	Ground cover, % 9/95	Ground cover, % 6/96		Total yield, Mg/ha
Common bermudagrass	(CB)	0	42.8	3.2		0.47
Empire Birdsfoot trefoil			33.9	94.4		6.49
(Lotus corniculatus)	(BFT)				total	6.96
	CB	33	55.0	8.0		1.13
	BFT		12.3	87.5		5.41
					total	6.54
	CB	50	67.3	69.8		3.84
	BFT		0.9	16.3		0.54
					total	4.38
Blackwell Switchgrass	(SG)	0	14.8	20.3		1.06
Appalow Sericea Lespedeza			17.5	8.3		0.28
(Lespedeza sericea)	(SL)				total	1.34
	SG	33	32.3	46.1		2.24
	SL		11.1	14.8		0.67
					total	2.91
	SG	50	30.8	61.6		2.43
	SL		10.5	13.0		0.46
					total	2.89
El Reno Sideoats grama	(SO)	0	13.0	7.0		1.05
Common Alsike Clover						
(Trifolium hybridum)	(AC)		16.8	19.6		1.09
Kenland Red Clover			20.8	74.3		2.56
(Trifolium pratense)	(RC)				total	4.70
	SO	33	0.9	0.0		0.26
	AC		15.3	24.7		1.54
	RC		14.8	67.5		2.00
					total	3.80
	SO	50	0.0	0.2		0.09
	AC		12.8	24.8		0.99
	RC		10.9	27.0		0.87
					total	1.95

Table 5. Effect of soil on the ground cover and dry matter yield of different grass species, Experiment 3

Species variety & scientific name	% soil	Ground cover, % 9/95	Ground cover, % 6/96	Total yield, Mg/ha
Kentucky 31 tall fescue				
(Festuca arundinacea)	0	59.8	61.9	2.50
	33	45.2	53.8	2.51
	50	54.2	64.4	3.36
Forager tall fescue				
(Festuca arundinacea)	0	64.6	63.6	2.43
	33	50.2	56.4	2.25
	50	54.0	60.8	2.66
Orchardgrass				
(Dactylia glomerata)	0	51.7	58.8	1.56
	33	56.0	61.0	2.71
	50	70.0	78.8	3.75
Rescue Hard fescue				
(Festuca ovina)	0	38.3	45.4	1.13
	33	34.2	43.3	2.25
	50	51.5	65.0	3.29
Common Kentucky Bluegrass				
(Poa pratensis)	0	53.1	53.6	1.86
	33	53.5	51.0	2.33
	50	59.6	69.2	3.65

Additional Observations[5]

Nitrogen had an effect on the ground cover, yield, and N uptake. In general, for all species, grass survival was favored by N fertilization on all soil media in both experiments 1 and 3, emphasizing the need for adequate N fertilization to aid vegetation establishment on these media. This was especially true when grasses were not seeded with legumes. The effect of N was not tested for grass-legume mixtures, however, it is likely that N addition would favor grasses at the expense of legumes.

Phosphorus had an effect on ground cover, yield, and P uptake. In general, the response to fertilizer P was observed in the total dry matter yield and more so in P uptake for the grass-legume mixtures involving birdsfoot trefoil as the legume. Response to P was obsersved on the 0 and 50% soil media, but not the 33% soil.

Thus, response to P depended not only on the species tested, but also on the soil medium. Examined across all soil media, P uptake for the KY 31-birdsfoot trefoil system was related to the Mehlich III extractable P (PU = 5.918 + 0.062P; R^2 = 0.5187, water soluble P (PU = 5.116 + 2.780P; R^2 = 0.6778), aluminum phosphate (PU = 1.554 + 6.668P; R^2 = 0.5664), calcium phosphate (PU = 4.465 + 10.406; R^2 = 0.4369), but not iron phosphate (R^2 = 0.1443). Since iron phosphate is the predominant form of P in this fly ash (Table 1), results suggest that although some of this fraction may be extracted by the Mehlich III extractant (r = 0.4138, $P<0.05$), this form is not available for plant utilization. Soil test P data for fly ash using Mehlich III extractant may therefore not necessarily reflect plant available P, as

[5]Data not presented here due to space limitations, see Semalulu, 1997

Table 6. Effect of soil on the ground cover and dry matter yield of different grass and legume species, Experiment 4

Species variety & scientific name	% soil	Ground cover, % 9/95	Ground cover, % 6/96		Total yield, Mg/ha
Kentucky 31 tall fescue (KF)	0	13.3	8.7		1.00
Empire birdsfoot trefoil (BFT)		43.1	84.5		5.48
				total	6.48
KF	33	15.6	11.8		1.09
BFT		23.4	81.6		4.75
				total	5.84
KF	50	28.1	21.2		1.84
BFT		17.3	57.6		3.82
				total	5.66
Forager tall fescue (FF)	0	35.8	44.0		1.37
Appallow sericea lespedeza (SL)		10.8	8.4		0.23
				total	1.60
FF	33	18.6	39.1		1.93
SL		16.6	13.6		1.11
				total	3.04
FF	50	28.3	37.2		1.75
SL		19.8	31.6		2.11
				total	3.86
Kentucky bluegrass (BG)	0	9.7	33.3		1.23
Common Korean lespedeza		49.4	33.5		1.48
(Lespedeza stipulacea) (KL)				total	2.71
BG	33	8.0	49.4		2.97
KL		64.7	20.3		0.93
				total	3.90
BG	50	11.9	58.2		2.63
KL		58.4	30.7		0.60
				total	3.23

as observed in a preliminary greenhouse study (Barnhisel, 1994).

In general, vegetation establishment on all soil media was limited by N, P, Ca, Mg, and K deficiencies in all species, for both years (Semalulu, 1997). Deficiencies were more prevalent for grasses than for legumes. In general, all tissue concentrations for N, P, Ca, Mg, and K of the various species grown on all three soil media were lower than the normal levels as reported by Jones,1974. Although the primary goal of this study was to establish vegetation cover, rather than grow forage for animal utilization, the results stress the need for supplemental addition of the above nutrients if the vegetation grown were aimed at producing good quality forage. These low nutrients will likely affect long-term survival of these species as well, especially on the fly ash plots in which levels were lower than when soil was added to the mixture.

Conclusions

Results of this study suggest that stabilization of weathered fly ash can be achieved using species such as bermudagrass, tall fescue (KY 31 or Forager), and birdsfoot trefoil. The addition of 33% soil would facilitate establishment of other species: such as switchgrass, orchardgrass, bluegrass, and hard fescue. However, increasing soil to 50% resulted in reduced legume survival possibly due to acidity problems associated with soil addition. Acidity could, however, have been corrected had we been able to predict the level of acidity earlier, in which case lime would have been applied prior to establishment of the experiments.

In general, for most species yields from the 33% soil medium were not significantly different from those from the 50% soil, suggesting no probable benefit in using higher amounts of soil. Sufficient N fertilization is essential for successful vegetation establishment on fly ash and ash-soil mixtures especially, in the absence of legumes. Results show that the need for supplemental P fertilization will depend on the nature of species tested, as some did respond, while others did not. However, extensive N, P, Ca, Mg, and K deficiencies were observed in most grass species, suggesting the need for supplemental addition of these nutrients. Results presented here are based on a two-year field study. Longer-time studies could provide more conclusive results.

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