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Use of Fly Ash as Soil Amendment for Biofuel Feedstock Production with Concomitant Disposal of Waste Accumulations

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ABSTRACT

Increasingly higher costs of disposal of fly ash (FA) on the one hand, and on the other, the current focus on bioenergy offer opportunities for using FA as soil amendment for producing biofuel feedstock while cleaning up accumulations of the product. Greenhouse pot experiments were conducted in a silt loam soil amended with 0%, 2.5% and 20% FA to determine boundary shoot and root biomass productivity by the cellulosic herbaceous perennials (CHPs) switchgrass (SG), eastern gamagrass (GG) and big bluestem (BB) grown at pH=4.5 and 6.5. After three months of growth at pH=4.5, shoot biomass productions was generally in the order SG>GG>BB. Root biomass was slightly different and it was in the order SG=GG>BB. Soil amendment with 2.5% FA did not affect biomass production either CHP; however, biomass production at 20% FA amendment declined in all cases. Results for SG and BB only evaluated at pH 6.5 were similar to those at pH 4.5. Needs were identified to define optimum levels of FA amendment to add to soil and combinations of FA and organic amendment that could enhance simultaneous utilization of FA and biofuel feedstock production.

INTRODUCTION

According to the US Energy Information Administration coal was the fuel for about 42% of the 4 trillion kilowatt-hours of electricity generated in the United States in 2011 [18]. Annually, this leads to production of 130 million tons of coal combustion wastes (*CCW*) [3], which require safe disposal to avoid threats to human and environmental health. Of this amount, 68 million tons consist of *fly ash* (FA), the fine, mostly inorganic residues, which are generally stored in large, wet impoundments or disposed of in landfills [20].

Increasingly higher costs of management and disposal of FA has prompted growing advocacy for greater beneficial uses of FA and other CCPs as disposal strategy, including their utilization in agriculture [5]. Merits of FAs as soil amendment in agriculture have long been recognized. The products can provide macro- and micronutrients for plant growth, correct soil acidity as well as alkalinity [11] [12] [14] [15] [16] and impart to soil, improved physical characteristics such as structure, permeability, and water holding capacity to improve crop performance [9] [10]. Ironically, to date, less than 0.4% of the 68 million tons FA produced annually in the US is used in agriculture [3]. The lack of enthusiasm for use of FA in agriculture in the US is generally attributable to real or perceived human health concerns associated with the product [19].

Historically, FAs have found beneficial uses mainly in the construction industry with growing contributions in the mining industry. For example, the 2010 American Coal Ash Association (ACAA) survey reported the following uses of FA (million tons): concrete and concrete products (13), structural fills (4.7), waste stabilization/stabilization (3.3), mining applications (2.4) and road base construction (0.2) [3]. However, an ever-growing world's need for food, feed, fiber and now, bioenergy strongly suggests that the largest untapped markets of sustainable utilization of FA could be their use as soil amendment in crop production. Utilization of FA as soil amendment for plant growth possesses perhaps the greatest potentials for increasing consumption of the waste products and thereby reducing significantly the amounts that must be disposed of in ash ponds and landfills. Unlike construction markets that can become saturated or are vulnerable to market volatilities [7], demand of agricultural markets will always be high to meet human needs.

Experiences from use of FA as soil amendment for producing various crops together with knowledge from bio/phytoremediation for overcoming the physicochemical limitations of remediation at FA disposal sites [6] [13] present opportunities to develop strategies for neutralizing adverse attributes of FA so the product can be used routinely for crop production. These opportunities are enhanced further by the emergent global need of biofuel feedstock production; in particular, growing non-food crops as biofuel feedstocks. At first sight, this proposition appeared promising; however, it ran into the debate of the competition between land for food versus biofuels. Now, attention has been focused on the use of *marginal land* for biofuel feedstock production. The use of marginal lands for biomass production requires soil amendments with materials such as fly ash and organic substrates and /or microbial inoculations [2] [6] [8] [12].

This paper reports preliminary studies on the feasibility of for using FA as soil amendment for biofuel biomass production, with concomitant beneficial consumption (disposal) of the waste product.

MATERIALS

Soil: Soil used for these pot studies is Amour silt loam (*fine-silty, mixed, thermic Ultic Hapludalfs*) collected from Tennessee State University Research and Education Station, Nashville, TN.

Plants (cellulosic herbaceous perennials, CHPs): 'Alamo', switchgrass (SG) and 'Roundtree' big bluestem (BB) were purchased from Star Seed Inc., Osborn, KS, and 'Highlander' eastern gamagrass (GG) was obtained gratis from Jimmy May Gamagrass Co., Cave Springs, KY.

Coal Fly Ash: Fly ash (FA) was supplied through arrangements with Tennessee Valley Authority Kingston Plant (Carriker and Rogers, pers. comm.).

METHODS

Soil Preparation and Amendment: Soils were sieved through 2mm sieve and they were adjusted to experimental pH levels using $AlK_2(SO_4)_3.18H_2SO_4$ or $CaCO_3$ [4], following modifications described by Dzantor et al., [4]. Appropriate amounts of FA were added to separate portions of pH-adjusted soils to provide 2.5% and 20% FA amendment based on soil and FA dry weights. Each pot contained about 1kg of mixture.

Planting: Seeds of each plant were started in germination trays containing potting mix (Fafard #2 mix) and 3- to 4-leaf stage seedlings of the grasses were transplanted into 5 inch pots containing pH-adjusted Amour soil to give four plants per pot. Because of their well-known dormancy problems, gamagrass seedlings were generally started in trays about 10-14 days before starting switchgrass and big bluestem seedlings.

Experimental Design: Treatments consisted of the following factorials: CHPs of (GG, BB and SG) x Amendment (0%, 2.5%, 20% FA) arranged in completely randomized design on greenhouse benches with four (4) replications. The plants were watered as needed and the pot locations were rotated at least every 2-3 days to minimize effects associated with pot placement.

Harvesting and Biomass Determinations: After three months in pots, the aboveground biomass (shoot) of the grasses were harvested by cutting their tops to heights of 15 cm. Shoots from each replicate were bagged separately and dried at 70^oC to constant weight (3-5 days). For determining root biomass, roots were physically separated by carefully washing away soils and rinsing thoroughly under a gently stream of water. Roots from each replicate were bagged separately and dried at 70^oC to constant weight.

Data Analyses: Biomass data were analyzed by ANOVA.

RESULTS AND DISCUSSION

In a previous experiment, we evaluated boundary biomass production of switchgrass (SG), eastern gamagrass (GG) and big bluestem (BB) under acid soil conditions [4]. We were interested in those conditions because they are estimated to affect 30% to 40% of the world's arable land area [21]. Results of those experiments showed that biomass production was in the order SG>GG>BB. Furthermore, biomass production by SG was not affected by soil pH 6.5, 5.0 and 4.5. In contrast, biomass productions by GG and BB were significantly reduced at pH 4.5. Table 1[4].

Table 1. Biomass yield of switchgrass, eastern gamagrass and big bluestem[a]

	Biomass Yield (g) at Indicated pH		
Cellulosic Herbaceous Perennial	4.5	5.0	6.5
Switchgrass	3.8a	4.2a	3.9a
Eastern Gamagrass	0.7b	2.8b	2.5b
Big Bluestem	1.0b	2.1b	2.0b

[a] Means values with the same letters are not significantly different.

Table 2 shows the biomass productivities of the grasses grown on fly ash-amended soils. The results show that at pH 4.5, biomass productivities by the grasses were generally unaffected by soil amendment with 2.5% fly ash (w/w) compared to unamended controls.

Table 2. Biomass yields of switchgrass, eastern gamagrass and big bluestem in fly ash-amended soils at pH 4.5[a]

Cellulosic Herbaceous Perennial	Fly Ash (%)	Shoot Biomass (g/pot)	Root Biomass (g/pot)
Switchgrass	0	5.8 (*0.5*)	9.9 *(3.1)*
	2.5	5.3 (*0.6*)	9.5 *(2.1)*
	20	4.7 (*0.3*)	7.8 *(0.9)*
Gamagrass	0	4.1 *(0.2)*	12.2 *(0.5)*
	2.5	4.7 *(0.3)*	9.1 *(1.5)*
	20	4.3 *(0.3)*	8.5 *(2.7)*
Big Bluestem	0	2.7 *(0.9)*	5.5 *(0.5)*
	2.5	2.7 *(0.8)*	6.3 *(1.9)*
	20	2.1 *(0.6)*	4.3 *(1.5)*

[a] Means followed by standard deviations in parentheses

Soil amendment with FA at the rate of 20% (w/w) caused slight declines in biomass production by the three grasses. Visual appraisal of pots suggested that at least some of the decline in biomass production at 20% could be attributed to problems with water permeability relations at the higher rate of FA amendment. That rate may not be practical under field conditions; however, we wanted to evaluate boundary levels of amendment upon which field evaluations may ultimately be based. For these experiments, shoot as well as root biomass productions were measured.

In the same experiment, biomass production by SG and BB were assessed at pH of 6.5. Results in Table 3 showed that the biomass trends were similar to those described above for pH 4.5 Additional evaluations involving GG at pH 6.5 is being reported elsewhere.

Table 3. Biomass yields of switchgrass, eastern gamagrass and big bluestem in fly ash-amended soils at pH 6.5[a]

Cellulosic Herbaceous Perennial	Fly Ash (%)	Shoot Biomass (g/pot)	Root Biomass (g/pot)
Switchgrass	0	5.5 *(0.6)*	8.88 *(0.99)*
	2.5	5.5 *(0.4)*	9.18 *(0.88)*
	20	4.6 *(0.4)*	9.03 *(1.73)*
Big Bluestem	0	2.9 *(1.2)*	7.53 *(1.58)*
	2.5	2.4 *(0.5)*	6.63 *(1.56)*
	20	1.5 *(0.6)*	3.93 *(1.98)*

[a]Means followed by standard deviation in parentheses

Conclusions

Potentials exist for developing amendment strategies to capitalize of on consumption of fly ash to produce biofuel feedstock. Some of our ongoing greenhouse investigations are examining use organic amendment (poultry litter) and/or microbial inoculation strategies to advance the concepts of coupling FA utilization as soil amendment to enhance biofuel feedstock production. Our experiments with poultry litter are particular promising; prospects of turning ‘wastes’ into bioenergy are sound concepts in the current focus on energy security and environmental sustainability.

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