ESTABLISHING PERENNIAL SEED-BASED ENERGY CROPS ON RECLAIMED SURFACE MINE SOILS IN THE CENTRAL APPALACHIANS

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Abstract.—Renewable energy has been at the forefront of the United States' energy policies. Cellulosic feedstocks have received considerable interest in the Appalachian region because of their abundance and availability, but cost competition from other energy sectors has limited their use in the region. Some other bioenergy feedstocks, such as corn and soybeans, are not a viable alternative for most of the region. Though not considered suitable for traditional agricultural crops, a large portion of disturbed mine land in West Virginia, Pennsylvania, and eastern Ohio has been reclaimed and planted with perennial grasses. To find an alternative to the more traditional feedstocks, we are exploring the use of perennial seed-based energy crops harvested from trees established on these reclaimed lands. Dunstan hybrid chestnuts (*Castanea dentata* × *Castanea mollissima*) and hybrid hazelnuts (*Corylus* sp.) were planted on a reclaimed surface mine in north-central West Virginia. Individual seedlings were planted with or without composted manure. Soil from the same site was used to study the effects of various combinations of poultry-based biochar, wood-based biochar, and two water sources (rainwater and mine drainage) on the survival and growth of Dunstan chestnut, hybrid hazelnut, and Allegheny chinkapin (*Castanea pumila* var. *pumila*) in a greenhouse. We will describe the first-year results of field and greenhouse tests of Dunstan chestnut and Allegheny chinkapin; hybrid hazelnut survival was so low that this species was not further analyzed. Growth and development of chestnut and chinkapin seedlings in the field and greenhouse during the first growing season did not benefit from amendments. Creating a sustainable bioenergy industry based on perennial seed-based crops in the central Appalachian region will depend on the rapid establishment and growth of tree crops over large areas. Results from these studies will help to inform decisions about establishing and maintaining these crops.

INTRODUCTION

Energy production has been a major driver for the central Appalachian region for more than a century. Coal and gas/oil extraction have traditionally supported the largely rural economies and community social programs. Although coal remains a locally abundant and low-cost fuel, its high carbon emissions coupled with the low price of natural gas have reduced its use for electric power generation. With reduced coal output and mounting public concern over the environmental impacts of nonrenewable energy development including recent shale gas extraction, new opportunities are needed for the region. It is expected that renewable energy will fill the energy void being left by fossil fuels. More than 200 large-scale ethanol and 100 biodiesel operations are currently converting corn, soybeans, and other crops into liquid fuels. To date new opportunities for the development and adaptation of sustainable energy technologies have gone unrealized in central Appalachia, in part due to the lack of bioenergy production facilities and feedstocks appropriate for the region.

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Corn and soybeans are currently the seed crops most often utilized for biofuel production in the United States. The central Appalachian region, however, is constrained in agricultural production because it lacks suitable site conditions. Despite having one of the most productive growing climates in the eastern United States, with moderate temperatures and abundant rainfall (exceeding 200 cm/yr in areas), the region is limited by terrain and soil conditions. Its sloped and rocky soils are less compatible with intensive and mechanized farming practices associated with modern annual crop production systems.

One new potential pathway for creating a sustainable bioenergy industry for the region involves the use of perennial seed energy crops harvested from tree plantations. Currently some tree species are grown specifically for their seeds. Pecans (*Carya illinoiensis*), walnuts (*Juglans* spp.), hazelnuts (*Corylus* spp.), and pistachios (*Pistacia* spp.) are some of the more commonly grown trees for “nut” production in the United States. Select perennial oilseed crops have high oil contents ranging from 560 to 1,400 L/ha (Molnar 2012), ≥5,600 L/ha for Chinese tallow (*Triadica sebifera*) (Breitenbeck 2008), and 2,150 L/ha (Hill et al. 2010) for sweet pecan. In contrast, soybeans yield approximately 517 L/ha (Hill et al. 2010). Similarly, some species have seeds low in oil but high in carbohydrates, such as chestnuts (*Castanea dentata*), which can be processed by using technologies similar to those used by corn-to-ethanol platforms.

Perennial seed energy crops are desirable in central Appalachia as in other regions for many reasons: one-time establishment cost, reduced site disturbance, fewer cultural inputs (e.g., fertilizers, irrigation, pesticides), and reduced energy inputs. Although the Appalachian region lacks agricultural land capable of supporting significant production of annual seed energy crops, it has a tremendous amount of idle land that could potentially be converted into production areas for other energy feedstocks, such as perennial seed crops. There are an estimated 0.5 million ha of surface mine sites in central Appalachia, and an additional 3.6 million ha of marginal crop land potentially available. Some of the disturbed mine land in West Virginia, Pennsylvania, and eastern Ohio has been reclaimed. Much of the reclaimed mine lands have been “restored” by grading the blasted overburden material, replacing native topsoil salvaged from the site, and seeding aggressive perennial cool-season grasses for erosion control.

The extreme disturbance to the normal structure, chemistry, and biology of these soils makes them challenging as substrates to support productive crop growth. They are characterized by low or high soil pH, high salinity, high heavy metal content, variable drainage, high rock fragment content, and absence of typical soil microbes. Therefore, some recent effort has looked into amending soil properties to improve conditions to better support tree growth. For example, waste products such as fly ash, animal manures, and sewage have been added to the surface to improve the soil properties (Skousen et al. 2013). Additionally, biochar, a carbon-rich substance produced when organic matter is combusted under low oxygen, is gaining interest as a potential soil amendment, specifically because of its potential to increase crop productivity and improve soil physical properties and long-term carbon storage (Lehmann and Joseph 2009).

As an alternative to the more traditional energy feedstocks, perennial seed-based energy crops harvested from trees established on these reclaimed sites are being explored to create a sustainable bioenergy industry for the Appalachian region. The objectives of our study are to examine growth rates and establishment practices of perennial seed crops on one of the many reclaimed mine sites in Appalachia. One field study was initiated to compare seedling establishment on a former surface mine site using Dunstan chestnut (*Castanea dentata* × *Castanea mollissima*) and hybrid hazelnut with and without soil amendment. A companion study was initiated to further examine opportunities to improve growing conditions for several perennial seed crop species using wood- and poultry-based biochar in a greenhouse trial.

METHODS

Field Study

A 2-ha portion of a former surface mine in north-central West Virginia was used for this study. Twelve single-species blocks containing 20 trees each were planted in April 2013 using two species and two soil amendment treatments. Hybrid hazelnut and Dunstan chestnut were each hand planted into augered holes on six planting blocks. Three blocks per species were amended with composted cow manure. Cow manure (7,275 cm^3) was incorporated into each hole during augering. The hazelnuts were planted at 3.0 m by 3.0 m spacing; the chestnuts were spaced at 6.1 m by 6.1 m.

Immediately after planting, 1.2-m-tall tree shelters (Jump Start® "Full Sun," Plantra, Inc., Eagan, MN) were installed around each seedling to reduce deer browse. Directed herbicide applications (2 percent glyphosate solution) were also performed around each seedling in the spring and midsummer during the first growing season to control competition.

Initial basal diameter and total height were measured 2 weeks after planting, which was before budbreak. Foliage samples were collected from five seedlings per plot in August 2013. End-of-year survival, basal diameter, and total height were determined in September 2013.

Greenhouse Study

The main experiment evaluated growth and survival of Allegheny chinkapin (*Castanea pumila* var. *pumila*) grown in mine soil subjected to two amendment levels and two types of irrigation:

1. No amendment + rainwater irrigation
2. Poultry-based biochar (mixed 2.5 percent volume/volume) + rainwater irrigation
3. No amendment + mine drainage water
4. Poultry-based biochar + mine drainage water

Each treatment was repeated six times and randomly assigned a position on a greenhouse bench. Pots were periodically rearranged to ensure similar growing conditions.

The irrigation treatments were initiated because of the availability of mine drainage water for irrigation at the mine site used in the field study. Rainwater was collected as runoff from a plastic trap and stored in a plastic barrel. Mine water was collected at the reclamation site directly from the pipe before it was applied to the surface outside the area of the field study. The mine water was recirculated daily over limestone to increase the pH of the water. Rain water pH averaged 5.85 and ranged from 5.64 to 6.07. Mine water pH averaged 7.59 and ranged from 7.25 to 8.25.

Table 1.—Chemical analysis† of biochar samples used in greenhouse study, West Virginia

Sample	N	P_2O_5	K_2O	S	B	Zn	Mn	Fe	Cu	Ca	Mg	Na	Al
							percent						
Poultry (n=2)	3.33	9.61	6.245	0.99	0.01	0.075	0.095	0.53	0.215	6.415	2.05	2.13	0.615
Wood (n=1)	0.79	0.08	0.23	0.01	0.001	0.002	0.01	0.02	0.01	0.37	0.03	0.02	0.01

† N: nitrogen; P_2O_5: phosphate; K_2O: potash; Na: sodium; Al: aluminum.

The greenhouse study used surface soil from the same area used for the field study. Three mine soil samples were collected and analyzed by an independent lab (Waters Agricultural Laboratories, Inc., Camilla, GA). The average results were 6.7, 250, 722, 6674, 162, 1.39, 9.74, 310, 408, 7.3, and 2.02 kg/ha for phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), boron (B), zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu), respectively. Soil pH was 7.8 and cation exchange capacity was 18.7 meq/100 g. A chemical analysis of the poultry-based biochar samples used in the greenhouse study is given in Table 1.

Dunstan chestnut and hybrid hazelnuts were included as a comparison to the chinkapin. However, only the untreated soil versus poultry-based biochar treatments were included as treatments. Each combination of species and amendment was repeated five times.

A final set of treatments was included to explore the response of Allegheny chinkapin to a different type of biochar. Seedlings growing on unamended mine soil were compared to ones growing with soil amended with wood-based biochar (2.5 percent volume/volume, Table 1). These seedlings were not directly compared to those grown as part of the main greenhouse study because seedling quality differed between the experiments.

All pots were well watered with rain water (except those designated to receive mine drainage water) 3 days per week beginning at establishment in April through September 2013. Foliage samples were randomly collected from each seedling in August and composited by treatment for analysis (no statistical comparison was performed). Height and basal diameter were measured for each seedling just before harvest in September after one growing season. Following harvest, individual plants were separated into their biomass components (root, stem plus branches, and leaves), dried to a constant temperature at 65 °C, and weighed.

DATA ANALYSIS

All data were evaluated using SAS Proc GLM (SAS Institute Inc., Cary, NC) with a P = 0.10 level of significance. Hybrid hazelnut survival was poor in both experiments (<10 percent for the field study and 0 percent for the greenhouse study) and was not analyzed further.

RESULTS

Field Study

First-year survival of Dunstan chestnut was 78 and 90 percent for manure and control seedlings, respectively. Manure-treated seedlings were shorter and had smaller diameters than control seedlings, although differences were not significant (Table 2). By the end of the growing season, control seedlings increased in height approximately 20 cm compared to only 10 cm for treated seedlings. Similarly, control seedlings grew in diameter 1.3 mm on average compared to 0.8 mm for treated seedlings. Foliage testing revealed manure-treated seedlings had significantly higher nutrient concentrations for nitrogen (N), P, and Mg, whereas control seedlings had higher foliar Ca concentrations (Table 3).

Greenhouse Studies

Greenhouse experiment 1 sought to examine the effects of two types of irrigation water and biochar on Allegheny chinkapin growth and survival. The addition of 2.5-percent biochar was detrimental to both growth and survival (Table 4). The addition of biochar significantly increased mortality in chinkapin, regardless of irrigation type (main effect, P = 0.0001). Although individual seedling biomass was reduced, a significant difference between rainwater + biochar and rainwater-treated seedlings was limited to the leaf tissue, which was reduced by more than 50 percent. Mine water and rainwater treatments were not significantly different. Mean biomass of the three components differed by 1 to 12 percent between the two types of irrigation, and total biomass differed by 8.5 percent.

Chemical concentrations in the foliage based on one composite sample for each treatment are listed in Table 5. The poultry-based biochar treatment resulted in higher elemental concentrations in chinkapin compared to nonamended seedlings in greenhouse study 1. Compared to treatment with rainwater, seedlings irrigated with mine water had lower elemental concentrations for all elements except for Ca, S, and Al.

Table 2.— First-year mean growth and survival (+ standard error) of Dunstan chestnut planted on a reclaimed mine site in West Virginia

	Height (cm)		Groundline diameter (mm)		
Treatment	Year 0	Year 1	Year 0	Year 1	Survival (%)
Control	81.3 (1.2)	98.3 (3.0)	8.1 (0.15)	9.4 (0.19)	90 (0.11)
Manure	82.2 (1.2)	91.1 (3.2)	7.9 (0.15)	8.7 (0.20)	78.3 (0.11)
P-value	0.59	0.65	0.09	0.26	0.46

Table 3.—Foliar concentrations of various elements for Dunstan chestnut growing on a reclaimed mine site in West Virginia

Treatment	N	P	K	Mg	Ca	S	B	Zn	Mn	Fe	Cu	Al
	---------------%					---------------	---------------mg/kg					---------------
Control	2.13	0.12	0.64	0.31	1.69	0.19	46.7	28.7	165.0	84.3	4.7	26.3
Manure	2.26	0.13	0.71	0.35	1.25	0.19	46.0	29.0	121.7	76.7	5.0	23.0
P-value	0.10	0.02	0.15	0.02	0.06	1.00	0.95	0.89	0.40	0.40	0.64	0.63

Table 4.—Mean biomass accumulation (+ standard error)† for the greenhouse experiments after one growing season, West Virginia

Species	Treatment	Leaf	Root	Stem	Total	Survival
Greenhouse study 1		----------------------------------	------------g------------	----------------------------------		%
Chinkapin‡	Rainwater	11.4 (0.9)a	22.0 (2.7)	9.1 (1.2)	42.5 (4.0)	100
Chinkapin	Rainwater+PBC§	4.5 (1.6)b	14.4 (4.7)	12.6 (2.1)	31.5 (6.9)	33.3
Chinkapin	Mine Water	10.1 (0.9)a	19.8 (2.7)	9.0 (1.2)	38.9 (4.0)	100
Chinkapin	Mine Water+PBC	na	na	na	na	0
	P-value	0.01	0.41	0.35	0.41	
Greenhouse study 2						
Chinkapin	Rainwater	6.1 (1.2)	18.6 (2.8)	4.3 (0.7)	29.0 (3.8)	100
Chinkapin	Rainwater+WBC§	7.2 (1.2)	12.6 (3.1)	3.7 (0.7)	23.4 (4.2)	80
	P-value	0.53	0.19	0.56	0.36	0.96
Greenhouse study 3						
Chestnut‡	Rainwater	16.6 (1.6)a	43.9 (7.9)a	28.8 (3.9)	89.4 (12.6)a	100
Chestnut	Rainwater+PBC	7.5 (2.1)b	16.2 (10.1)b	20.6 (5.1)	44.4 (16.2)b	60
	P-value	0.01	0.07	0.25	0.07	0.94

† Values with the same letter within a biomass component and study are not statistically different.
‡ Chinkapin = Allegheny chinkapin. Chestnut = Dunstan chestnut.
§ PBC= poultry-based biochar. WBC = wood-based biochar.

The second study compared Allegheny chinkapin seedlings grown in mine soil only to ones with mine soil amended with wood biochar (Table 4). Again, no statistically significant difference existed between the treatments. The largest difference between treatments was for root biomass, which differed by 32 percent. Stem and leaf tissue biomass differed by 16 and 18 percent, respectively.

Foliar elemental concentrations for seedlings growing in wood-based biochar amended soil were higher for N, K, Ca, and Al compared to unamended seedlings (Table 5). The greatest difference between treatments was for Al concentrations, which differed by a factor of three.

Foliar concentrations for rainwater-irrigated treatments between studies 1 and 2 were quite different for most elements. However, these treatments are not directly comparable because the initial seedling quality of the second study was relatively poor (much smaller seedlings) when compared to the rainwater-treated seedlings of the first greenhouse study.

The third greenhouse study investigated the growth and survival of Dunstan chestnut in soil amended with poultry biochar. All biomass values were significantly smaller (except for stem) for seedlings under the biochar treatment (Table 4). The most sizable difference between treatments occurred for root biomass, which differed by 270 percent.

Foliage testing on the composite samples suggests the poultry biochar treatment greatly increased the macronutrients in Dunstan chestnut seedlings (Table 5). Although not statistically comparable, foliage analyses between the field and greenhouse studies for Dunstan chestnut suggest similar concentrations for unamended seedlings. Biochar-treated seedlings had greater concentrations than manure-treated ones.

Table 5.—Foliar concentrations for seedlings grown in a greenhouse on soils from a reclaimed mine site in West Virginia

Species	Treatment	N	P	K	Mg	Ca	S	B	Zn	Mn	Fe	Cu	Al
		---------------------------%-------------------------------						-----------------------mg/kg---------------------------					
Greenhouse study 1													
Chinkapin[†]	Rainwater	2.93	0.16	0.80	0.53	1.88	0.29	27	34	377	93	11	13
Chinkapin	Rainwater+PBC[‡]	3.21	0.28	1.40	0.76	2.77	0.45	40	72	472	144	18	16
Chinkapin	Mine water	2.62	0.12	0.64	0.52	1.99	0.29	20	23	254	73	6	23
Greenhouse study 2													
Chinkapin	Rainwater	2.09	0.09	0.53	0.43	1.78	0.22	23	23	210	70	4	28
Chinkapin	Rainwater+WBC[‡]	2.24	0.09	0.54	0.40	1.87	0.20	23	23	182	59	4	86
Greenhouse study 3													
Chestnut[†]	Rainwater	2.29	0.11	0.62	0.37	1.29	0.22	29	32	157	70	5	24
Chestnut	Rainwater +PBC	2.66	0.13	0.76	0.52	1.96	0.28	28	24	171	67	6	22

[†] Chinkapin = Allegheny chinkapin. Chestnut = Dunstan chestnut.
[‡] PBC = poultry-based biochar. WBC = wood-based biochar.

DISCUSSION

If perennial seed-based energy crops (e.g., tree plantations established for seed production) are to be a viable feedstock for energy production in the future, large areas will need reforesting. Critical to this endeavor will be rapid establishment and development of these tree crops.

The amendments used in these field and greenhouse studies were not beneficial to seedling growth and development through the first growing season. Though it is possible that the treatment effects will manifest themselves in coming years, a major goal for any planting is to maintain high survival and promote early growth. Rapid growth is especially desirable in reclaimed mine sites in Appalachia to overcome intense weed competition and high deer populations. Weeds and deer were managed in the field study via herbicides and tree tubes; however, these treatments were expensive. Eliminating the need for tubes and reducing subsequent herbicide applications will more than offset the expense of applying fertilizer or manure (Barlow et al 2009, Texas Forest Service 2013).

Composted cow manure as soil amendment has been beneficial for many crops. Beneficial changes in the soil environment include increases in pH, cation exchange capacity, organic matter, and nutrient concentrations (Gil et al. 2008, Raviv 2005). The lack of response to the manure was not supported by the foliar analysis, which indicated increased nutrient concentrations for many major elements (Table 3) relative to the control. These tests did suggest N, K, S, and B are still somewhat low even for seedlings growing on manure-treated soils. Typical composted manure contains 1.38 percent N, 0.042 percent P, 0.054 percent K, 0.003 percent Ca, and 0.003 percent Mg, and has a pH of 7.5 (Miller et al. 2012). It is possible that a greater amount of manure (or more time to become available) will be required to overcome soil deficiencies (especially N, P, K).

The poultry biochar treatment was initially toxic to many of the seedlings. Though not quantified, many seedlings treated with poultry biochar lost leaves during the early summer, likely due to high soluble salt concentrations. Towards the end of the growing season, however, the surviving poultry biochar-treated seedlings looked much healthier (less chlorotic) than the untreated seedlings, presumably because some of the salts were leached out. Some agricultural crops have been shown to have reduced germination and yields with poultry biochar applications greater than 2.5 percent (Revell et al. 2012). Further research is needed to determine appropriate poultry biochar application rates.

Similar to our results, other studies have shown wood-based biochar has no effect on tree seedling growth. McElligott (2011) demonstrated that *Populus trichocarpa* did not respond to 25- and 50-percent hardwood biochar additions to native Andisols. Heiskanen et al. (2013) failed to show a growth response after applying up to 60 percent conifer-based wood biochar to Norway spruce. Both studies suggest the lack of response was partly due to low N levels in the biochar (the principle limiting element) and possibly immobilization, and indicate that biochar plus inorganic fertilizers may be required to see beneficial effects related to biochar.

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