HARDWOOD STOCKING AFTER FIVE YEARS ON RECLAIMED MINED LAND IN CENTRAL APPALACHIA: A PRELIMINARY ANALYSIS[1]

Ted Auch[2], James A. Burger, and David O. Mitchem

Abstract. Restoring mined land to native forest after surface mining could provide short- and long-term financial, environmental, and societal benefits. This study was conducted to test establishment procedures for short- and long-rotation tree species that consider (i) tree and ground cover compatibility, (ii) seeding versus hand-planting of certain short-rotation hardwood species (sycamore, green ash and tulip poplar), (iii) performance toward bond release, (iv) stocking among species and species types, and (v) the influence of spoil type, grading intensity, and site factors on tree performance. Reforestation treatments including natural invasion, direct seeding, and planting of nurse trees, softwoods and hardwoods were established on ten 2-ha recently-mined sites in Virginia, West Virginia, and Kentucky. A broad gradient in spoil type, degree of compaction, and ground cover amount occurred across the 10 sites. Natural invasion was negligible (7 trees/ha), and direct seeding of nurse and softwood species produced only 353 trees/ha. Planted softwoods (sycamore, green ash, red maple) had the highest stocking level (907-930 trees/ha), while planted hardwoods (oaks, sugar maple, white ash) survived with 783-865 trees/ha. Stocking levels of the commercially-valuable long-rotation hardwoods were significantly less then short-rotation softwoods. Stocking was influenced by groundcover competition, mine spoil density, and slope. None of the reforestation treatments were sufficiently stocked to meet state bond release criteria. Better mine soil conditions and less competitive ground covers are needed to ensure adequate stocking of native hardwoods.

Additional Key Words: hydroseeding, short-rotation softwoods, long-rotation hardwoods, reforestation, mine soil quality.

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Introduction

Historical Background

Strip mining of coal became a significant industry in the Appalachian Region during the late 1940s, and it became commonplace by the 1950sbecause it is the safest and most economical method of extracting coal from mountainous terrain. Strip mining causes dramatic changes on large tracts of land. Native forest systems are typically removed, and current mining and reclamation techniques may deter the recovery of the native forest (Brenner, 2000). The SMCRA requires that reclaimed lands be returned to an equal or higher land use than was present prior to mining. In most cases this involves a conversion to grassland for grazing or hay production (Chaney et al., 1995). Forests as a post-mining land use have decreased significantly since 1977 (Miller, 1990). However, 25 years after the law was implemented, landowners, the mining community, and the public at large realized that most mined land reclaimed as so-called grassland or wildlife habitat became low-grade, early successional scrubland with little or no value. Accordingly, there has been a resurgence of interest in restoring the native hardwood forest for its traditional uses and benefits. The question is how to do it in a way that is biologically feasible, economically viable, and satisfies the current reclamation regulations.

Limitations to Reforestation

A major impediment to the success of planted native hardwoods is the competition for resources from erosion-control groundcovers that are used initially during reclamation. Andersen et al. (1989) and Wali (1999) reported that non-invasive groundcover must be selected for timber species compatibility and the establishment of tree and shrub communities. Binns (1983) felt that the only instance when aggressive groundcover should be used is on sites where significant erosion is likely. There was a consensus among researchers that if the proper ground covers were used, or if herbicides were used to control their density, a variety of native tree species could be established.

In addition to competing ground cover, a factor constraining reforestation success is the use of proper topsoil substitutes with good physical and chemical properties (Daniels and Amos, 1981; Roberts et al., 1988; Rodrigue and Burger, 2004; Scullion and Malinovszky, 1995). Poor mined land productivity is due to the use of subsurface materials containing little organic matter and having poor chemical and physical properties (Skujinš and Richardson, 1985). Research on topsoil substitutes for tree growth has shown that ideal materials are sandstones that weather to a sandy-loam texture, have pH values ranging from 5.0 to 6.5, have low soluble salt content, and are non-compacted for good air/water balance (Limstrom, 1952; Torbert and Burger, 1990).

Recently there has been a concerted effort to establish timber-producing species such as black walnut (*Juglans nigra* L.), red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), sweetgum (*Liquidambar styraciflua* L.), and black cherry (*Prunus serotina* Ehrh.) (Ashby, 1996; Chaney et al., 1995; Scullion and Malinovszky, 1995; Torbert and Burger, 1990). Short-rotation species are the "soft" hardwoods, with low specific densities making them useful in oriented-strand board (OSB) and related composite wood products. They have small seeds that can be hydroseeded with ground covers. Long-rotation species are the “hard” hardwoods, with higher specific densities, making them suitable for sawtimber and other solid wood products. Most have large, heavy seeds that cannot be hydroseeded. Nurse trees collectively mitigate soil compaction, fix nitrogen, provide wildlife habitat, help close canopy, and count toward bond release, while yielding to crop trees by age 20 (Burger et al., 2002).

Torbert and Burger (1990) described a forestland reclamation approach that included tree-specific spoil selection, minimum grading to prevent compaction, use of tree-compatible ground cover, and use of good planting stock. This approach could restore mined land back to the characteristic mixed mesophytic forest of the region for benefits that include: (i) long-term financial returns from wood products, (ii) permanent site stability, (iii) prevention of the invasion by less desirable, weedy species, (iv) improved watershed control and quality, (v) development of wildlife habitat, (vi) erosion control, (vii) and the possibility of carbon sequestration credits (Baral and Guha, 2004; Brenner, 2000; El-Ashry, 1979).

The purpose of this study was to: (i) test hydroseeding versus hand-planting of certain short-rotation species; (ii) to determine the ground cover effect on tree stocking; and (iii) to determine the influence of spoil type, grading intensity, and site factors on tree stocking.

Materials and Methods

This study was conducted on 10 post-SMCRA mined sites in Virginia, West Virginia, and Kentucky. Sites were chosen to represent gradients in mine spoil type, grading intensity, and slope (Fig. 1). Sites ranged from grey sandstone to shale, with a spectrum of slopes (Table 1). Site compaction ranged from heavily compacted to very loose. Sites were located on a variety of slope positions.

MINE SPOIL TYPE

Sandstone (Site 1) -------------------------------- Mixture -- Siltstone

GRADING INTENSITY

Loose -- (Site 1) Medium ---------------------- Heavily Compacted

SLOPE

Flat (< 10%) ------------------------------ Intermediate (10-35%) --------------- (Site 1) Steep (> 35%)

Figure 1. Gradients of mine spoil type, grading intensity, and slope along which sites were selected for study. For example, Site (Block) 1 consisted of 90% sandstone spoil that was moderately compacted and had a slope of 36%.

Table 1. Descriptions and characteristics of study sites.

		------------------------- Treatment	-------------------------	
Site No.	Location	Slope %	Spoil Type	Compaction
1	Inez, KY (4/96)[1]	36	grey/brown sandstone	medium
2	Inez, KY (4/96)	25	grey sandstone	medium
3	Inez, KY (4/96)	23	grey sandstone	heavily compacted
4	Wise, VA (5/96)	2	shale	heavily compacted
5	Wise, VA (5/96)	19	grey/brown sandstone w/small amount of shale	medium
6	Inez, KY (3/97)	39	brown/grey sandstone	loose
7	Gilbert, WV (3/97)	9	brown sandstone	heavily compacted
8	Gilbert, WV (5/97)	48	brown sandstone	loose
9	Leivasy, WV (3/98)	35	brown sandstone/shale	loose
10	Rainelle, WV (4/98)	10	brown sandstone/shale	heavily compacted

[1] Installation date.

The sites were installed during a three-year period between April 1996 and April 1998. Five replications were planted in 1996, two in 1997, and three in 1998 (Table 1). For all sites, a tree-compatible ground cover (Torbert and Burger, 2000) was sown over a 2-ha area. The ground cover mix was designed to control erosion with 70% cover, while allowing adequate survival and growth of planted trees. Reforestation success of both short-rotation and long-rotation species was evaluated. The feasibility of establishing nurse trees and softwoods via seeding versus planting and the feasibility of establishing hardwoods in mixed-species stands via planting were tested (Fig. 1).

The six treatments were randomly assigned to 0.1-ha plots, which were the experimental units within each of the 10 blocks (Fig. 2). The treatments were: (1) natural succession (Natural Invasion), (2) seeded nurse trees (N) and seeded softwoods (S) (N & S seeded), (3) seeded nurse trees and planted softwoods (N seeded & S planted), (4) planted nurse trees and softwoods (N & S planted), (5) seeded nurse trees and planted hardwoods (H) (N seeded & H planted), and (6) planted nurse trees and hardwoods (N & H planted) (Fig. 2). All plots except for the control (natural invasion) contained nurse trees and crop trees. All crop trees were selected based on their present or potential commercial value, seed or seedling availability, and long-term ability to succeed in mixed stands.

The four softwood tree species were American sycamore (*Platanus occidentalis* L.), red maple, green ash (*F. pennsylvanica*), and tulip poplar (*Liriodendron tulipifera* L.), and the six hardwood tree species were black cherry, black walnut, sugar maple, northern red oak, white oak, and white ash. All species are native to the southern Appalachian mixed mesophytic forest and with the exception of black cherry all early successional species are softwoods. Nurse tree species, including autumn olive (*Elaeagnus umbellata* Thunb.) and bicolor lespedeza (*Lespedeza bicolor* Turcz.), were sown at a rate of 0.56 kg/ha. Green ash, sycamore, red maple, and tulip poplar were hydroseeded at rates of 2.24, 0.56, 1.68, and 11.21 kg/ha, respectively. Expected germination rates were 75, 30, 55, and < 10%, respectively, based on estimates by Plass (1976). Nurse, softwood, and hardwood trees were hand-planted at rates of 217, 247, and 163 trees/ha, respectively. Softwoods and hardwoods were hand-planted on 3.2 × 3.2m spacing, while nurse trees were planted on 4.5 × 3.4 spacing.

Reforestation Treatments and General Layout (Total Area = 1 ha)					
Natural Succession	Reforestation “Soft” Hardwoods			Reforestation “Hard” Hardwoods	
1) Natural Invasion	2) Seeded Nurse Trees (N) and Softwoods (S)	3) Seeded Nurse Trees (N) and Planted Softwoods (S)	4) Planted Nurse Trees (N) and Softwoods (S)	5) Seeded Nurse Trees (N) and Planted Hardwoods (S)	6) Planted Nurse Trees (N) and Hardwoods (H)
-- 6 subplots--					

Figure 2. Reforestation treatments applied to a total of 10 sites in Kentucky, West Virginia, and southwestern Virginia.

During the fall and winter of 2003-04, five soil samples (20-cm diam. x 30-cm deep) for physical and chemical analyses were taken from randomly located positions in each plot. Mine soil density was determined using a modified version of the excavation method described by Blake and Hartge (1986). Particle-size analysis was determined using the hydrometer method (Gee and Bauder, 1986). Soil acidity (pH) was measured using a glass electrode-calomel electrode cell.

Herbaceous groundcover was measured at age 5 by establishing six transects across each plot. Groundcover was estimated by viewing the soil surface through a 5-cm diameter PVC pipe at 0.3-m intervals (Chamblin et al., 2004; Provencher et al., 2001). Ground cover was put into the following categories: (i) grasses, (ii) legumes, (iii) weeds, (iv) bare soil, (v) rock, (vi) mosses, (vii) and ferns.

Tree numbers by species were recorded for five years following establishment. The significance of treatment, ground cover, site, and soil factors on tree survival was tested using a randomized complete block design. Ground cover, site, and soil properties were regressed with tree stocking to determine their influence. The best regression model was selected based on criteria that included minimizing variable significance, adjusted R^2, R^2, and biological and statistical significance ($P < 0.10$). R-squared values are shown as an estimate of the amount of variation in tree stocking attributed to the ground cover, site, and soil factors (SAS Institute Inc., Cary, NC 2001).

Results

Tree Stocking

An average of 7 trees/ha volunteered on the control plots (Table 2). The seeded nurse tree and softwood treatment had an average of 353 trees/ha, with nurse trees accounting for virtually all of the stocking. Stocking was not different with respect to the two planted softwood treatments, one with seeded nurse trees and one with planted nurse trees. They had 930 and 907 trees/ha, respectively. Hardwood stocking in the presence of seeded nurse trees was greater than when nurse trees were hand-planted, with 865 and 783 trees/ha, respectively. Bicolor lespedeza and autumn olive did well either seeded or planted. Neither bristly locust nor black locust were sown; their presence in the study was probably due to seed contamination in the hydroseeded mulch. Three softwoods, American sycamore, green ash, and red maple, survived well when planted, with stocking rates ranging from 115 to 226 trees/ha. Tulip poplar survival was poor, with stocking between 23 and 38 trees/ha. Except for white ash, with approximately 150 trees/ha, the hardwoods had lower stocking rates than the softwoods. Excluding white ash, hardwood stocking rates ranged from 38 to 87 trees/ha (Table 2).

In a comparison of stocking by site (Table 3), none of the control plots had more then 20 trees/ha, with most of those being nurse trees. The success of seeded nurse and softwood trees varied greatly among sites; stocking rates ranged from 37 to 1476, demonstrating the great influence of variable site factors on germination, emergence, and survival of seeded trees. Site 9 was the only one that met the target stocking level of 1000 trees/ha; it had 1476 trees/ha. Aside from site 9, this treatment yielded < 500 trees/ha across the rest of the 9 sites. Sites 1, 6, and 8 yielded the fewest stems, with 37, 58, and 71 trees/ha, respectively. Six of the ten N seeded & S planted treatments had stocking levels that approached 1000 trees/ha, with Sites 9, 8, 1, and 6 exceeding the target, with 1588, 1153, 1126, and 1025 trees/ha, respectively. Half of the N & S planted treatments had stocking levels that approached the target. Sites 9, 8, 2, and 1 exceeded the target, with 1551, 1136, 1057, and 1047 trees/ha, respectively. Site 6 had the only N seeded & H planted treatment that exceeded the target, with 1057 trees/ha. Multiple sites had more than 900 trees/ha, including Sites 9, 1, 2, 5, 3, and 8, with 958, 956, 954, 939, 921, and 917 trees/ha, respectively. Sites 6 and 8 were the only locations where the N & H planted treatment exceeded 1000 trees/ha, with 1107 and 1037 trees/ha, respectively. Sites 1 and 2 had stocking levels that exceeded or approached 900 trees/ha. In all planted treatments, whether S or H, site 10 yielded the lowest number of stems, with 448, 356, 491, and 415 trees/ha for N seeded & S planted, N & S planted, N seeded & H planted, and N & H planted, respectively (Table 3).

Table 2. Stocking (trees/ha) means as a function of species and treatment type.

	-------- Nurse Trees[1] --------				----- Soft Hardwoods[1] -----				-------------- Hard Hardwoods[1] --------------						
Treatment[2]	AO	BL	BrL	BlkL	AS	GA	RM	TP	BC	BW	NRO	SM	WA	WO	Mean Stocking
Natural invasion	1	2	0	3	0	0	1	0	0	0	0	0	0	0	7e
N & S seeded	96	195	46	15	0	1	0	0	0	0	0	0	0	0	353d
N seeded, S planted	144	218	101	0	130	198	116	23	---	---	---	---	---	---	930a
N & S planted	120	166	88	10	115	226	144	38	---	---	---	---	---	---	907a
N seeded, H planted	142	227	82	0	---	---	---	---	80	53	39	54	144	44	865b
N & H planted	114	176	66	3	---	---	---	---	87	56	38	39	152	52	783c
Species Means	103bc	163a	64de	9g	61de	106b	65de	15fg	42ef	27fg	19fg	23fg	74cd	24fg	

[1] AO = autumn olive; BL = bicolor lespedeza; BrL = bristly locust; BlkL = black locust; AS = American sycamore; GA = green ash; RM = red maple; TP = tulip poplar; BC = black cherry; BW = black walnut; NRO = northern red oak; SM = sugar maple; WA = white ash; WO = white oak.

[2] N = nurse trees; S = softwoods; H = hardwoods.

Table 3. Stocking (trees/ha) totals as a function of site and treatment.

Treatment	Site[1] 1	2	3	4	5	6	7	8	9	10
Natural invasion	0	0	0	0	20	10	0	0	20	20
N & S seeded	37	184	497	241	445	58	249	71	1476	271
N seeded, S planted	1126	903	839	607	988	1025	604	1153	1588	448
N & S planted	1047	1057	771	731	800	929	603	1136	1551	356
N seeded, H planted	956	954	921	832	939	1057	616	917	958	491
N & H planted	909	899	781	583	830	1107	514	1037	721	415

[1] See Table 1 for site descriptions.

Groundcover Distribution

There was no difference in groundcover distribution or total cover, with respect to treatment (Table 4). Total cover was greatest on Sites 6 (95%), 7 (96%), and 8 (96%), with Site 4 (34%) having the least herbaceous cover (Table 5). All but two of the sites (3 and 4) had >50% herbaceous cover five years after reclamation. Fractured rock or boulders (rock) at the spoil surface was greatest at Site 3 (12%) and was least on Sites 8 (0.0%), 7 (0.3%), and 6 (1%). Spoil devoid of herbaceous cover, fractured rock, or boulders (bare) was greatest on Site 4 (65%). Sites 6, 7, and 8 all had 4% bare ground. Grass cover was greatest at Site 8 (78%) and least at Site 4 (11%). Legume cover was highest on Sites 7 (33%), 6 (38%), and 5 (40%), with the least amount of legume cover occurring on Site 8 (10%). Weed cover was greatest at Site 9 and least at Site 10, with 5 and 0%, respectively. Moss cover was greatest on Sites 6 (5%) and 8 (6%), with Sites 3, 4, 5, 7, and 10 having no moss cover. Sites 9 (3%), 8 (2%), and 6 (2%) had the highest fern cover, while Sites 3, 4, 5, 7, and 10 had no fern cover.

Table 4. Groundcover distribution (%) as a function of treatment.

Treatment	Groundcover Distribution (%)[1] Rock	Bare	Grass	Legume	Weed	Moss	Fern	Total Cover[2]
Natural invasion	2a	23a	46a	25a	1a	1a	1a	75a
N & S seeded	4a	24a	41a	27a	1a	2a	1a	72a
N seeded, S planted	4a	24a	50a	20a	1a	1a	1a	72a
N & S planted	5a	31a	41a	19a	1a	2a	1a	64a
N seeded, H planted	3a	28a	37a	29a	2a	2a	1a	70a
N & H planted	2a	19a	50a	25a	2a	2a	1a	79a

[1] Rock = fractured rock or boulders; Bare = bare ground; Legume = legume spp.; Weed = weed spp.; Moss = moss spp.; Fern = fern spp.

[2] Total Cover = grass + legume + weed + moss + fern

Table 5. Groundcover distribution (%) as a function of site.

Site	Groundcover Distribution (%)							Total Cover
	Rock	Bare	Grass	Legume	Weed	Moss	Fern	
1	2de	15d	56bc	20bcd	2b	3c	2b	83b
2	4cd	26cd	51bc	16cd	2bc	1de	1b	71cd
3	12a	45b	25d	16cd	1bcd	0e	0e	42ef
4	1de	65a	11e	22bc	1bcd	0e	0e	34f
5	6bc	26c	27d	40a	1cd	0e	0e	68d
6	1de	4e	50c	38a	1bcd	5b	2b	95a
7	0e	4e	63b	33a	0d	0e	0e	96a
8	0e	4e	78a	10d	0d	6a	2ab	96a
9	8b	38b	30d	16cd	5a	1d	3a	55e
10	1de	20cd	50c	30ab	0d	0e	0e	80bc

After testing for variable multi-colinearity and normality, a regression model of total groundcover as a function of silt + clay and pH was selected as the model best describing the influence of site and soil factors on ground cover (Eq. 1). Silt + clay and pH accounted for 34% of the variation in groundcover distribution across the 10 study sites. As silt + clay and pH increased in value, groundcover decreased.

$$\text{Total Groundcover (\%)} = 235.51866 - 1.42_{\text{Silt + Clay (\%)}} - 14.57_{\text{pH}} \qquad \text{[Eq. 1]}$$

$$\text{pH} - R^2 = 0.2174;\ P = 0.0024$$

$$\text{Silt + Clay} - R^2 = 0.3398;\ P = 0.0127$$

A simple regression of tree stocking as a function of percent cover was not significant despite the fact that ground cover varied between 15% and 95% and stocking varied from 250 to nearly 1600 trees/ha (Fig. 3). It is likely that other site and soil factors were masking a ground cover influence on tree stocking.

Site and Soil Properties Influencing Tree Stocking

Slope steepness ranged from nearly flat at 2% to a high of 48% (Table 6). Percent coarse fragments (CF) ranged from 48 to 67%, and sand content ranged from 46 to 68% of the fine earth fraction. Bulk density varied greatly across the sites, with a high of 2.11 g/cm^3 to a low of 0.99 g/cm^3. Soil reaction was also highly variable, with pH levels ranging from 5.7 to 8.3 (Table 6).

The influence of site factors (slope) and soil factors (coarse fragments, silt + clay, bulk density, and pH) on tree stocking was tested with single factor correlations and with multiple regression (Fig. 4). There was a clear relationship between slope and stocking levels across all species, with stocking levels increasing from a low of approximately 500 trees/ha on slopes ≤ 10% to a high of 1600 on slopes greater than 35% (Fig. 4). Slope accounted for 52% of the variation in stocking across species and sites.

Table 6. Selected soil physical and chemical properties by site.

		Soil Physical Properties					
		Soil Particle Distribution (%)				BD	
Site	Slope (%)	CF[1]	Sand	Silt	Clay	(g/cm^3)	pH
1	36	57cd	68a	15f	17e	1.34f	8.2a
2	25	62ab	59cd	21c	22b	1.41e	8.3a
3	23	65a	63b	17e	19cd	1.81c	8.1a
4	2	62ab	55de	19d	25a	1.96b	8.2a
5	19	61bc	53e	20cd	26a	1.73d	7.4b
6	39	60bc	58cd	20cd	21bc	1.13g	7.2b
7	9	48f	59cd	22c	19ed	1.98b	6.6c
8	48	54de	61bc	20cd	18ed	1.12g	5.4e
9	35	51ef	46f	27a	27a	0.99h	6.2d
10	10	66a	53e	25b	22b	2.11a	5.7e

[1] CF = coarse fragments.

Stocking tended to decrease with increasing CF, but the relationship was not significant at the 0.10 level. On average, highest stocking was found on sites with < 55% coarse fragments (Fig. 5).

Stocking levels decreased with increasing silt + clay content, with the exception of the N seeded & S planted and N & S planted treatments at Site 9, which had the highest levels of stocking across all treatments and sites (Table 3 & Fig. 5). When these two outliers were removed from the data set using studentized, PRESS, and RStudent residuals, the relationship between stocking and silt + clay was significant, with stocking decreasing as silt + clay content increased. Stocking levels were generally below 1000 trees/ha when silt + clay content was ≥ 40% (Fig. 6).

Stocking was strongly correlated with bulk density. As bulk density approached 1.7 g/cm^3 stocking levels dropped below 1000 trees/ha (Fig. 7).

There was no correlation between stocking and soil pH (Fig. 8).

There was a strong linear relationship between slope and soil bulk density, showing that soils on steeper slopes are less compacted during the process of reclamation. Relative to tree stocking, slope and bulk density are highly co-linear, thus accounting for the same variation found in tree stocking across sites (Fig. 9).

Using step-wise multiple-linear regression, stocking was regressed with all cover, site, and soil variables (Table 5 and 6). After testing for multi-colinearity and normality, a regression model of stocking as a function of bulk density and ground cover was selected as the model best describing the influence of site factors on tree stocking (Eq. 2). Bulk density and ground cover explained over 70% of the variation in tree stocking across the 10 study sites, with bulk density explaining approximately 63% of the variation and ground cover accounting for the remaining variation.

$$\text{Stocking} = 2021.27 - 3.22_{\text{Total Groundcover (\%)}} - 595.68_{\text{Bulk Density (g/cm}^3\text{)}} \quad \text{[Eq. 2]}$$

$$\text{Bulk Density} - R^2 = 0.6269;\ P < 0.0001$$

$$\text{Total Groundcover} - R^2 = 0.7102;\ P = 0.0024$$

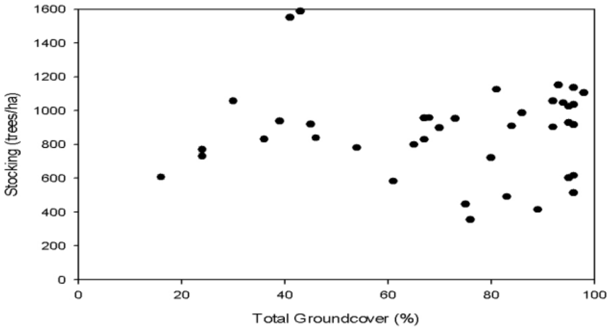

Figure 3. Tree stocking (trees/ha) including all species as a function of total groundcover (%) on 10 post-SMCRA sites in Virginia, West Virginia, and Kentucky.

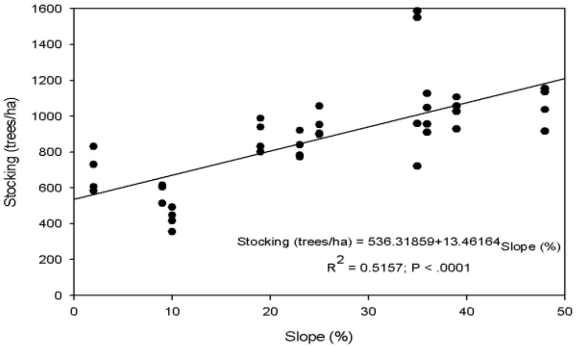

Figure 4. Tree stocking (trees/ha) across species as a function of slope (%) on ten post-SMCRA sites in Virginia, West Virginia, and Kentucky.

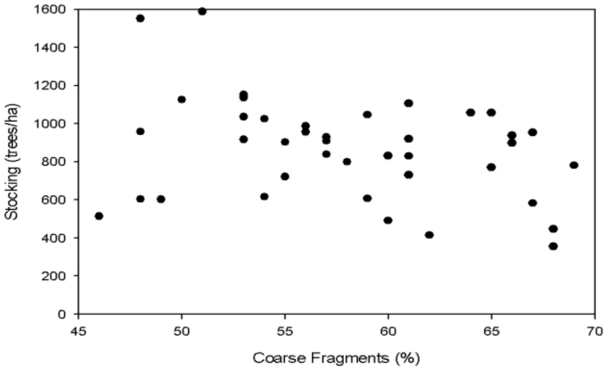

Figure 5. Tree stocking (trees/ha) across species as a function of coarse fragments (%) on ten post-SMCRA sites in Virginia, West Virginia, and Kentucky.

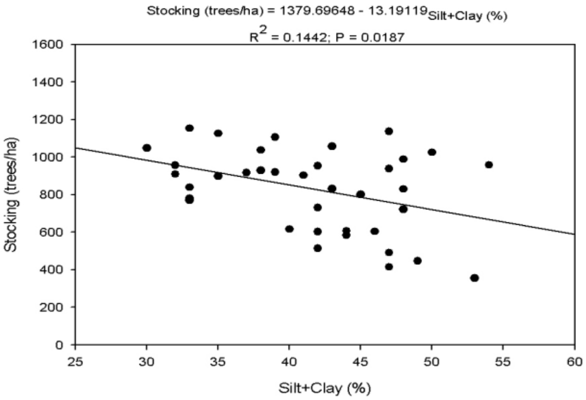

Figure 6. Tree stocking (trees/ha) across species as a function of silt + clay (%) on 10 post-SMCRA sites in Virginia, West Virginia, and Kentucky.

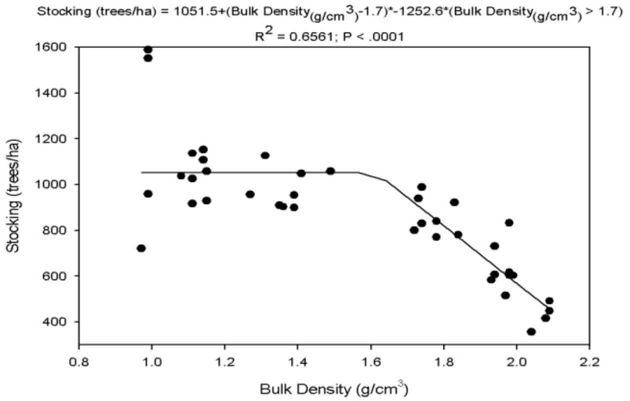

Figure 7. Tree stocking (trees/ha) across species as a function of mine soil density on 10 post-SMCRA sites in Virginia, West Virginia, and Kentucky.

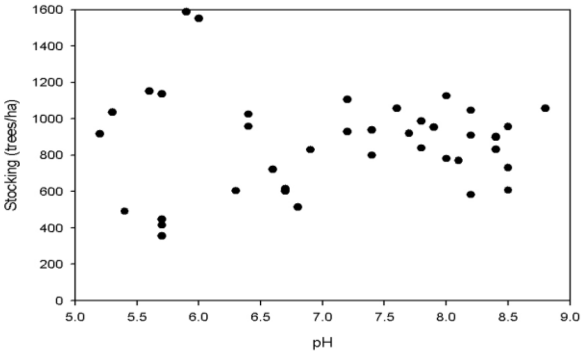

Figure 8. Tree stocking (trees/ha) across species as a function of soil pH on 10 post-SMCRA sites in Virginia, West Virginia, and Kentucky.

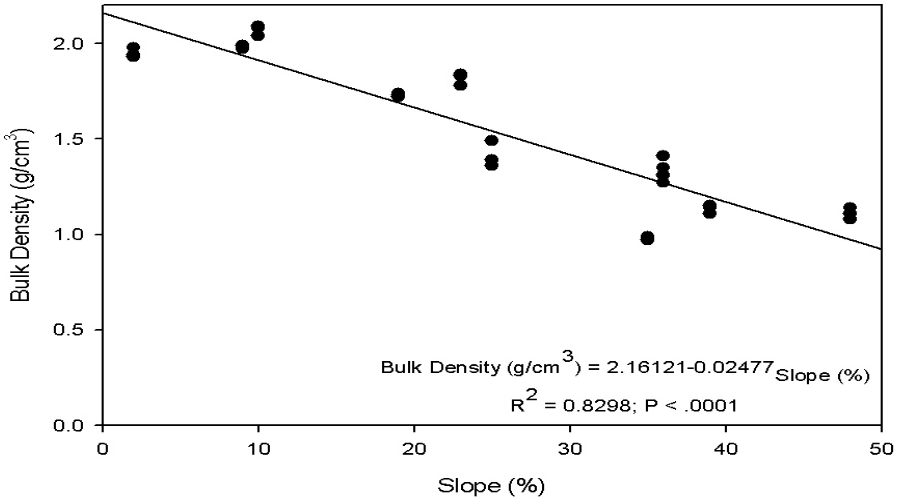

Figure 9. Bulk density (g/cm^3) as a function of slope (%) on 10 post-SMCRA sites in Virginia, West Virginia, and Kentucky.

Discussion

This preliminary analysis of our data shows that groundcover sown for erosion control suppresses the invasion of native woody plants; only an average of 7 woody plants per ha were able to invade over a period of 5 years. Early-successional nurse trees (autumn olive, bristly locust, and bicolor lespedeza) were moderately successful when hydroseeded along with the herbaceous cover. An average of 353 trees had established themselves after 5 years. Black and bristly locust were not seeded, but many bristly and a few black locusts volunteered. On the other hand, virtually no seeded hardwood trees were able to establish themselves. As long as regulators require herbaceous vegetation exceeding 70% cover, seeding trees is not an option for reforesting reclaimed surface mines, except for certain nurse species. Despite the use of a “tree-compatible ground cover“ recommended by Burger et al. (2002), 70% herbaceous cover is too dense for trees to emerge and survive from seed. Tree-compatible ground covers are designed to be low-growing so as to not overtop tree seedlings once they are established; however, they still out-compete trees for light, water, and nutrients, particularly at seeding rates meant to achieve 70% cover.

Except for tulip poplar (10% survival), planted softwood species survived fairly well across the 10 study sites when planted. Eighty-five percent of the green ash and 50% of the sycamore and red maple survived. Total survival of the planted nurse and softwood tree combination (treatment 3) was 65%; stocking was 907 trees/ha, which was short of the 1000 trees/ha required for bond release for this three-state region. The hardwood species, even less tolerant of competing ground cover and adverse mine soil conditions, did not do as well. As expected, white ash did well at 85%, but the remaining five species had survival rates ranging from 23% to 48%. Average total survival of the planted nurse and hardwood tree combination (treatment 6) was 55%; stocking was 783 trees/ha, which was considerably short of the required 1000 trees/ha requirement. Nurse trees accounted for 46% and 49% of all stocking in the planted softwood and hardwood treatments, respectively. These results are in agreement with other studies indicating that planted softwoods are better able to out-compete aggressive reclamation ground cover (Cunningham and Wittwer, 1984).

Stocking ranged widely across sites, with three of the 10 sites meeting or approaching the performance standard. Half the sites were clearly below standard. This shows that a combination of cover, site, and soil factors are differentially affecting survival. A cause and effect regression of tree stocking as a function of ground cover alone was not significant, but groundcover together with soil bulk density was highly significant. The two variables combined explained 71% of the variation in tree stocking. Bulk density alone explained 63% of the variation in tree stocking. No other site or soil properties were significantly correlated with stocking except for slope steepness. As slope steepness increased, stocking increased. This is counter-intuitive, given that the opposite relationship is found for undisturbed sites. Andrews et al. (1998) found the same result relative to better growth on steeper slopes. They attributed this response to lesser amounts of machine traffic on steep slopes compared to flats or gently-sloped areas. Indeed, we found slope steepness and bulk density highly correlated and co-linear in respect to their influence on tree stocking; therefore, in lieu of bulk density, slope was dropped from the regression model. These results support other observations and experimental results that bulk density and herbaceous vegetation remain the dominant hindrance to tree establishment in southern Appalachia (Limstrom, 1952; Torbert and Burger, 2000). High-density mine soils are poorly aerated, have low available water holding capacities, are poorly drained, and have high mechanical impedance to root growth (Raney et al., 1955).

Coarse fragment content and silt + clay content both had some influence on tree stocking, but their relationships were not significant at the 0.10 level. Other authors (Andrews et al., 1998) reported significant negative influences of coarse fragments and silt + clay on tree growth; that is, as coarse fragments exceed 50% by volume, tree growth declined, and soil texture finer than a sandy loam reduced tree performance. A number of other site and soil factors were analyzed including OM%, pH, and total nitrogen; none had an effect on overall tree stocking, but as we continue our assessment of these experimental sites, we hypothesize that several of these site and soil factors will influence the rate of tree growth of some species. We also expect that species groups (nurse, softwood, hardwood) as well as individual species will respond differently across sites as a function of site quality.

This preliminary analyses across 10 reclaimed mined sites shows that adequate stocking can be achieved if cover, site, and soil factors are appropriate for native deciduous tree species. It is easier to achieve required stocking levels with nurse and softwood species, but our results show that valuable, hardwoods can also be established in adequate numbers if good-quality sites are left uncompacted, and if ground cover competition is kept to a minimum or eliminated. It is clear that reclamation must be better tailored towards conditions required for tree growth, and that site-specific selection of species must be made to maximize the potential for bond release and future forest value.

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