SECOND YEAR RESPONSE OF APPALACHIAN MIXED HARDWOODS TO SOIL SURFACE GRADING AND HERBACEOUS GROUND COVER ON RECLAIMED MINE LAND[1]

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Abstract. Recent experience suggests that native Appalachian hardwood trees can be successfully established on coal surface mining sites if appropriate reclamation techniques are used. The Forestry Reclamation Approach (FRA) is a set of mine reclamation techniques developed for that purpose. Questions remain regarding how soil surface grading and choice of herbaceous vegetation affect tree survival, soil erosion and plant succession. An experiment was begun in the spring of 2008 with the goal of evaluating effects of grading and hydroseeding treatments prescribed by the FRA on reforestation success. Three steep (approximately 60% slopes) reclaimed mine sites were prepared in the coalfield of southwest Virginia. Half of each site was graded using conventional pre-FRA grading practices that cause compaction of the surface soil. The other half was loose-graded as per FRA recommendations. Within each grading treatment at each site, one third of the area was seeded with a conventional herbaceous vegetation mix that included competitive grasses and legumes; one third with a tree-compatible herbaceous mix comprised of less competitive grasses and legumes; and one third with 100% annual ryegrass. All experimental areas were planted with the same mix of native hardwood trees. Tree survival over one growing season was similar on the loose (71%) and compacted (70%) grading treatments, as well as on the conventional (65%), tree-compatible (71%), and annual ryegrass (75%) revegetation treatments. Recruitment diversity of non-planted species was greatest on the annual ryegrass treatment (12 volunteer species), suggesting this re-vegetation practice creates the most favorable conditions for natural succession. Soil erosion rates were significantly higher on the compacted treatment (-8mm soil soil surface change) than on the loose-graded treatment (+10mm soil soil surface change) over the course of two years. The annual ryegrass treatment produced significantly less ground cover (55% total) after two years than the conventional ground cover treatment (83% total), but this did not result in greater soil erosion.

Additional Key Words: compaction, grading, ground cover, reforestation, native hardwoods, reclamation, mine land succession

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Introduction

Recent progress has been made in the science and implementation of the Forestry Reclamation Approach (FRA), guidelines used for revegetating lands disturbed by surface mining for coal in the Appalachian region. The FRA is a mine reclamation protocol designed to improve the establishment of high-value hardwoods, increase the survival and growth of planted trees, and accelerate forest succession. The FRA has been approved by regulatory agencies and can be implemented more cost-effectively than traditional mine reforestation approaches prescribing extensive soil grading and dense herbaceous cover (Burger and Zipper, 2002). The FRA is intended to restore forested ecosystems on reclaimed mine sites and to recognize that productive forests produce economically valued products such as harvestable timber while providing ecosystem services such as production of clean water and air, sequestration of atmospheric carbon and provision of wildlife habitat (Angel et al., 2005).

Key aspects of the FRA include loose grading of the soil surface and tree-compatible ground covers. Low compaction grading helps planters install trees at the proper depth, allows rain to readily infiltrate the soil rather than causing erosive surface flow, increases soil moisture availability, improves soil aeration, and facilitates root growth by the planted trees. Low compaction grading is less expensive than conventional grading practices because fewer passes with grading equipment are required (Sweigard et al., 2007). Tree survival and growth are generally higher on loose-graded mine sites than on compacted and tracked-in mine sites. Numerous studies have demonstrated that high soil bulk density, which occurs as a result of excessive soil compaction, has a negative effect on tree growth (Jones et al, 2005; Rodrigue and Burger, 2004; Andrews et al, 1998; Torbert and Burger, 2000; Torbert and Burger, 1990).

Low density, low-growing herbaceous vegetation minimizes soil moisture competition and allows sufficient light penetration for tree seedling growth. Because of the vigorous nature of many forage species used for hay or pasture applications, most are not conducive to tree seedling establishment and growth. These species include Kentucky-31 tall fescue (*Festuca arundinacea*), red clover (*Trifolium pratense*) and sweet clover (*Melilotus alba*). Less-competitive legumes, considered to be more compatible with tree survival and growth and commonly recommended for use in the FRA, include birdsfoot trefoil (*Lotus corniculatus*) and white or ladino clover (*Trifolium repens*), while recommended annual grasses include foxtail millet (*Setaria italica*) and annual ryegrass (*Lolium multiflorum* Lam.). Perennial grasses that are considered "tree compatible" include perennial ryegrass (*Lolium perenne*), timothy *(Phleum pratense)* and orchardgrass (*Dactylis glomerata*) on steep slopes. Weeping lovegrass (*Eragrostis curvla*) is a tall grass that is useful on low soil pH sites at low seeding rates (Burger and Zipper, 2002).

Goal and Objectives

The goal of this study was to assess the effects of different surface grading techniques and herbaceous ground covers on forest ecosystem re-establishment on active mining operations.

We tested the following hypotheses:

-Increased intensity of grading and tracking by mining equipment reduces the survival of planted native hardwood trees and accelerates soil erosion.

-Increased levels of competitive herbaceous ground cover reduce the survival of planted native hardwood trees and hinder the recruitment of native vegetation.

Testing these hypotheses will allow refinement and improvement of the FRA prescriptions with a corresponding improvement in survival of planted trees and accelerated forest succession. This paper reports second year results for a study that was also described, after the first year, by Fields-Johnson et al. (2009).

Methods and Materials

Overview of Treatments and Design

Three experimental sites (blocks) were established by cooperating mining firms on active mining sites in southwestern Virginia. At each site, two grading treatments and three ground cover vegetation treatments were installed as a 2 x 3 factorial randomized block design, resulting in 6 treatment combinations and 18 total treatment plots. Each block was approximately 2.5 ha and the treatment plots averaged approximately 0.4 ha in size, although individual treatment plot sizes varied from this average. The two grading treatments were 1) smooth-grading with tracking-in (i.e. covering the surface with dozer cleat marks) or back-blading (dragging the bulldozer blade backwards across the site to create a smooth surface); and 2) loose-grading with a single dozer pass. Three revegetation treatments were sown on each grading treatment plot: 1) a conventional mix of herbaceous species intended to create >90% ground cover within the first few months of a growing season after seeding, 2) a tree-compatible mix (designated as "Powell

River Project mix" in Fields-Johnson et al., 2009) intended to create a moderate level of initial ground cover while eventually fully covering the soil surfaces, and 3) annual ryegrass, intended to create the lowest level of groundcover by planted species (Table 1).

The conventional ground cover treatment seed mix prescription is one that is commonly applied by a commercial hydroseeding firm on coal mining operations in southwestern Virginia. The tree-compatible mix prescription has been developed by the researchers using a process of trial, error and observation of many herbaceous species over many years. Hydroseeding was performed by a commercial contractor using operational procedures, under supervision by the mining firms but using our prescriptions, following final grading of mine spoil. Fertilizer was prescribed for inclusion in all hydroseeding mixtures at an approximate rate of 22 kg ha^{-1} nitrogen (N), 68 kg ha^{-1} phosphorous (P) and 18 kg ha^{-1} potassium. This fertilization prescription for reforestation has been developed by trial and error as a way to provide trees ample P without causing excessive herbaceous growth with large amounts of N. Block 1 was hydroseeded in the fall of 2007, Block 2 was hydroseeded in the winter of 2007-2008, and Block 3 was hydroseeded in early spring of 2008. Mining was completed for these sites at different times, hence the staggered hydroseeding schedule.

All sites were planted with the same mix of native trees (Table 2) by a commercial tree-planting contractor in mid-January of 2008. The tree species mix prescription has also been developed by trial, error and observation and included 205 trees ha^{-1} for each of seven commercially valuable hardwoods, lesser rates for two other commercial species, and low rates for several species of specific wildlife value. The planting contractors modified the actual planting rates based on available nursery stock and deviated somewhat from the planting prescription. These trees were all planted as one-year-old, bare-root seedlings without supplemental watering or fertilization. The overall tree survival rate in 2008 was 39% (Fields-Johnson et al. 2009), a rate considered unacceptably low by reclamation standards. As a result, all sites were re-planted in January of 2009 to bring them back to full stocking (Table 2). Photographs and maps for treatments and block locations can be found in Fields-Johnson et al. (2009).

Erosion Measurement

Erosion pins made of 1/2-inch (1.25 cm) diameter steel rebar were used to estimate loss and accumulation of surface soil. Nine erosion pins were driven into the ground to a depth of approximately 60 cm in each of the 18 treatment plots. Once installed, the sections of the pins that remained exposed were measured in height to the nearest mm on the uphill side. Thereafter, the pins were measured before the growing season (May) and after the growing season (November) of each year.

Table 1. Prescribed seed and mulch mixtures for ground cover treatments.

Annual Ryegrass Only	Rate
Seed Mix:	(kg ha^{-1})
Annual ryegrass (*Lolium multiflorum*)	22
Wood Cellulose Fiber	1680
Tree-Compatible Mix	Rate
Seed Mix:	(kg ha^{-1})
Annual ryegrass (*Lolium multiflorum*)	22
Perennial ryegrass (*Lolium perenne*)	11
Timothy (*Phleum pretense*)	6
Birdsfoot trefoil (*Lotus corniculatus*)	6
Ladino clover (*Trifolium repens*)	3
Weeping Lovegrass (*Eragrostis curvula*)	2
Wood Cellulose Fiber	1680
Conventional Mix	Rate
Seed Mix:	(kg ha^{-1})
Rye grain (*Secale cereale*)	34
Orchardgrass (*Dactylis glomerata*)	22
Perennial ryegrass (*Lolium perenne*)	11
Korean lespedeza (*Lespedeza cuneata*)	6
Birdsfoot trefoil (*Lotus corniculatus)*	6
Ladino clover (*Trifolium repens*)	6
Redtop (*Agrostis gigantea)*	3
Weeping lovegrass (*Eragrostis curvula*)	2
Wood Cellulose Fiber	1680

Soil Sampling and Testing

Soil samples were gathered for each of the 18 plots in the Spring of 2008. Samples were composed of nine sub-samples taken within each plot, each taken one meter from an erosion pin, and composited. The surface 5cm of soil were removed in order to eliminate hydroseeding materials from the sample and a 10-cm depth sample taken (i.e. 5 – 15 cm below the soil surface). Soil samples were air dried then sieved through a #10 screen to separate coarse and fine fractions. Fines were analyzed for pH, extractable cations, cation exchange capacity, soluble salts and organic carbon content (Soils data in Fields-Johnson, 2009). The coarse fragment fraction (fragments >2mm) was analyzed to determine the percent of each major rock type (weathered brown sandstone, un-weathered gray sandstone, siltstone, black shale, and coal).

Table 2. 2008 planting prescription and actual survival rates and 2009 re-planting prescription for trees to be planted alongside surviving trees to replace trees lost to mortality.

	2008 Planting Prescription	**2008 Survival**		**2009 Re-planting Prescription**
Species	**(trees ha^{-1})**	**(trees ha^{-1})**	**Rate[a]**	**(trees ha^{-1})**
White Ash (*Fraxinus americana*)	205	138	67%	67
White Oak (*Quercus alba*)	205	119	58%	86
Redbud (*Cercis canadensis*)	54	27	50%	27
Gray Dogwood (*Cornus racemosa*)	54	27	50%	27
Red Mulberry (*Morus rubra*)	25	12	49%	13
Black Cherry (*Prunus serotina*)	205	93	45%	112
Red Oak (*Quercus rubra*)	205	88	43%	117
Chestnut Oak (*Quercus prinus*)	205	67	33%	138
Black Oak (*Qurecus velutina*)	205	65	32%	140
Yellow-poplar (*Liriodendron tulipifera*)	124	33	27%	91
Sugar Maple (*Acer saccharum*)	205	28	14%	177
White Pine (*Pinus strobus*)	91	6	6%	85
Shagbark Hickory (*Carya ovata*)	62	3	4%	59
Total	**1,845**	**728**	**39%**	**1,139**

[a] Calculated from prescribed planting rate, which may have differed from the actual rate.

Vegetation Sampling

Five 0.02-ha, circular, woody-plant measurement plots were established on each treatment plot. Species, ground-line diameter, and distance from soil surface to highest live bud were measured for all trees within measurement plots in November of 2009. Additionally, four 0.0004 ha circular herbaceous plant plots were nested inside of each woody plant measurement plot. Within each measurement plot an ocular estimate of total living and dead ground cover percent was made in August of 2009 by comparing observed coverage with pre-established diagrams of various coverage rates. Samples of all observed plant species were collected for identification and separated into “planted” versus “volunteered” categories in order to distinguish the origin of each species.

Statistical Analysis

Data were analyzed using JMP 7.0 (SAS Institute Inc., Cary NC). Differences among treatments were determined using a randomized block ANOVA. Tukey-Kramer HSD was used for mean separations ($P < 0.10$). Multi-factor analysis was also performed to analyze treatment interactions and block effects.

Results

Significant differences were found in rock composition in the coarse fraction of the loose versus the compacted treatments (Table 3). Compacted treatments had higher average levels of weathered sandstone spoil, whereas loose treatments had higher levels of un-weathered sandstone. Amount of compaction had no significant effect on herbaceous ground cover or tree survival over the course of the 2009 growing season (Table 4). One mining firm reported that it required approximately 7.5 to 8.5 additional machine hours per ha to complete conventional grading treatments compared to loose graded treatments. The conventional ground cover treatment produced significantly more cover than the annual ryegrass treatment, but tree survival differences between ground cover types was minimal. In some cases the exposed height of erosion pins decreased over time, indicating a positive soil surface change (Table 5). This unexpected result was attributed to soil expansion caused by physical unloading, freeze-thaw processes, mineral slaking, moisture swell, and rooting expansion. Hence, erosion-pin measurements are expressed as “surface change,” a relative measurement calculated from the pins’ exposed heights; with negative change (erosion) indicating increased erosion-pin exposure. Visual observations indicated that soil was being lost even at sites where measured surface change was positive. Loose grading resulted in significantly less apparent erosion (as indicated by measured surface change) than compact grading. The tree compatible and annual ryegrass ground cover treatments eroded nominally less than the conventional mix. Grading treatment had no significant effect on volunteer herbaceous species richness, but the annual ryegrass revegetation treatment allowed more volunteer species to establish than the other two ground cover treatments (Table 5). No significant interaction effects between ground cover type and grading type were found for tree survival and soil erosion rates.

Table 3. Coarse fragment rock type analysis: Percentage by weight of soil samples made up of > 2mm coarse fragments, and percentage by volume of > 2mm fragments made up of weathered brown sandstone, un-weathered gray sandstone (with significant difference in means by Tukey HSD between grading treatments indicated by different letters beside values, α = 0.10), siltstone, shale and coal.

Treatment	Coarse Fragments	Weathered Sandstone	Un-weathered Sandstone	Siltstone	Shale	Coal
Grading:						
Compact	59%	47% a	15% b	36%	1.1%	1.4%
Loose	59%	39% b	28% a	31%	0.7%	1.6%
Groundcover:						
Conventional Mix	59%	46%	23%	29%	0.3%	0.8%
Tree Compatible Mix	58%	45%	18%	33%	1.3%	2.5%
Annual Ryegrass Only	62%	38%	22%	38%	1.0%	1.3%

Table 4. Treatment effects on percent ground cover rates and surviving trees per acre with significant differences (Tukey HSD) by alpha (α) level with differences indicated by different letters beside values within categories.

Grading	Ground Cover	α = 0.10	Tree Survival Rate	α = 0.10
Compact	72%	a	70%	a
Loose	70%	a	71%	a
Ground Cover				
Conventional Mix	83%	a	65%	a
Tree Compatible Mix	75%	ab	71%	a
Annual Ryegrass Only	55%	b	75%	a

Table 5. Cumulative treatment effects on surface change over the 2008 and 2009 growing seasons and on number of 2009 volunteer species. Significant differences (Tukey HSD) are depicted by different letters beside values within categories.

Grading	Surface Change (mm)	α = 0.10	Volunteer Spp.	α = 0.10
Loose	10	a	8	a
Compact	-8	b	6	a
Ground Cover				
Annual Ryegrass Only	8	a	12	a
Tree Compatible Mix	2	a	5	b
Conventional Mix	-7	a	4	b

Discussion

Neither the amount of ground cover nor tree survival was significantly affected by grading treatments after the second growing season (Table 4), a result similar to that found by Torbert and Burger (1992). The confounding factor of spoil selection may have biased the effects of grading treatments (Table 3). Past experiments have shown that tree survival and growth for most species improves with reduced grading activity (Angel et al., 2006). Loose graded plots in this experiment had significantly more un-weathered sandstone ($p = 0.01$) and less weathered sandstone ($p = 0.10$) than compacted plots. Research demonstrates that weathered sandstone in this region is an excellent substrate for growing native trees (Emerson et al., 2009; Showalter and Burger, 2006), and weathered sandstone materials are recommended for surface placement where available (Burger et al., 2005). Although efforts were made to control spoil selection during experimental plot construction, variability in local sources resulted in measurable differences in spoil type between grading treatments. Another possible explanation for grading not having an effect on tree survival may relate to plot steepness (often 60% slopes or steeper). Mining equipment creates less compaction on steep slopes than on near-level grades. Although we did not find a difference between the grading treatments at year two, the long term response on very steep slopes has yet to be determined. Other research has suggested that soil compaction effects may be more evident in the long-term (Burger and Evans, 2010).

Although significant differences in ground cover rates were achieved by the different herbaceous vegetation treatments, reduced plant cover did not result in significantly increased tree survival. Nominally, tree survival did vary inversely with ground cover percentage across the three treatments (Table 4), indicating that significant relationships might emerge with more time. In the first year after replanting, tree survival was considered acceptable across the entire experiment at 65-75%. The positive effects of lower herbaceous planting rates on tree survival on reclaimed mined land have been demonstrated (Torbert et al., 2000, Burger et al., 2005b, Skousen et al., 2006). Tree-compatible and annual ryegrass only ground cover treatments may produce significant long-term differences in tree growth and survival due to the reduced competition between trees and herbaceous vegetation for water, sunlight and soil nutrients as the transplanted trees move from the establishment to the growth phase. Re-planting brought all plots up to full stocking before the 2009 growing season, during which rainfall was abundant. The fact that re-planted trees were not subjected to significant moisture stress during their first summer may have influenced the lack of observed effect by grading treatment on tree survival.

We hypothesized that higher levels of compaction would lead to higher levels of surface erosion, and this basic hypothesis is supported by our study results (Table 5) and those of Torbert and Burger (1992). Our hypothesis was based on previous research findings that the increased erosion associated with greater grading intensities results from reduced soil macro-porosity and poor water infiltration (Evans and Loch, 1998) caused by excessive grading, but the exact mechanism causing our results has not been determined. Although our results did not demonstrate an effect by grading on tree survival, other effects, such as reduced grading costs and decreased soil erosion, are also important reasons for preferring minimization of surface grading to limit soil-surface compaction.

Our hypothesis that grading treatments would exert primary controls over erosion rates, suggests that all three experimental ground cover treatments would control erosion equally well. This was the case at the end of year two (Table 5). Past study has shown that ground cover with as little as 50% coverage can drastically reduce runoff and erosion compared to bare soil (Loch, 2000). Even though the annual ryegrass ground cover died back after the first year, this treatment resulted in the least nominal soil erosion. Heavy first-year growth of annual ryegrass created a dense mat of dead biomass that protected the site the second year. Furthermore, the ryegrass cover allowed more recruitment of non-planted species (Figure 1), which may lead to additional reductions in erosion over longer intervals.

We hypothesized that lower cover rates would facilitate faster recruitment of volunteer plants and succession relative to the other two ground cover treatments. Earlier studies have shown that plantings of non-native, aggressive ground covers can impede herbaceous plant succession (Holl, 2002; Burger et al. 2005b). The annual ryegrass treatment did have a significantly higher number of volunteer herbaceous species at the end of the second growing season (Table 5), most likely the result of reduced cover by living plants and reduced herbaceous competition. Contaminants in the annual rye seed may have also contributed to these other observed species, although we consider that to be unlikely because several of the plant species observed did not appear on the other ground cover treatment sites, where annual ryegrass was also a seed mix component, and because the seed sources were certified to have low levels of contamination. Planting only annual ryegrass may speed succession without increasing erosion or reducing tree survival. Annual ryegrass treatments have been shown to be compatible with tree establishment while achieving other reclamation goals (Groninger et al., 2007), especially at locations with near native seed sources and with soil properties that are favorable for native volunteer species establishment.

One concern with seeding practices that produce low levels of groundcover, such as the annual ryegrass in this experiment, is that they may result in exotic species invasion along with desirable natives. An alternative hypothesis is that less competitive groundcovers result in faster native plant recruitment, thus reducing the potential for exotic species invasion (Burger et al., 2009). Past study has shown that native trees can become established on sites even when they are not planted, where aggressive groundcover is not present (Skousen et al., 2006). Our finding that seeding with annual ryegrass is compatible with native plant recruitment is consistent with this earlier study. Further monitoring will be necessary to determine how herbaceous ground covers affect long-term recruitment of both desirable and un-desirable species. Another longer-term question regarding the annual ryegrass treatment, which can only be answered with long-term monitoring, is whether the lack of planted N-fixing legumes will negatively affect available soil N and, as a result, decrease forest productivity.

Figure 1. Research personnel on the loose grading, annual ryegrass treatment of Block 1 in late summer of experimental Year 2. The photo shows how a variety of unplanted species are being recruited to the reclaimed area.

Conclusions

After two growing seasons no significant differences in survival rates of mixed native hardwoods were observed to occur in association with, or caused by, different grading and ground cover treatments, but rates of soil erosion and unplanted species recruitment were affected. On the steep slopes of these experimental sites, loose-graded reclamation treatments had less soil surface loss, an indicator of soil erosion, than the more intensively graded treatments. Considering the fewer machine hours required for loose grading, these study results support the loose-grading methods recommended with the FRA (Sweigard et al., 2007). Planting only annual ryegrass appears to be an appropriate technique for promoting faster ecological succession on reclaimed mined lands on these study sites, without any associated negative effects such as increased rates of soil erosion. How widely or generally this finding can be applied on coal mine reclamation sites has yet to be determined.

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