INFLUENCE OF GRADING INTENSITY ON HERBACEOUS GROUND COVER, EROSION, AND TREE ESTABLISHMENT IN THE SOUTHERN APPALACHIANS [1]

John L. Torbert and James A.Burger [2]

Abstract: In the southern Appalachian coalfields of Virginia, southern West Virginia and eastern Kentucky, the opportunity exists to create productive forests capable of providing good timber management opportunities on surface mined land. Unfortunately, this opportunity is seldom realized, in part because minesoil compaction caused by excessive surface grading hinders tree establishment and long-term tree growth. This five-year study was established in eastern Kentucky to evaluate the effect of several surface grading treatments on minesoil erosion, herbaceous ground cover development, and tree survival and growth. Three grading treatments were each replicated three times on a 40% slope. The treatments were 1) the operational "intensive" grading practice used by the operator, 2) a more "moderate" grading, and 3) a "ripped" treatment that created a rough surface. During the course of the study, the intensive graded treatment had the greatest erosion and the poorest ground cover development and tree growth. This traditional practice of intensive surface grading to create a smooth surface is not only unnecessarily expensive but, as this study clearly indicates, compaction caused by grading can have detrimental effects for environmental quality (erosion) and forest productivity. When forestry is the post-mining land use, grading practices should be minimized to leave minesoil in a loose condition to reduce erosion and increase tree growth.

Additional Key Words: compaction, minesoils, reclamation, productivity.

Introduction

Since passage of the Surface Mining Control and Reclamation Act (SMCRA), reclamation throughout the southern Appalachians has been conducted in a fashion that creates a "golf course appearance" by making a smooth landscape covered with lush grass. This reclamation scenario has become standard operating practice for most coal operators, and regulators have come to expect smoothly finished surfaces with dense vegetation, regardless of the designated post-mining land use. These practices may be desirable for creating a "hayland/pasture" land use, but they are counter-productive for a forestry land use, an important land use in the southern Appalachians.

Following a 30-year assessment of tree plantings on graded and ungraded spoil in Ohio, Larsen and Vimmerstedt (1983) concluded that spoil compaction was the most important SMCRA-related problem in need of solution for forest-land reclamation. Other researchers have voiced concern that SMCRA encourages excessive spoil grading that results in growth-limiting levels of compaction. Soil compaction increases soil strength, decreases soil aeration and water infiltration, and increases surface runoff. Compacted soils are difficult to plant, seedling mortality is often high, and surviving trees have slower growth rates.

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[1] Paper presented at the 1996 National Meeting of the American Society for Surface Mining and Reclamation, Knoxville, Tennessee, May 1996.

[2] J.L. Torbert, Soil Scientist, Mead Coated Board, Box 9908, Columbus GA 31908; J.A. Burger, Professor Forest Soils, Virginia Polytechnic Institute and State University, Blacksburg VA 24061.

Proceedings America Society of Mining and Reclamation, 1996 pp 637-646
DOI: 10.21000/JASMR96010637

https://doi.org/10.21000/JASMR96010637

Minesoil compaction seems most detrimental to tree growth on level areas. After the landforming stage is finished, operators typically do a "*final grading*" to smooth the surface and remove any protruding boulders, large roots, or any other debris that may be included in the spoil material. Finally, before the site is seeded, it is "*walked-in*", "*tracked-in*", or "*trammed*" using a bulldozer to cover the entire surface with indentations from the bulldozer treads. This practice breaks the surface crust that may have developed between the time of grading and seeding, removes any rills or gullies that formed, and creates a uniform distribution of small microsites to capture grass seed and produce a uniform ground cover.

SMCRA does not explicitly require the intensive surface grading that has become so common. Section 816.102 pertains to general requirements for backfilling and grading, and states that "*Disturbed areas shall be backfilled and graded to: 1) achieve the approximate original contour ..., 2) eliminate all highwalls ..., 3) achieve a post-mining slope that does not exceed the angle of repose ..., 4) minimize erosion ..., and 5) support the approved post-mining land use.*" This underlined requirement suggests that grading practices should be land-use specific. We contend that, when forestry is the post-mining land use, level and gently sloping land (where erosion hazard is slight) should be "rough-graded" and left in a loose condition. It should be acceptable for some rocks, depressions, and woody debris to remain on the surface of reclaimed land that will be used for growing trees.

Minesoil compaction effects on tree growth

Early reports on the adverse effects of spoil grading on tree growth were presented by Limstrom (1952) and Chapman (1967). In Ohio, Larsen and Vimmerstedt (1983) found that yellow-poplar height and diameter were 142% and 67% greater after 30 years on ungraded versus graded spoil banks. White pine height and diameter were 32% and 23% greater in the ungraded spoil.

In Illinois, Josiah and Philo (1985) contrasted the physical properties of unmined soil, ungraded spoil, and graded spoil. The bulk density of the ungraded spoil and unmined soil were both 1.3 Mg m^{-3}, whereas the bulk density of the graded spoil was 1.8 Mg m^{-3}. Four years after planting, black walnut (*Juglans nigra*) trees were 35% taller and stem diameter was 31% greater in the ungraded spoil compared to the graded spoil. Where graded spoil was loosened by ripping, height and diameter were increased 38% and 55%.

Torbert and Burger (1990) compared the survival and growth of six commercially important tree species planted on two adjacent slopes, each comprised of the same spoil material. One was operationally regraded and tracked-in, and the other was left in a rough-graded condition. After two years, tree survival averaged 42% on the conventionally regraded site and 70% on the rough-graded slope. For some species, average height growth was almost doubled by eliminating the compacting process.

Surface grading effects on erosion

Rough graded sites are less prone to erosion since the loose soil has a higher infiltration rate (Merz and Finn, 1951). In a discussion about mined land shaping and grading, Glover et al. (1978) listed five practices to reduce or detain surface runoff. First on the list was "roughening and loosening the soil" (followed by mulching and revegetation, topsoiling and use of soil amendments, reduction of slope length or gradient, and use of concave slopes). Minesoil that is left in a loose condition, either as a result of rough grading to avoid compaction, or by ripping to ameliorate compaction, has a greater infiltration rate that decreases overland flow and erosion. Furthermore, the lower strength of uncompacted soils is more conducive to root growth for trees and other plants and ensures that better vegetative cover will be capable of further protecting the soil.

Despite the common-sense knowledge

that loose soils have a greater infiltration rate and less runoff than compacted soils, there is a common belief among some reclamation contractors and inspectors that intensive grading is necessary to reduce erosion. To dispel the belief that intensive grading is necessary to prevent erosion, a research/demonstration project was established in eastern Kentucky to evaluate the effect of surface roughness on ground cover establishment, erosion, and tree growth.

Objectives

The specific objectives of this study were to:

1) compare the influence of three surface grading treatments on erosion. The treatments are i) standard intensive grading, ii) a moderate level of grading, and iii) intensive grading followed by ripping.

2) compare the influence of these three surface grading treatments on herbaceous ground cover development.

3) compare the influence of these three surface grading treatments on survival and growth of five tree species: white pine (*Pinus strobus*), loblolly pine (*Pinus taeda*), sycamore (*Platanus occidentalis*), sweetgum (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*).

Methods

Site Selection and Treatments

The study is located on land mined by Martiki Coal Corp. near Lovely, KY. A slope, approximately 50 m (upslope) by 500 m (along the contour) had been reconstructed and moderately graded to its final contour (40% slope). The site was not topsoiled. The topsoil substitute was an alkaline spoil derived primarily from gray siltstone with a minor component of gray and oxidized sandstone. Spoil pH before hydroseeding ranged from 7.7 to 8.8. The site was awaiting final surface grading and hydroseeding when it was selected for study in January 1991.

The slope was divided into nine plots (50 x 50 m) that were used for three replications of three grading treatments. The three grading treatments, installed on March 26, 1991 were:

Intensive grading. This treatment was the standard operational practice used by Martiki and other operators in the region. Bulldozers (D-9 Caterpillars) smoothed the slopes by backblading (dragging their blades as they backed downhill), afterwhich the surface was tracked-in by running the bulldozer up and down the slope until the entire surface was covered with indentations from cleats on the bulldozer treads.

Moderate grading. For this treatment, no further grading was applied. Grading already completed when the study site was selected resulted in a fairly smooth surface, although some rocks and rills were present. A hard crust was present at the surface since six months elapsed between the time of grading and seeding.

Ripped. This was an ameliorative treatment intended to mimic the surface conditions that might be created by rough-grading. The initial study design called for a rough grading treatment where the slope would be returned to its approximate original contour with a minimal amount of grading, leaving some boulders, depressions, and loose soil at the surface. Unfortunately, when selected, the study site was already graded to the moderate level. The decision was made to backblade and track-in these plots to the intensive level of treatment, and then ameliorate the compaction by ripping with a 1-m deep subsoiling shank pulled directly downslope by the D-9 bulldozers. Rips were created at 3-m (10 ft) intervals. Ripping created a very rough surface in the immediate vicinity of the rips. Some large boulders (> 1 meter) were pulled to the surface and some deep holes were opened. This treatment did not loosen the entire soil; approximately 1.5 m between the rips remained compacted and unaffected by ripping.

Tree Planting

Trees were planted on April 1-2 1991, less than one week after installation of the grading treatments. Five species of trees were planted: white pine, loblolly pine, yellow-poplar, sweetgum, and sycamore. Approximately 40 of each pine species and 20 of each hardwood were planted in each plot on a 3 m x 3 m (10 ft x 10 ft) spacing. Two rows of each hardwood species and four rows of each pine species were planted. All species were 1-year-old seedlings except white pine which were 2-years-old. Trees in the ripped plots were planted in or very near the rip. After the fifth growing season, tree heights were measured and survival was determined.

Ground Cover Establishment

On April 16, two weeks after tree planting, a "tree-compatible" ground cover (Table 1) was established by hydroseeding. After the first and fifth growing seasons, three 30 m (100 ft) transects were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. At 0.6 m (2 ft) intervals along the transect, a 2.5 cm sighting tube was used to assess ground cover. If more than half the area observed through the tube consisted of bare soil, the point was tallied as such. If more than half the area was vegetated, the vegetation was tallied as grass or legume. This was done at 150 points per plot.

Erosion Measurements

Soil movement from the slope and deposition at the toe of the slope were monitored by measuring the changes in the distance between the soil surface and the top of metal rods installed in each plot. Three rows of metal rods were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. Ten rods were installed in each row, 3 m (10 ft) apart from each other. The above-mentioned vegetation transect was conducted along these rows of rods. A row of measurement rods was also placed at the toe of each plot on the level area. Rods were measured in October 1991, and October 1993, after the first and third growing season.

Results

The study was conceived with the goal of quantifying the amount of erosion and the response of herbaceous and woody vegetation to rough grading on a minesoil with desirable chemical properties for tree growth. Unfortunately, the ripped treatment did not accurately imitate rough grading because the area between rips was still compacted and the area within the rip was rougher than desired. The objective of rough grading is to leave an uncompacted surface that is similar to the surface of natural forest land with respect to undulations of the surface and the presence of rocks and boulders on the ground.

The ripped treatment in this study represented what many people would consider to be a worst-case scenario. If rough grading were likely to increase erosion, then deep ripping directly up and down a steep slope would surely represent a worst case opportunity for erosion to occur. Although the authors believe oxidized (brown) sandstone spoil is the best medium for tree growth in the southern Appalachians (Burger and Torbert 1990), and oxidized sandstone existed at this mining site, it was not possible to locate experimental plots where oxidized sandstone was placed at the surface. Unlike most coal operators in the southern Appalachians, Martiki's spoil handling is mostly done with a dragline. As such, the spoil that exists closest to the surface (oxidized sandstone) is placed immediately at the bottom of the adjacent, previously mined pit. In this situation, the best overburden for trees is buried about 20 m below the surface, and the spoil that exists immediately above the last coal seam will almost always end up on the final surface. For operations such as this, where the desired overburden material for forest productivity is not economically available, a research challenge exists to develop alternative reforestation strategies. The hardwood species used in this experiment were selected to evaluate their performance on near-neutral pH minesoils.

Ground Cover Establishment

All plots had a southerly aspect, which resulted in high surface temperatures on the dark gray spoil during the summer in the first year. The site received no rainfall from July to September in the first year, and rainfall in June occurred as short thunderstorms. As a result, ground cover was very sparse during the first year. Average ground cover after the first year was only 44% and unaffected by grading treatment. After five years, average ground cover increased to 86% and was still unaffected by treatment (Table 2). Most of the ground cover during the first three years was provided by weeping lovegrass (*Eragrostis curvula*), a heat-tolerant species. On some of the moderate and intensively graded plots, weeping lovegrass was almost the only species at the end of the first growing season. Although it is generally considered to be an acid-tolerant species (Vogel 1981) it survived very well on this dark, droughty, alkaline spoil.

Average legume cover was only 12% after the first year and 61% after three years. Birdsfoot trefoil (*Lotus corniculatus*) was the predominant legume species during the first three years, but crownvetch (*Coronilla varia*) was the most common after the fifth year. For the most part, ground cover on the moderately and intensively graded treatments was uniformly distributed across the plot. On ripped plots, however, values in Table 2 are a weighted average of the relatively sparse vegetation that existed in the area between rips, and the relatively vigorous vegetation that existed within the loose soil of the rips. Within a 1-meter band up the rip, ground cover was 100%.

Minesoil erosion

Compaction on intensively graded plots increased surface runoff. During a thunderstorm in June of the first year, surface runoff was observed flowing off the slope at the base of the intensively graded plots. On the ripped plots, there was overland flow occurring on the compacted soil between individual rips, but within the rips and the soil immediately adjacent to the rip, water was absorbed into the soil and no overland flow occurred. No water flowed from the rips at the bottom of the slope. Rips did not develop into gullies during the course of this study. The surface roughness created by ripping diminished as soil next to the rip moved into the rip and collected.

Erosion was quantified by two approaches: 1) as the average depth of spoil lost from the 30 erosion rods on each plot, and 2) by the average deposition at the erosion rods at the base of the plot (Table 3).

After the first growing season, erosion, based on measurements from erosion rods in the treatment plots, was 18 times greater in the intensively graded treatment than in the ripped treatment, and almost twice as high as the moderate-graded treatment. Variability among treatment replicates was so high that these differences were not statistically different, based on an analysis of variance and a probability level of 0.1.

Erosion results from third year measurements are confusing and probably unreliable. They indicate that no erosion occurred during the course of the study and that soil accumulated on the slope since year one. Measurements of the rods indicate a net deposition of approximately 0.4 cm on the slope in the ripped and moderate graded plots and no deposition or erosion from the intensively graded plots. Perhaps some loosening or swelling of the soil occurred as a result of disintegration of rock fragments or freezing in the winter.

Erosion appraisal based on a

measurement of deposition at the base of the slope seems to be a more meaningful assessment, although there are still some unexplainable effects between the first and third years. If soil freezing and expansion confounded results on the slope, it would also affect results at the base of the slope. After the first growing season, deposition at the base of the intensively graded plots was about 130% greater than the ripped treatment, and almost 600% greater than the moderately graded treatment. After three years, deposition at the base of the intensively graded plots was about 20% greater than the ripped treatment, and 118% greater than the moderately graded treatment.

Our method of measuring erosion does not provide an opportunity to calculate the Mg ha^{-1} of soil movement from the slope with any definitive level of confidence. Results are still valid however for accomplishing the fundamental purpose of this study: to compare the relative advantage or disadvantage of intensive grading to other treatments which leave the surface in a looser condition. It is reasonable to conclude that intensive grading did not prevent or decrease the amount of erosion compared to the treatments with looser soil. It's obvious that the intensively graded treatment had as much or more erosion than the moderate or ripped treatments. These results should help dispel the idea that intensive grading is beneficial for reducing erosion.

Tree survival and growth

The study included two species of pines (white and loblolly) and three hardwoods (sycamore, sweetgum, and yellow-poplar). It was known beforehand that the pH would be undesirable for pine growth, and thus the hardwood species were included. They were selected because of their reported ability to tolerate neutral-pH to slightly alkaline soils (Vogel 1981).

As anticipated, the pine species suffered on this minesoil (Table 4). Only 3% of the white pines survived to the fifth year. Almost all of the loblolly pines appeared dead within two months of planting, but by age five, 29% were still alive. The surviving loblolly pines were healthier than white pines, but still not vigorous. Foliage on loblolly pines was yellow, and some trees displayed reddish coloration at the tips of needles suggesting high soluble salt concentrations. The overall poor general health of these trees did not provide a good opportunity to evaluate the effect of these grading treatments on pine growth. Nonetheless, the height of loblolly pines was significantly lower on the intensively graded treatment than the moderate graded and ripped treatments (64, 120, and 99 cm, respectively).

Sycamore performed better in this study than any other species, and because it was relatively tolerant of the minesoil chemical conditions, it provides the best demonstration of compaction effects on survival and growth. In the ripped and moderate graded treatments, sycamore survival averaged 70%, but in the intensively graded treatment, survival was only 50%. Growth followed the compaction gradient created by treatment with the best growth occurring on the ripped treatment. Compared to the intensively graded treatment, average height was about 34% greater in the moderate treatment, and 74% greater in the ripped treatment.

Survival of sweetgum and yellow-poplar was significantly greater in the ripped versus intensively graded treatment. Only 3% of yellow-poplar survived in the intensively graded plots whereas almost 70% survived in the ripped plots. Growth of yellow-poplar was improved about 78% by ripping, but even in the ripped treatment, growth was not good for yellow-poplar or sweetgum. Overall poor growth was attributed to chemical properties of the minesoil. Even though these species are tolerant of a high pH, they would grow better in minesoils with a pH more typical of natural forest soils.

Conclusions

The study was established to compare the traditional intensive grading treatment with a less intensive "rough grading" treatment with respect to erosion, ground cover development, and tree performance. The experiment did not include a treatment that fairly represented rough grading conditions. The ripped treatment was an ameliorative treatment that mimicked rough grading to some extent. Ripping did not loosen soil between the rips, and the loose soil in and immediately adjacent to the rip was much rougher than would result from rough grading. The ripping process pulled some boulders (more than one meter in diameter) to the surface, creating huge depressions and open chasms that could be hazardous to people walking on the site.

Even though this study did not provide the opportunity to quantify the beneficial effect of a rough-graded oxidized sandstone, it is useful for concluding that the intensively graded treatment, which represents the standard operating practice for most coal operators in the Appalachians, did not provide any improvements in erosion control, ground cover establishment or tree survival and growth. All measures of performance were lowest on the intensively graded treatment. In some respects, the ripping treatment provides the opportunity to assess what many would consider a worst-case scenario: ripping a steep slope (where erosion potential was high) with rips oriented directly up and down the slope. The fact that ripping did not result in gullies or any observable increase in erosion provides evidence that the presence of loose soil does not necessarily lead to increased erosion.

Other researchers have found ripping to be beneficial to improving tree rooting and growth, and have recommended ripping as a standard practice where trees are planted on minesoils (Josiah and Philo 1985, Berry 1985). Although ripping can ameliorate compacted soils, the wiser approach would be to avoid the compaction in the first place. Ripping is an expensive operation which, if necessary to achieve decent tree survival and growth, could discourage operators from selecting forestry as a post-mining land use. Furthermore, ripping can create hazards by uplifting large boulders and creating holes that could be dangerous for anyone walking on the site.

We believe all aspects of reclamation, including final surface grading, should be land-use specific. In order for operators to satisfactorially reclaim surface-mined forest land to a level of productivity at least as high as prior to mining (as required by SMCRA) and to reduce erosion caused by surface runoff, operators should reduce the intensity of bulldozer activity when preparing the final soil surface. Reduced grading will not only decrease the operator's reclamation costs, but it will result in a looser, more productive soil which improves the success of tree planting, long term growth, and environmental protection.

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Table 1. Ground cover species and seeding rates used in experiment.

Species	Application Rate (kg ha^{-1})
Winter rye (*Secale cereale*)	10
Perennial ryegrass (*Lolium perenne*)	5
Orchard grass (*Dactylis glomerata*)	5
Weeping lovegrass (*Eragrostis curvula*)	3
Redtop (*Agrostis gigantea*)	3
Kobe lespedeza (*Lespedeza striata* var Kobe)	5
Appalow lespedeza (*Lespedeza cuneata* var Appalow)	5
Birdsfoot trefoil (*Lotus corniculatus*)	5
Ladino clover (*Trifolium repens*)	3
Crownvetch (*Coronilla varia*)	1

Table 2. Ground cover (%) after five years on a reclaimed minesoil in Kentucky as affected by grading treatment.

Grading Treatment	Total Cover (%)		Legume Cover (%)	
	average	range	average	range
Moderate	90	71-100	68	42-92
Intensive	85	62-97	61	33-81
Ripped	83	68-95	54	36-82

Table 3. Average soil loss and deposition after the first and third growing seasons on a reclaimed minesoil in Kentucky as affected by grading treatment.

Grading Treatment	Soil Loss from Slope (cm)		Soil Deposition at Base (cm)	
	Year 1	Year 3	Year 1	Year 3
Moderate	.44	-.39	0.50 b	0.85
Intensive	.72	0.0	3.48 a	2.21
Ripped	.04	-.38	1.51 ab	1.84

Values within a column followed by different letters indicate a statistically significant difference according to Duncan's Multiple Range Test at a probability level of 0.10.

Table 4. Survival and height of five tree species after five years on a reclaimed minesoil in Kentucky as affected by grading treatment.

Tree Species	Ripped		Moderately Graded		Intensively Graded	
	Survival - % -	Height - cm -	Survival - % -	Height - cm -	Survival - % -	Height - cm -
White pine	2	42	7	51	0	--
Loblolly pine	43	99 ab	32	120 a	15	64 b
Sweetgum	74 c	61	41 b	83	39 b	52
Yellow-poplar	69 a	79 ab	38 b	99 a	3 c	44 b
Sycamore	77 a	142 a	63 ab	109 ab	50 b	82 b

Values for survival and height within a species/grading treatment combination followed by different letters indicate a statistically significant difference according to Duncan's Multiple Range Test at a probability level of 0.10.