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LOOSENING COMPACTED SOILS ON MINED SITES

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Because successful surface-coal mining businesses must move earth materials efficiently, mining operations today use large and heavy equipment. Track dozers and haul trucks used for mining can weigh in excess of 100 tons each, while wheel loaders and loaded haul trucks often exceed 200 tons. It is becoming well known within the mining industry that successful reforestation of reclaimed sites requires loose and uncompacted surface materials, but some areas become compacted due to machinery operation, traffic, and storage that is necessary for the mining business to be successful.

Figure 1. Even when empty, haul trucks can weigh 50 - 100 tons or more; this weight exerts force where tires meet the land surface, causing severe compaction of mine soils. Loaders, dozers, and other heavy mining equipment also cause compaction that hinders tree growth when operated on surface soils.

Trees require deep, loose mine soils to survive and grow into healthy, productive forests. Such forests can support viable forest-products' businesses, protect the watershed, store carbon, and serve as wildlife habitat. This advisory describes procedures that can be used to loosen soils that have become compacted by mining equipment in order to restore land capability for forests.

Avoiding Soil Compaction

The best way to deal with compaction on mine sites is to avoid compacting the soil in the first place. Uncompacted conditions suitable for trees can be created using techniques that cost less than traditional smooth-surface "tracked in" reclamation. Loose dumping of surface materials, combined with the minimum grading necessary to shape the land, creates loose soils and rough surfaces, increases rainwater infiltration, and increases the survival and growth of trees. Throughout Appalachia, coal operators are finding these techniques to be a cost-effective successful method for establishing forests and achieving timely bond release when used with the Forestry Reclamation Approach (Burger and others 2005).

Coal operators can minimize equipment use on the final surface but there will often be areas that become compacted, generally the flatter areas and sites used for equipment storage. Many Appalachian and midwestern mine sites reclaimed under SMCRA have become compacted due to excessive equipment operation (Angel and others 2005). In order for such lands to support a forested postmining land use, soils must be loosened prior to reforestation.

What Can Be Done to Loosen Compacted Soil?

Ripping of the soil with a ripper blade or a deep plow attached to a dozer can alleviate most soil compaction effects on mine sites (Figure 2).

Figure 2. A dozer is ripping to loosen soils and produce soil conditions favorable to successful reforestation in a former roadway.

Subsurface ripping was first used for reclamation on prime farmlands disturbed by mining in the Midwest. In years following SMCRA's passage, rubber-tired equipment was often used to replace the subsoil and topsoil on prime farmland sites. Such practices compacted soils and created lands that could not produce the required crop yields.

Various deep plows were developed and used to overcome compaction in prime farmland reclamation, and research studies have shown that their use helps to restore soil productivity (Dunker and others 1995, 2000). More recently, similar methods have been used to alleviate soil compaction on post-SMCRA sites (Conrad and others 2002).

The choice of ripping device and procedure depends on site conditions. Available ripping devices include single, double, and triple shank rippers, with and without plow attachments.

Figure 3. A single-shank ripper is capable of ripping the soil to a depth suitable for forest trees when attached to a large dozer.

In areas where topsoil is lacking and surface spoils contain large boulders, a single shank ripper (Figure 3) will generally produce the best results. As the shank encounters boulders, they are lifted and rotated which has the effect of loosening the material around and above the boulders (Figure 4), which increases the operation's effectiveness. With this type of ripper in rocky soil, it is usually adequate to rip in only one direction.

When ripping is done on mined land with thick soil that is relatively free of boulders, a deep plow will do a better job of loosening the soil than a straight-shank ripper. In this case the plow's shape is important because, without boulders to be pulled up, the subsurface blade must lift and fracture the soil. A plow-like attachment has been used successfully on a single shank ripper blade (Figure 5). Such devices cannot withstand the stresses of moving large boulders and are not recommended where boulders are present.

If soils have a high clay content, ripping in two perpendicular directions ("cross-ripping") is recommended, as ripping in only one direction in clayey soils tends to cut a narrow trench without shattering the surrounding soil. The tree roots tend to grow only in the direction of the trenches, which makes them susceptible to being blown over by wind after they develop a crown.

Since forest trees require at least 4 feet of uncompacted rooting medium to achieve their growth potential, compacted mined land being prepared for trees should be ripped to a depth of at least 4 feet. Although 4 feet will be an effective ripping depth on most sites, deeper is better. In order to rip a compacted mine site to 4 feet, a dozer size equivalent to a Cat D-9 or larger is generally required. Use of shorter (less than 4 feet) rippers can be beneficial in areas where surface soils have been compacted but deeper soils remain loose. If a shorter single-shank ripper (less than 4 feet) is used, the entire area should be crossed-ripped to ensure adequate loosening of the surface. Using a triple shank ripper should eliminate the need to cross-rip because it loosens most of the total surface area. Unless a very large dozer is used, however, a triple-shank ripper may not reach as great a depth as a single-shank ripper.

Figure 4. A ripping operation has brought large boulders to the surface, thus loosening the surrounding soil materials on this Appalachian surface mine. Note that the ripping has reduced ground cover density near the ripped channel, which will help tree seedlings planted over that channel to survive and become established.

When ripping is done on nearly level ground, the direction of ripping is not critical. However, when ripping is done on slopes, it is advisable to rip along the contour to minimize erosion.

In all cases, it is best to rip when the ground is dry because dry soils fracture much better than damp or moist soils; this is especially important for clayey mine soils. Ripping operations during late summer or fall take advantage of the relatively dry seasonal conditions while allowing soil settling for early-spring tree planting.

Figure 5. This ripper with a plow attachment can be used to loosen soils that do not contain large rocks and boulders. The "wings" on the ripper blade will loosen soils located beside ripping trench.

Is Ripping Needed?

On Appalachian surface mines it is common for relatively flat areas to be more compacted than steeper slopes, especially if those areas have been used for equipment storage, maintenance, and operations; such heavily compacted soils will require ripping to produce commercially valuable trees. In contrast, soils on steeper slopes often remain relatively loose because they are not affected by equipment operations after grading.

It is relatively easy to determine whether or not soils have been compacted to an extent which makes ripping necessary to ensure satisfactory tree growth. A common hand spade or a drain spade shovel can be used to estimate the extent of compaction by putting a modest amount of foot pressure (50 pounds) on the spade while rocking its tip to by-pass coarse fragments (if a rock big enough to block the spade is encountered, move to another spot). The depth of spade penetration will be affected by the degree of compaction and is an indicator of forest site quality (Table 1). For example, a highly compacted soil could be penetrated with a spade to a depth of 1 to 3 inches. Without ripping, the site would be classified as "fair" and would be capable of growing oaks only 50 feet tall at age 50. Trees growing at this rate would have little value except as firewood so the land would have little or no value as a forest-products investment. Ripping the site would improve the soil by 1 to 3 site-quality classes, depending on the type and quality of the ripping practice (This assumes other soil properties are suitable for growing trees, and good forestry practices are applied after the area is ripped.). Note that return on investment doubles when site quality is improved by one class.

Figure 6. A spade can be used to estimate mine soil density and the need for ripping. Depth of penetration when applying foot pressure and a rocking motion is an indicator of soils' capability to support trees that will survive and grow into commercial products (see Table 1). This long-nosed drain spade was able to penetrate spoil easily; this area should be able to grow trees successfully without being ripped.

Relationships between soil compaction, soil physical properties, and tree growth (Table 1) have been worked out in research studies. The term "bulk density" refers to a technical measure of soil density that is often used in such studies. A low bulk density indicates a loose soil that allows

Table 1. The relationship among degree of compaction, spade penetration depth, forest site quality, and relative return on a forestry investment (after Burger and others 1998, 2002; and Probert 1999). Forest site quality is an indicator of the soil's ability to support growing trees.

Soil Density Condition	Very Dense	Dense	Moderately Compacted	Slightly Compacted	Loose
Spade penetration	0-1 inches	1-3 inches	3-6 inches	6-9 inches	9-12 inches
Site Quality Class	V (poor)	IV (fair)	III (medium)	II (good)	I (excellent)
Oak site index [a]	40	50	60	70	80
Use for wood products	None	Firewood	Railroad ties	Saw timber	Veneer
$ /1000 board ft stumpage value[b]	-	Less than $100	$200	$500	$2000
Relative return on investment	-2%	0%	2%	4%	8%

[a] Approximate height in feet of a white or red oak growing at age 50. These ratings assume that all other factors (other mine soil properties, ground cover, seedling quality, etc.) affecting productivity other than soil density are optimum.
[b] As of 2/07. J. Hayek, Timber Blog. Univ. of Illinois Extension Div. http://web.extension.uiuc.edu/forestry/blogs/eb94/

rainfall to infiltrate easily, which helps to prevent erosion, and will not impede root extension by growing trees. Bulk density can be measured in different ways including specialized field sampling methods. Research has found that, in rocky spoil, dry bulk density should be less than 100 pounds per cubic foot at a depth of 2 inches, which correlates with relatively deep shovel penetration.

Figure 7. A tractor-mounted cone penetrometer is being used to evaluate soil density on a Kentucky surface mine.

Another way of evaluating soil density conditions is with a cone penetrometer, a common geotechnical testing device that drives a steel cone into the ground with a hydraulic ram. To ensure good tree growth in rocky spoil, the cone should be able to penetrate at least one foot into the ground. This is an average value that can vary based on soil type and rock content.

Has Ripping Been Effective?

Our experience shows that a deep and thorough ripping of very dense mine soils can improve the soil by as many as 3 or 4 site quality classes (Table 1). Even a moderately compacted site can be greatly improved because the economic value of trees increases disproportionately on the high end of the site-quality gradient due to improved wood product class (*e.g.,* veneer has a much greater value than saw timber – Table 1) as well as faster growth rates.

Is Ripping Cost-Effective?

Ripping should be considered a practice of last resort. It is far less expensive to avoid compaction during reclamation than to correct it once it has occurred. Loose grading costs less than the excessive grading that compacts soils because loose grading requires less dozer time – and loose-graded sites can grow trees successfully without the expense of ripping. Nonetheless, it is difficult to avoid all surface compaction on an active mine site; the pre-mining capability to grow trees cannot be restored on areas that have been compacted by repetitive equipment traffic unless such areas are ripped prior to planting.

Experience has shown that it takes about an hour to rip one acre with a D-9 dozer or equivalent with a single-shank ripper. In 2006 using contract equipment, the cost was approximately $150 per acre. The type of ripper used will also affect the per-acre cost. For example, a triple-shank ripper would require a larger tractor and more time.

Conclusions

The Forestry Reclamation Approach (FRA) is a way of reclaiming active surface mines to maximize reforestation potentials (Burger and others 2005). A non-compacted growth medium is essential to FRA reclamation. Soil conditions suitable for trees can be created by placing materials on the surface loosely, and minimizing surface grading. On areas that do become compacted, soil conditions suitable for trees can be restored through deep ripping. Although ripping may not produce land that is as desirable as land that has been loosely graded from the outset, it can alleviate soil compaction so that reforestation can be successful and restore land capability to pre-mining levels.

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