INTRODUCTION

Successful surface coal mining businesses must move earth materials efficiently, so mining operations today depend on large and heavy equipment (Fig. 5-1). Track dozers and haul trucks used for mining can weigh more than 100 tons each. Wheel loaders and loaded haul trucks often exceed 200 tons. The mining industry has learned that successful reforestation of reclaimed sites requires loose and uncompacted surface materials, but some areas become compacted due to the machinery operation, traffic, and storage that are necessary for the mining business to be successful.

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 Forest Reclamation Advisory describes how to loosen soils that have become compacted by mining equipment; these procedures can be used 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
Loosening Compacted Soils on Mined Lands

Uncompacted conditions suitable for trees can be created by 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 trees’ survival and growth. Throughout the Appalachian region, mine 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 (FRA) (Chapter 2, this volume).

Mine operators can minimize equipment use on the final surface, but there will often be areas that become compacted. These areas are generally the flatter areas and sites used for storing equipment. Many Appalachian and midwestern mine sites reclaimed under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) have become compacted due to excessive equipment operation (Chapter 1, this volume). In order for such lands to support a forested postmining land use, soils must be loosened before reforestation.

WHAT CAN BE DONE TO LOOSEN COMPACTED SOIL?

Deep tillage or ripping of the soil with a deep plow or ripper blade attached to a dozer can alleviate most soil compaction effects on mine sites (Fig. 5-2). Subsurface ripping was first used for reclamation on prime farmlands disturbed by mining in the Midwest. In the years immediately following the passage of SMCRA, rubber-tired equipment was often used to replace the subsoil and topsoil on these 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 mine 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. In areas where topsoil is lacking and surface spoils contain large boulders, a single-shank ripper (Fig. 5-3) will generally produce the best results. As the shank encounters boulders, it lifts and

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Figure 5-2.—A dozer ripping to loosen soils and produce soil conditions favorable to successful reforestation in a former roadway. Photo by P. Angel, OSMRE.

Figure 5-3.—A single-shank ripper attached to a dozer. This type of ripper is capable of ripping the soil to a depth suitable for forest trees when attached to a large dozer. Photo by P. Angel, OSMRE.
rotates them; this action has the effect of loosening the material around and above the boulders (Fig. 5-4), 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 (Fig. 5-5). Such a device cannot withstand the stresses of moving large boulders and is 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. Roots of trees tend to grow only in the direction of the trenches, which makes them susceptible to being blown over after they develop a crown.

Most forest trees require at least 4 feet of uncompacted rooting medium to achieve their growth potential, so compacted mined land being prepared for trees should be ripped to at least that depth. 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 equivalent to a Cat® D-9 (Caterpillar Inc., Peoria, IL) 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 using a shorter single-shank ripper (less than 4 feet), cross-rip the entire area 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.
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 tree planting in early spring.

**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 soils have been compacted to an extent which makes ripping necessary for satisfactory tree growth. Use a common hand spade or a drain spade shovel (Fig. 5-6) to estimate the extent of compaction by putting a modest amount of foot pressure (50 pounds) on the spade while rocking its tip to bypass 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 5-1). 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

**Table 5-1.—The relationship among degree of compaction, spade penetration depth, forest site quality (an indicator of the soil’s ability to support growing trees), and relative return on a forestry investment (after Burger and others 1998, 2002; Probert 1999).**

<table>
<thead>
<tr>
<th>Soil density condition</th>
<th>Very dense</th>
<th>Dense</th>
<th>Moderately compacted</th>
<th>Slightly compacted</th>
<th>Loose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spade penetration</td>
<td>0–1 inches</td>
<td>1–3 inches</td>
<td>3–6 inches</td>
<td>6–9 inches</td>
<td>9–12 inches</td>
</tr>
<tr>
<td>Site quality class</td>
<td>V (poor)</td>
<td>IV (fair)</td>
<td>III (medium)</td>
<td>II (good)</td>
<td>I (excellent)</td>
</tr>
<tr>
<td>Oak site index&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>Use for wood products</td>
<td>None</td>
<td>Firewood</td>
<td>Railroad ties</td>
<td>Sawtimber</td>
<td>Veneer</td>
</tr>
<tr>
<td>$/1,000 board ft stumpage value&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$0</td>
<td>Less than $100</td>
<td>$200</td>
<td>$500</td>
<td>$2,000</td>
</tr>
<tr>
<td>Relative return on investment</td>
<td>-2%</td>
<td>0%</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
</tr>
</tbody>
</table>

<sup>a</sup> Approximate height in feet of a white oak or northern red oak growing at age 50. These ratings assume that all factors other than soil density (for example, other mine soil properties, ground cover, seedling quality) affecting productivity are optimum.

<sup>b</sup> Source: Hayek (2007).
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 one to three 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.

Relationships between soil compaction, soil physical properties, and tree growth (Table 5-1) 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 rainfall to infiltrate easily—which helps to prevent erosion—and that 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. Another way of evaluating soil density conditions is with a cone penetrometer (Fig. 5-7), 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 1 foot into the ground. This is an average value that can vary with 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 three or four site-quality classes (Table 5-1). 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 (for example, veneer has a much greater value than sawtimber; Table 5-1) 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 needed for compacted 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 before planting.

Experience has shown that it takes about 1 hour to rip 1 acre with a D-9 dozer or equivalent with a single-shank ripper. Costs, using contract equipment, range from about $150 to $200 per acre (2016 estimates; B. Strahm, personal communication). 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.
SUMMARY

The FRA is a way of reclaiming active surface mines to maximize reforestation potentials (Chapter 2, this volume). A noncompacted 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 land capability can be restored to pre-mining levels.

LITERATURE CITED


