Economics of Soil Disturbance

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Abstract

Economic implications of soil disturbance are discussed in four categories: planning and layout, selection of harvesting systems and equipment, long-term site productivity loss, and rehabilitation treatments. Preventive measures are more effective in minimizing impacts on soils than rehabilitation treatments because of the remedial expenses, loss of productivity until mitigation occurs, and the possibility that original soil conditions may not be restored. Alternative harvesting practices that are designed to minimize impacts on soils, such as use of designated skid trails and wide trail-spacing, increase overall harvesting costs. Sites with high risk for soil disturbance may require use of expensive wood extraction methods (e.g., skyline yarding), as opposed to lower cost options (e.g. ground skidding). Tillage treatments in severely compacted areas appear to be cost effective if properly implemented. An accurate estimation of economic consequences from long-term site productivity losses is difficult, although there is a general consensus that soil disturbance at some locations can reduce tree growth.

Introduction

Questions on the economics of soil disturbance are often raised regarding long-term productivity losses, efforts to minimize soil impacts, and rehabilitation of damaged soils. What are potential financial impacts from site productivity losses? Should we require every ground-skidding machine on high-risk sites to use designated skid trails and how does this affect logging costs? Would it be cost-effective to ameliorate compacted soils? Are we financially getting a significant benefit from soil rehabilitation treatments? These questions have not been extensively answered because of the difficulty in obtaining appropriate data about tree responses to site disturbance across an entire rotation, the value of offsite impacts, and other pertinent information such as preventive and remediation measures (Lousier 1990; Miller and others 2004).

Lack of information on the economics of soil disturbance limits forest practioners from attempting to develop harvesting plans and timber sales. A harvesting plan needs to account for soil disturbance risks, previous impacts on soils, and preventive measures that minimize further damage to soils. Preventive measures may require cable logging systems on gentle slopes (<30 percent) or wider spacing of designated skid trails, but these often result in higher logging costs. Lack of compelling evidence to justify these high logging options often causes disagreements among forest managers, although there is a general consensus that soil disturbance may reduce tree growth at some locations (Miller and others 2004). One would also wonder if these preventive measures would financially benefit landowners in the long run.

This paper summarizes economic information related to soil impacts in four categories: planning and layout, selection of harvesting systems and equipment, long-term site productivity loss, and rehabilitation treatments. In this paper, soil disturbances include soil compaction, scalping, puddling, and soil displacement.

Planning and Layout: Measures to Prevent Soil Disturbance

Soil disturbance from timber harvesting may not be avoidable, but can be minimized through careful planning and operations. Preventive measures are more effective in minimizing impacts on soils than remedial mitigation because of the remedial expenses, loss of productivity until mitigation occurs, and the possibility that original soil conditions may not be restored (Miller and others 2004). Existing guidelines and requirements for soil protection should always be observed when the harvesting plan is developed. A good harvest plan can minimize soil disturbance by recognizing and identifying the risk of soil disturbance. Some important factors determining "risk rating" include soil texture, moisture content, slope, and organic materials at the top soil.

Planning and layout components for timber harvesting include locations for roads and landings, marking trees to cut or leave, and flagging skid trails or skyline corridors. These vary with different harvesting systems. For example, skyline yarding requires locating anchors for rigging and ground-profile analysis for available deflection, causing higher planning and layout costs for cable logging than ground-based harvesting system. Kellogg and others (1998) compared planning and layout cost for logging contractors in various silvicultural treatments. They found that a CTL system using a mix of random and designated skid trails (60-ft spacing) had the lowest cost, followed by the tractor-based winching system for hand-felled trees that used 130-ft spacing designated skid trails. The skyline systems had the highest cost.

Use of designated skid trails has been recommended in past soil compaction studies because it effectively reduces the skid trail areas in a harvesting unit and facilitates rehabilitation efforts (Andrus and Froehlich 1983). Designated skid trails at a wide spacing increase logging costs. In an earlier study (Bradshaw 1979), the harvest unit with pre-planned skid trails and winching had a 29 percent higher skid cost than the conventionally harvested unit. However, only 4 percent of its area was in skid trails, compared to 22 percent for the conventionally harvested unit.

There are other planning and layout components that increase costs, but are difficult to estimate. These include expenses related to evaluating soil disturbance risks, identifying areas in the field that pose a high risk for soil damage and erosion, and development strategies and guidelines to minimize soil impact. Delaying logging operations to dry seasons or winter season logging and strict requirements for best management practices (BMP) are examples for preventive efforts at a planning stage. These expenses usually occur in the form of overhead or administrative cost and can be estimated based on companies or agencies' indirect cost rates.

Selection of Harvesting Systems and Equipment

Because harvest equipment creates ground pressures and soil disturbance types (e.g., compaction and scalping), choice of harvesting systems and equipment type can greatly affect the degree and extent of soil impacts. Cable systems are often preferred over ground-based systems because cable logging does not require heavy machines moving on harvesting areas. Logs are fully or partially suspended to the skyline and pulled to the landings. Allen (1997) reported that a skyline thinning operation in western Oregon left only 2 percent of soil disturbance while a single entry of cut-to-length (CTL) system caused 25 percent of the harvest area compacted.

However, cable logging is typically more expensive than a ground-based system: cable yarding costs are 65 to 160 percent higher than conventional ground-based logging (Lousier 1990). For example, Keegan and others (1995) surveyed stump-to-truck harvest costs in the Montana and northern Idaho region and found that the cost for ground-based systems was lowest ($87 to $124/thousand board feet (MBF)), followed by cable systems ranging from $13 to $164/MBF. Helicopter systems were most expensive at $233/MBF. Compared to mechanized ground-based systems, cable logging requires more labor to manually handle trees or logs on steep grounds (typically >30 percent slope) as well as to set-up and tear down an entire yarding system, which results in low daily production of timber. Time spent changing skyline roads and rigging also contributes to high costs in cable logging. High logging costs in cable logging becomes more noticeable when handling small-diameter trees. At average 10-inch diameter at breast height (DBH), skyline and helicopter stump-to-truck logging and chipping costs were about 3 and 6 times more expensive, respectively, compared with a mechanized whole-tree harvesting system that showed the lowest cost at $34.23/100 cubic feet (Han and others 2004).

Cable yarding, combined with mechanized felling and processing, has been considered as a way of reducing soil compaction and other types of soil disturbance from the ground skidding or forwarding phase of timber harvesting. Although mechanized felling and in-woods processing using a feller-buncher or a harvester have insignificant impacts on soils, subsequent ground skidding and forwarding cause significant increase in soil bulk density (Allen 1997). The question is how much more expensive it is to use skyline yarding than ground-based skidding. Johnson (1999) reported that cable yarding ($\$0.51/ft^3$) resulted in 113 percent cost increase over forwarding ($\$0.24/ft^3$) of logs felled and processed by a CTL harvester. However, the average forwarding distance (212 ft) for cable yarding was much longer that the one (129 ft) with forwarding. This may lower the road density required for timber harvesting activities and reduce the area of soils disturbed. In eastern Oregon, a skyline yarder was used to extract logs processed by a CTL harvester in an effort to avoid further damage to soil from fuel reduction thinning on slopes that averaged 12 percent or less on all units, with maximums of 25 percent (Drews and others 2000). They reported that the harvester-yarder system averaged much higher ($80/green ton) stump-to-mill costs than the harvester-forwarder system ($46/green ton).

Low ground-pressure machines, such as log loaders and wide-tired skidders, for wood extraction from stump to landing are also often considered to minimize soil compaction. Shovel logging uses a hydraulic log loader to repeatedly swing the logs to reach the road or landing area, and has been used as an alternative to a cable system on moderate grounds (20 to 40 percent slope) or a ground-based system on gentle slopes (<20 percent). The average unit production cost for shovel logging in western Washington was 40 percent less than the one with cable logging at an average external yarding distance of 600 feet (Fisher 1999). Use of a skidder equipped with wide tires to reduce ground pressure has been used by machinery manufacturers as machines have increased in size and weight (Brinker and others 1996). Past studies indicated that wider tires resulted in 13 to 23 percent increase (Meek 1994) or no significant difference (Klepac and others 2001) in skidding cost. Klepac and others (2001) also noted that loggers are reluctant to use wide tires because of additional overhang during machine transport from one site to another, and requirement for a higher torque, heavy-duty rear axle in the skidder.

When selecting a mechanized, ground-based system for timber harvesting, a CTL system is often compared with a whole tree system consisting of a feller-buncher, skidder, a processor, and a loader for its harvesting productivity and cost. While production rates and costs for these two systems are comparable (Hartsough and others 1997; Lanford and Stokes 1996; Gingras 1994), impacts on sites can differ significantly (Lanford and Stokes 1995; Gingras 1994). A CTL system is often favored over a whole-tree harvesting system because a harvester processes trees to log length at the stump, leaving all branches and tree tops on site. A forwarder drives over the slash mat, and this helps to minimize impacts on soils.

Long-term Site Productivity Losses

A concern for site productivity losses after soil disturbance from timber harvesting activities is a primary reason for imposing strict requirements for soil protection in the context of sustainable forestry. Some studies have shown that soil compaction adversely impact tree growth. However, estimation of actual or possible productivity losses resulting from soil disturbance is a complicated issue because of difficulties of accurate estimation of soil disturbances consequences on tree growth (Miller and others 2004; Heninger and others 2002; Lousier 1990; Helms and others 1986). Miller and others (2004) suggested that forecasts of reduced timber yield from degraded soils are uncertain because tree response to soil disturbance is greatly affected by other site-specific, growth-determining factors.

In addition to tree's biological and physical responses to soil disturbances, discount rates also have significant impact on the overall economic analysis of soil disturbances; the analysis performs over the entire tree rotation period and discount rates are greatly sensitive to time. Stewart and others (1988) developed an economic model that addressed financial impacts of soil compaction on a long-term basis. The model used a stand-growth simulator and included various scenarios of management options. At a 4 percent discount rate, net-present value analysis showed positive values, thus encouraging preventive efforts (wide trail spacing) and indicating higher affordability for careful logging. Under an assumption that tree yield was reduced on 100 percent of skid trail areas, the net present value (NPV) with 4 percent was $504/ac while it was $144/ac with 8 percent discount rate. One could afford to spend an extra $144/ac to avoid these yield reductions.

Rehabilitation

Soil rehabilitation involves mechanical measures (e.g. tillage) to break up severely compacted soils. It helps promote water and air movement (Andrus and Froehlich 1983) and increase nutrient availability (Miller and others 2004) in a compacted soil. The efficacy of tillage in loosening compacted soils depends on equipment types used and soil properties (Unger and Cassel 1991; Andrus and Froehlich 1983), number of machine passes (Andrus and Froehlich 1983), and tillage depth (McNabb and Hobbs 1989). The overall cost of tilling is directly influenced by these factors.

Andrus and Froehlich (1983) studied production rates and costs for skid-trail tillage at selected sites in Oregon and Washington. Four types of tillage equipment were evaluated in the study: disk harrow, rock ripper, brush blade, and winged subsoiler. Production rates were highest when tilling with one pass of the machine. Uphill tilling on steep grounds required a large crawler tractor at a higher machine cost. The winged subsoiler lossened more than 80 percent of the compacted soil in a single pass and was the most cost-effective tillage method (fig. 1). The authors indicated that tillage results for these sites would have improved if the tillage improvement had made additional passes along the skid trails, but additional passes would increase the cost of tilling.

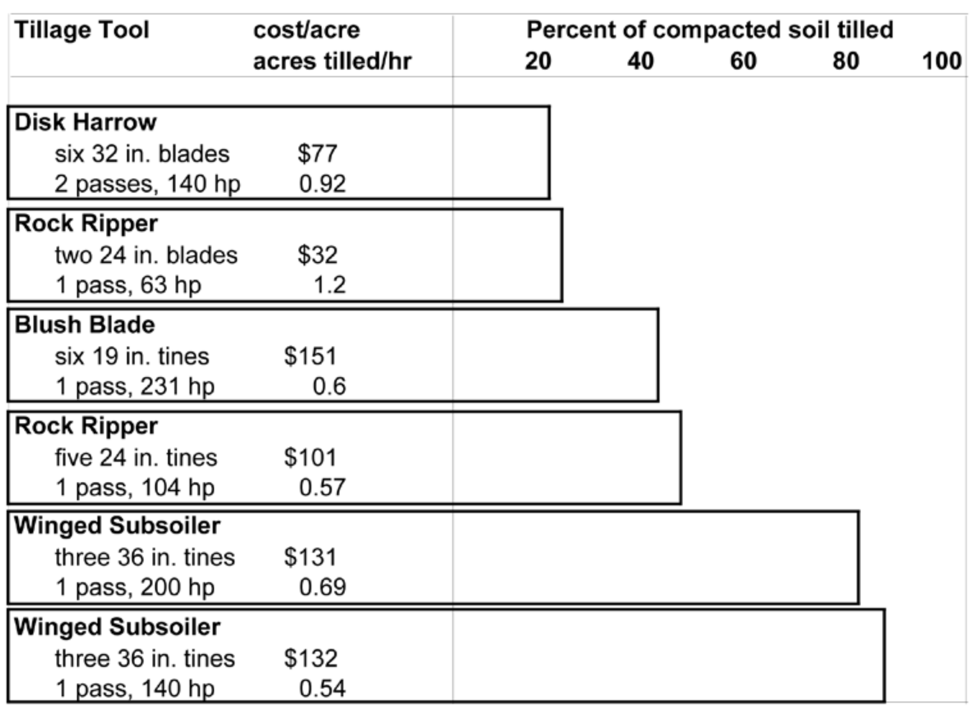

Figure 1—Tillage costs and rates for various type of tillage equipment (Andrus and Froehlich 1983)

If properly implemented, tillage may be cost-effective under the most extreme compaction situations, such as landing areas and heavily traveled skid trails. Stewart and others (1988) estimated the justifiable increased cost for high-cost logging or rehabilitation per harvest entry with 125-ft skid trail spacing. The net financial benefit from tillage was notably affected by discount rates and site index and ranged from $86/ac to $284/ac. This range of justifiable costs is far more than a cost estimate ($20/ac or $176/mile) for skid trail restoration with a winged subsoiler mounted behind Cat D6C crawler tractor (Froehlich and Miles 1984).

Conclusion

Economics of soil disturbance is complicated and requires measuring economic consequences from long-term site productivity losses and expenses for preventive and rehabilitation measures. An accurate estimation of soil disturbances consequences on tree growth is difficult because the tree's response to soil disturbance is affected by other site-specific, growth-determining factors. Many assumptions are needed to estimate future growth and yield and these greatly affect overall financial analyses. Although direct costs for prevention and rehabilitation can be estimated, direct and indirect financial benefits from these practices are not well documented. Major uncertainties originate from the requirement for long-term economic analysis of unknown biological impacts from soil disturbance and inconsistent discount rates used in the analysis.

Preventive measures are more effective in minimizing impacts on soils than rehabilitation treatments because of remedial expenses, loss of productivity until mitigation occurs, and the possibility that original soil conditions may not be restored. Careful planning and layout and selection of harvesting systems and equipment often increase overall harvesting costs. Alternative harvesting practices that are designed to minimize impacts on soils, such as use of designated skid trails and wide trail spacing, increase overall harvesting costs. Rehabilitation expenses are additional to these increased costs. However, these initial expenses can be justified when preventive and rehabilitation measures are focused on high risk sites and severely disturbed areas. Expenses for careful planning and layout, alternative logging practices and rehabilitation measures should be recognized as part of overall logging cost estimation to support the idea of minimizing impacts on soils.

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