Universal Soil Loss Equation (USLE)-Predicted Soil Loss for Harvesting Regimes in Appalachian Hardwoods

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ABSTRACT: *Soil erosion from forest harvesting is a major environmental concern. While there has been research comparing soil erosion on clearcut regeneration harvests with that on uncut forests, there has been little focus on the differences among common silvicultural harvests. Forest certification standards that are currently being evaluated for adoption across the country often encourage uneven-aged systems over even-aged or two-aged systems. We estimated soil loss using the Universal Soil Loss Equation (USLE) for forest land on five harvested treatments in the southern Appalachians. Treatments included a clearcut, leave-tree harvest, shelterwood, group selection, and uncut control. Results predicted that the group selection would have approximately 10 tons/ac more soil loss over a 100 yr rotation than the other harvested treatments. The higher rate was primarily from skid trails when the treatment was reentered for harvesting. These results should be considered when weighing the benefits of uneven-aged silviculture over even-aged or two-aged silviculture. North. J. Appl. For. 19(2):53–58.*

Key Words: Universal Soil Loss Equation (USLE), soil erosion, timber harvests, silvicultural system.

Forest harvesting is often blamed for causing excessive amounts of nonpoint source pollution (McNulty 1995, Binkley and Brown 1993, Sopper 1975). Concern for maintaining water quality and site productivity led to the passage of water quality legislation and the subsequent development of Best Management Practices (BMPs) to minimize the effects of harvesting (Park et al. 1994). However, harvesting on steep slopes in the Appalachians is still viewed as a potential cause of erosion and decreases in water quality (Kochenderfer et al. 1997).

Forest management uses several harvesting methods to achieve a variety of goals. Methods are designed primarily to enhance the value of an existing stand or to manipulate the regeneration for the next stand, but they can also be used for aesthetics, water yield, or wildlife management (Smith 1997). Foresters are now evaluating the effectiveness of two-aged (leave-tree) and uneven-aged (group selection, single-tree selection) silvicultural regeneration methods as an alternative to even-aged methods (clearcut, shelterwood, seed tree). The Forestry Stewardship Council (FSC) forest certification standards call for minimizing clearcuts (FSC 2001), and the proposed guidelines for the southeastern United States state that "uneven-aged management systems should be used when feasible" (FSC 1998). The Monongahela National Forest in West Virginia decreased the amount of even-aged silviculture during the past 5 yr in response to criticisms of clearcutting (Myers 1999). Each silvicultural regeneration method serves a purpose, but the assumption that uneven-aged or two-aged silvicultural methods are patently less damaging to the environment than even-aged systems oversimplifies the issue and may lead to future stand composition and structure that fail to meet the stated management objectives.

There is little research comparing the effects of commonly used silvicultural treatments in the Appalachian hardwoods on soil erosion (Bormann and Likens 1979, Patric 1980). Most studies focus on nutrient loadings from harvesting (Bolstad and Swank 1997, Hornbeck et al. 1993) but do not actually compare silvicultural treatments. Several studies have compared the erosion associated with different land uses and harvesting techniques. Using the USLE, Gianessi et al. (1986) found that forestry affects soil erosion less than any other nonurban land use (Table 1). Similar results were found by measuring sediment (Yoho 1980, Grayson et al. 1993). Yoho (1980) also reviewed differences in forest harvesting quality and the resulting erosion rates. Using BMPs while harvesting reduced sediment concentrations by 20% in Virginia (Park et al. 1994). Natural disturbances common to the Appalachians such as

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Table 1. Average annual sheet and rill erosion by land use. Adapted from Gianessi et al. (1986).

State	Cropland	Pasture	Forest	Other*
	(tons/ac/yr)			
Virginia	6.18	3.51	0.82	5.32
West Virginia	2.57	4.16	2.07	48.58
U.S. average	4.37	1.29	0.91	8.46

* Includes farmsteads, mines, quarries, pits, and other rural lands.

fire, ice, or windthrow can also cause high rates of erosion, depending on the severity of the disturbance (Scott and Van Wyk 1990, Shahlaee et al. 1991).

This study compares soil loss estimates from four silvicultural harvest treatments and nonharvested controls in the Southern Appalachians. These treatments are then evaluated for the long-term implications of different forest regeneration techniques. The silvicultural treatments included even-aged, two-aged, and uneven-aged methods. Because erosion is a natural process that occurs on undisturbed forestland, the erosion rates from harvested areas must first be put into context with rates from presently undisturbed forests. By comparing our harvested treatments with a non-harvested control, we can set baselines and tolerable limits of erosion that are comparable to those of undisturbed forests (Fowler and Heady 1981).

The universal soil loss equation (USLE), as modified for forestland by Dissmeyer and Foster (1984), is the most widely used method of predicting soil loss in forestry (Lane et al. 1992). This updated version of the original USLE was designed for forestland, whereas the original equation was specific to agriculture (Wischmeier and Smith 1978). The equation was developed using 35 watersheds in the South that were also sampled for sediment to compare accuracy. While there have been some criticisms of the USLE, and there exist more updated computer models such as the Revised Universal Soil Loss Equation (RUSLE) and the Water Erosion Prediction Project (WEPP) (Larson et al. 1997, Montgomery et al. 1997, Lane et al. 1992), the USLE remains the best known because of its sound scientific basis, ease of use, low cost, and direct application in forest systems. The updated USLE for forestland allows foresters to quickly and easily compare potential soil loss following different harvesting methods and evaluate which method is likely to have the least influence on soil erosion.

It is important to recognize that soil loss predicted from the USLE is site soil movement, which is not synonymous with delivery of sediment to stream channels. The USLE predicts sheet and rill erosion. The Dissmeyer and Foster guide (1984) defines erosion as "the amount of soil delivered to the toe of the slope where either deposition begins or where runoff becomes concentrated." The equation does not estimate gully, landslide, soil creep, stream channel erosion, or erosion from a single storm. The soil that is deposited downslope does not necessarily have an impact on water quality. It is only when the eroded soil enters a stream that it actually affects water quality (Yoho 1980). Gianessi et al. (1986) estimated that the ratio of gross erosion to sediment for forestland is 0.50 and 0.52 for Virginia and West Virginia, respectively.

Methods

Site Selection and Description

The USLE data collection and analysis is part of a larger, long-term research project designed to examine the effects of different levels of silvicultural disturbance on the tree, shrub, and herbaceous strata in Southern Appalachian forests (Wender et al. 1999, Wender 2000). Four sites were selected to represent common upland hardwood forest types in the southern Appalachians; specifically, sites that covered at least 35 ac with minimal silvicultural disturbance in the last 15 yr and were relatively uniform in stand composition, age, structure, and geophysical characteristics. Specific criteria included were: mid-elevation (2000–4000 ft) stands dominated by red and white oaks (*Quercus* spp.), hickories (*Carya* spp.), and maples (*Acer* spp.); a maturing overstory between 50–150 yr; moderate slopes (10–4%); average site index between 60–70 ft (base age 50 for upland oaks); and predominantly south-facing aspects.

Two of the sites are located in southwestern Virginia in the Clinch Ranger District of the Jefferson National Forest. The sites are located in Wise and Scott Counties in the Cumberland Plateau physiographic region. The remaining two sites are located in the Allegheny Plateau physiographic region in Randolph County, West Virginia. The sites are hilly, with an average slope of 2%.

The Ridge and Valley and Allegheny Plateau physiographic provinces are characterized by a moderately moist, temperate, mesothermal climate. Precipitation is distributed throughout the year, without a distinct dry season, although spring is consistently the wettest season. Temperature and precipitation for both regions can exhibit considerable local variation because of differences in relief, aspect, and vegetation patterns.

The study sites are contained within Braun's (1950) Oak-Chestnut Forest region of the eastern deciduous forest. Hammond (1998) characterized the pretreatment vascular plant community of the sites. *Quercus* species were the dominant overstory component of all sites. *Q. rubra, Q. prinus, Q. alba,* and *Acer rubrum* were the major components of the Virginia sites and one West Virginia site. The Virginia sites had an average preharvest basal area of 127 ft^2/ac, while the West Virginia site had 154 ft^2/ac of basal area. The second West Virginia site was dominated by *A. rubrum, Magnolia fraseri, Liriodendron tulipifera, A. saccharum,* and *Q. rubra,* and had a preharvest basal area of 142 ft^2/ac.

The soils of all sites are derived from sandstone and shale residuum and colluvium. As is typical of most Appalachian forests, the soils are rocky, well drained, and acidic, and are without exceptional moisture-holding capacity. All study sites fall within the mesic soil temperature class, meaning the winter-to-summer range of soil temperature at 50 cm is 8–15°C (Daniels et al. 1973). Soils were identified using soil surveys of Scott and Wise Counties, VA, and Randolph County, WV (Jurney 1951, Perry et al. 1954, Pyle et al. 1982). The Virginia site soils are predominantly classified as Muskingum series, a fine-loamy, mixed, mesic Typic Dystrochrept. The West Virginia sites are predominantly from the Gilpin and Dekalb series. The Gilpin series is classified as a fine-loamy, mixed, mesic Typic Hapludult, and the Dekalb series is classified as a loamy-skeletal, mixed, mesic, Typic Dystrochrept. These soils are often found together and form the Gilpin-Dekalb-Buchanan association. While other soil types may be found on the treatments, the series described are the dominant types across the sites.

Treatments were implemented in 1999 and included (1) clearcut (even-aged), (2) shelterwood (even-aged), (3) leave-tree harvest (two-aged), (4) group selection (uneven-aged), and (5) uncut control. Each treatment plot was 5 ac, with no buffers between treatments. Because there were no buffers between treatments, data were not collected within 1.5 chains of each treatment boundary. An on-site project forester designed skid trail placement in accordance with applicable BMPs, and all skid trails were located along the slope contour. Skid trails were designed to be temporary and were closed to vehicle access after harvesting was completed. There are no permanent roads in the treatments. Conventional harvesting methods using chainsaws and cable skidders were employed for all treatments. In the clearcut treatment, all stems greater than 2 in. dbh were felled. Nonmerchantable trees were felled and left on the site. Mast, snag, or cull trees could be left for wildlife purposes, but could not exceed 4 stems/ac. The shelterwood treatment was designed to leave 50-60 ft^2/ac evenly distributed over the treatment area, with removal of residual trees in 5–10 yr once adequate advanced regeneration is present. Residual trees were dominant or codominant stems. In the two-aged leave-tree harvest, trees in the dominant or codominant crown classes were retained such that the residual stand consisted of no more than 20 trees/ac (20 ft^2/ac). The group selection treatment typically had three small openings (0.25–0.5 ac in size) with improvement cutting between the group cuts. This silvicultural treatment will be repeated every 20 yr in the group selection, with 100% of the treatment area cut after 100 yr. No silvicultural activity occurred in the control treatment.

Data Collection and Analysis

To examine the effects of harvesting on soil erosion, we collected USLE data at each site during the growing season 1 and 2 yr following harvest. Collecting data 1 yr after harvest and a second time the following year allowed us to compare erosion rates between years to estimate the recovery time to predisturbance erosion levels. In each treatment, we collected USLE data for each factor in the equation as suggested by Dissmeyer and Foster (1984) on a grid with 6 plots spaced 2 × 4 chains apart with a 1.5 chain offset into the 5 ac treatment plot. Plots were located by pacing from the northwest corner of each treatment. If a plot fell on a skid trail, it was moved an additional 33 ft so that it was located away from any skid trails. In addition, we collected USLE data for each skid trail in the treatment, including length and width to determine area. In this manner, it is possible to separate treatment and skid trail effects. The temporary nature of the plots caused variation in plot locations between years.

USLE Factors

Data collection followed the standards set in "A Guide for Predicting Sheet and Rill Erosion on Forest Land" (Dissmeyer and Foster 1984). The USLE uses a number of factors and subfactors to estimate soil loss [Equation (1)].

$$A = RKLSCP \tag{1}$$

where

A = soil loss (tons/acre/year)

R = rainfall and runoff factor (EI)

K = soil erodibility factor

LS = slope length and the slope steepness factor

CP = cover management practice factor

The rainfall and runoff index (R) is the effect of raindrop impact on runoff (Risse et al. 1993). Areas of high annual precipitation and intense thunderstorms generally have higher R values. We determined R values for each site using Wischmeier and Smith's map of isoerodent lines of erosion index units (EI) for the United States (Dissmeyer and Foster 1984). The R factor for all sites is 150 EI units.

The soil erodibility factor (K) reflects each soil type's inherent susceptibility to soil erosion. The Natural Resources Conservation Service developed K factors for most soil types. The K factor for the Muskingum and Gilpin soil series is 0.28, while that for the Dekalb is 0.24. Because soil surveys were used to identify the soils, and it is not known on a plot basis what the exact series is, we used a K factor of 0.28 for all plots.

The LS factor represents the slope length (L) and the slope steepness (S). These two measurements are combined using the formula $LS = (\lambda / 72.6)^m (65.41 \sin^2 \theta + 4.65 \sin \theta + 0.065)$, where λ = angle of slope in degrees; and $m = 0.2$ for gradients less than 1%, 0.3 for 1 to 3% slopes, 0.4 for 3.5 to 4.5% slopes, and 0.5 for slopes of 5% and greater. The slope length was either measured by pacing or noted as 467 ft if the entire slope was uniform. A clinometer was used to determine slope gradient.

The CP factor is the product of several subfactors and represents the management practice factor for untilled and tilled forestland. We treated all treatment plots as untilled and all skid trail plots as tilled. The major subfactors for the treatment plots are (1) bare soil, (2) fine roots, (3) canopy height, (4) steps, (5) onsite storage, and (6) organic matter. For the skid trail plots the subfactors are (1) bare soil, (2) canopy height, (3) steps, (4) onsite storage, and (5) invading vegetation. All subfactors were estimated visually for the area surrounding the plot center. The plots were not a fixed size.

We calculated soil erosion estimates (A) for each measurement plot 1 and 2 yr following harvest. Differences between treatment erosion estimates were tested using PROC GLM in SAS V8 using a random complete block design ($n = 4$) with subsampling ($n = 6$) (SAS Institute 1999). To test for differences between blocks, we first calculated weighted averages based on the area in skid trails and treatments. These averages were then analyzed in SAS using a random complete block design. Percent area in skid trails was also compared by this method. All differences among means were tested using Duncan's multiple range test at $\alpha = 0.05$. Statistical analysis was performed for years 1 and 2 postharvest.

After obtaining erosion estimates for years 1 and 2, we extrapolated the data to a 100 yr rotation. We made several assumptions when calculating these estimates. Recovery rates after year 2 were based on the ratio of recovery between years 1 and 2. Once a treatment's erosion rate dropped to the control rate at year 2, we used the control rate for the rest of the rotation for that treatment. We cut one-fifth of the group selection every 20 yr and removed the shelterwood overstory at year 7. For these treatments, we assumed that erosion rates would again increase to the year 1 and 2 rates after the additional entries with the same recovery times.

Results

Estimated erosion in the clearcut and leave-tree treatments, excluding skid trails, was significantly higher than in the control 1 yr after harvesting (Table 2). The group selection and shelterwood treatments were not significantly different from the control, clearcut, or shelterwood. By year 2 there were no significant differences among the treatments. On a rotation-length basis, the group selection harvest had the highest projected rates of erosion, 24.4 tons over the 100 yr rotation, due to the multiple entries into the block. This was over 5 tons higher than the second highest treatment, the clearcut.

When the treatment and skid trail plots were combined, the results followed the same trends in year 1 as the treatment plot-only analysis (Table 3). Only the predicted soil loss from the leave-tree treatment was significantly different from the control at age 2, though it was not statistically different from that of the other harvested treatments. The group selection treatment again had the highest projected erosion rates for the rotation, 29.4 tons. The clearcut, leave-tree, and shelterwood treatments had very similar soil loss rates of approximately 19.5 tons. The control had slightly more erosion in the first year after harvest than in the second year. We feel this is likely due to using different sample points between years and a possible edge effect from adjacent harvested treatments.

Area in skid trails was highest in the group selection treatment (Table 3). All harvested treatments had a significantly larger percent area in skid trails than the control. There were no statistical differences among harvested treatments.

Table 2. Estimated erosion (tons/ac/yr) in treatments excluding skid trails during a 100 yr rotation with harvest at year 1 in Appalachian hardwood stands in Scott and Wise Counties, VA, and Randolph County, WV. Means with the same letter within years are not significantly different at α = 0.05 using Duncan's Multiple Range Test.

Treatment	Years since harvest 1	2	Average erosion for 100 yr rotation*	Sum erosion for 100 yr rotation*
			·········(tons/ac/yr)·········	
Clearcut	4.41 a	0.74 a	0.19	19.0
Leave tree	4.01 a	0.90 a	0.19	18.8
Group selection†	2.17 ab	0.16 a	0.24	24.4
Shelterwood†	1.75 ab	0.32 a	0.18	17.7
Control	0.21 b	0.14 a	0.14	14.2

[2] Average and sum estimates were calculated based on the ratio of recovery between years 1 and 2; e.g., the recovery ratio for the clearcut between years 1 and 2 was 0.74/4.41 = 0.17. Year 3 estimated soil loss equaled 0.13 tons/ac/yr (0.74*0.17 = 0.13). However, the value of 0.14 tons/ac/yr was used because soil loss was not allowed to go below the year 2 control amounts.

† One-fifth of the group selection will be harvested every 20 yr, and the shelterwood

Discussion

These data clearly show that silvicultural regeneration methods requiring multiple entries into a stand over a rotation period (group selections and shelterwoods) have the potential to cause as much or more erosion than one-entry harvests (clearcuts and leave-tree harvests). While the shelterwood and group selection treatments initially had lower soil movement rates than the clearcut and leave-tree harvests, after factoring in additional harvests, the group selection had 15.3 more tons of erosion than the control for the 100 yr rotation. The shelterwood had approximately the same soil movement as the clearcut and leave-tree, with about 5.5 more tons than the control. This is a critical point when deciding what type of harvest to implement. Multiple entries redisturb recovering skid trails, and it had been documented that up to 90% of the sediment from logging is due to permanent and temporary roads (Yoho 1980). While the skid trails in this study are temporary (there are no permanent roads in the treatments), repeated entries are expected to create the same disturbance intensities as in the initial harvests.

The soil movement rate of 0.14 tons/ac/yr found in the control was similar to the erosion rate of 0.1 tons/ac/yr suggested for responsibly managed forestland in the Appalachian region by Patric (1980). This rate is based on erosion

Table 3. Estimated erosion in treatments and skid trails (tons/ac/yr) during a 100 yr rotation with harvest at year 1 in Appalachian hardwood stands in Scott and Wise Counties, Virginia, and Randolph County, West Virginia. Treatment means with the same letter within years are not significantly different at α = 0.05 using Duncan's Multiple Range Test.

Treatment	Years since harvest 1	2	Average erosion for 100 yr rotation*	Sum erosion for 100 yr rotation*	Percent of 5 ac treatment plot in skid trails
			··················(tons/ac/yr)·················		
Clearcut	4.76 a	0.84 ab	0.19	19.5	6.1 a
Leave tree	5.29 a	1.12 a	0.20	19.7	5.4 a
Group selection†	2.47 ab	0.47 ab	0.29	29.4	9.4 a
Shelterwood†	2.38 ab	0.47 ab	0.17	19.7	7.1 a
Control	0.21 b	0.14 b	0.14	14.1	0 b

* Average and sum estimates were calculated based on the ratio of recovery between years 1 and 2. The recovery ratio for the clearcut between years 1 and 2 was 0.84/4.76 = 0.18. Year 3 estimated soil loss equaled 0.15 tons/ac/year (0.84*0.18 = 0.15). Year 4 estimated soil loss equaled 0.03 (0.15*0.18 = 0.03). However, the value of 0.14 tons/ac/yr was used because soil loss was not allowed to go below the year 2 control amounts.

† One-fifth of the group selection is harvested every 20 yr, and the shelterwood overstory removed at year 7, with years 1–5 erosion estimates assumed after each harvest period.

caused by normal geologic processes, regardless of anthropogenic effects. The slightly higher erosion rates in the control than the rate cited by Patric (1980) could be due to using the soil survey to identify the dominant soil series instead of identifying each soil type for every plot. There may be some soil types in the treatments that have lower *K* factors, such as the Dekalb series, that would lower the estimated erosion rates.

The rate of soil erosion peaked 1 yr after harvesting and then greatly decreased by year 2. Kochenderfer et al. (1997) reported that sediment export returned to preharvest levels by the third year after selectively harvesting a gauged West Virginia watershed. The results from our study also indicate that erosion will return to preharvest levels by year 3 or soon thereafter. Estimated soil movement decreased by approximately 80% between years 1 and 2 postharvest in all harvested treatments. According to Borman and Likens (1979), sediment yields from a careless clearcut in West Virginia were 1.35 tons/ac. This mass is roughly one-fifth of the USLE erosion estimates for clearcutting in this study. Patric (1976) and Smith and Stanley (1965) estimate sediment losses for carefully clearcut forests at 0.06 to 0.17 tons/yr.

Because the data were extrapolated over a 100 yr rotation based on the calculations made 1 and 2 yr after harvest, the rotation-length estimates will not be as accurate as actual measurements. The average and total rotation erosion estimates presented here point out the potential long-term management implications of different harvesting methods. We feel that the rotation estimates are reasonable and even if the actual numbers do change, the relative proportions among the treatments probably will not.

Management Implications

Emphasis should be placed on the value of careful design and placement of skid trails by professional foresters. Depending on how the road and skid trail system is implemented, sediment yields can vary by 25 times (Yoho 1980). Swift (1986) reported downslope sediment movement ranging from 2 to 314 ft, depending on site and road conditions. The skid trails in the harvested treatments in this study covered less than 10% of the total area. Careless logging without BMPs can disturb up to 40% of the area (Yoho 1980). The skid trails in this study were also laid out on the contour. Hornbeck and Reinhart (1964) reported that skid trails placed perpendicular to the contour on severe slopes in the Appalachians resulted in 40 tons/ac of sediment from the skid trails in the first year after harvesting (cited from Yoho 1980). Compare this with the highest rate of erosion from the skid trails in this study of 5.3 tons/ac in the leave-tree treatment, and the importance of properly planned skid trails is made clear.

The rate of soil erosion after harvesting in upland hardwoods rapidly approaches undisturbed forest erosion levels. The skid trails account for the greatest proportion of soil erosion. Therefore, a harvest treatment requiring multiple entries into a stand may cause more erosion on a longer time scale. Every time the stand is entered, the skid trails are redisturbed and subjected to rates of erosion similar to the initial harvest. The results presented here identify the relative impacts of multiple entries. The use of group selection as a harvest method may not be the best choice from the standpoint of site impact, and other methods should be considered, unless it is the only regeneration method that will result in achieving the desired future stand condition. In addition, the results suggest that erosion rates from clearcut, shelterwood, and leave-tree harvests return to baseline mature forest levels within the first few years after harvesting. The results from this study indicate that one- and two-entry silvicultural harvest treatments that follow BMP guidelines cause minimal soil movement and can quickly recover to pre-harvest erosion levels.

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