Soil erosion following forest operations in the Southern Piedmont of central Alabama

J.M. Grace III

ABSTRACT: In recent years, nonpoint source pollution (NPS) has been recognized as one of the major threats to the nation's water quality. Clearly, forest operations such as harvesting and site preparation have the potential to have degrading impacts on forest water quality. However, there exists a gap in the understanding of the nature and extent of NPS pollution problems related to forest operations. The study presented here was performed in Lee County, Alabama to investigate the impact of clear-cut harvesting and mechanical site preparation on a 20-year-old loblolly pine (*Pinus taeda* L.) plantation on sediment and runoff yield. Sediment and runoff yield responses on treated areas were compared to that of undisturbed areas. Impacts were evaluated by monitoring isolated small plots, 2 m (6.6 ft) by 5.5 m (18 ft), over a two-year period following the harvest prescription. Sediment yield from the control treatment was 0.11 t/ha (0.30 ton/acre) over the study period. Sediment yield increases of 0.11 t/ha (0.30 t/ac) and 1.3 t/ha (3.5 t/ac) were observed from clear cut harvest/site prep/plant (H-SP-P) treatment and clear cut harvest /plant (H-P) treatment, respectively. However, erosion losses from the most erosive treatment, clear cut harvest /plant, was still very low at less than 1 t/ha/yr. Runoff yield results were similar to those observed with sediment yields from treatments in the investigation. Differences in the two treatments were likely due to the differences in surface roughness, which affects infiltration and surface flow velocity.

Keywords: Forest operations, harvesting, site preparation, soil erosion, surface runoff

NPS pollution accounts for the majority of the total pollutant load to nation's inland surface waters (USEPA, 1993). In the southern United States, where NPS pollution is a major environmental concern, agriculture is the major contributor of NPS pollution (USEPA, 1984; Myers et al., 1985). In the region, NPS problems related to forestry activities are localized but can affect waters used for human consumption and fisheries habitat. Forest operations having the potential to impact NPS pollution include road construction, road maintenance, pesticide and fertilizer application, harvesting, and burning (Neary et al., 1989). Types of NPS pollution that can be generated by forestry activities include sediment, nutrients, pesticides, and organic chemicals. Sediment is perhaps of the greatest concern because many other pollutants are bound and transported with eroded sediment. Sediment alone can carry more than 1 million metric tons of nitrogen to surface waters in the Southern region (Larsen et al., 1983). Research has shown adverse impacts on the nation's water quality from soil erosion and stream sedimentation (Authur et al., 1998; Binkley and Brown, 1993; Megahan et al., 1991).

Undisturbed forest conditions afford a high level of protection against soil erosion and NPS pollution. Vegetative cover intercepts raindrops and therefore reduces the energy for soil detachment (Grace, 2000). Forest floor cover provides surface roughness

J. McFero Grace III is a research engineer at the Southern Research Station of the U.S. Department of Agriculture - Forest Service in Auburn, Alabama.

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and allows for greater infiltration of precipitation, thereby reducing surface runoff that could detach and transport sediment. However, even under these near optimal conditions, some soil erosion is inevitable. Undisturbed forestlands typically have erosion rates less than 0.30 t/ha/yr (0.80 ton/acre/yr) (Smith and Stamey, 1965; Beasley, 1979;Yoho, 1980).

Disturbances in the form of forest operations, however, can accelerate erosion due to scarification of the forest floor and removal of vegetative cover. Forest operations can influence NPS pollution by altering natural processes that maintain water quality. The magnitude of erosion losses in disturbed forest conditions is dependent on the type and extent of disturbance (Nutter and Douglass, 1978). Forest operations such as harvesting, roads, site preparation, and fire management can influence NPS pollution by altering water quality and water yield. The combination of these two influences directly affects forest outflow. Although each operation is unique, in terms of climate, topography, soils, and prescription, similar NPS pollution problems may result due to the commonalities of forest floor disturbance and runoff modifications presented by each operation.

The result of harvesting is tree removal, which increases available water by reducing evapotranspiration. Mechanized equipment used to carry out prescriptions also results in compaction, which increases surface runoff by reducing infiltration. The combination of increased soil moisture and reduced infiltration generally results in increased forest outflow (water yield). Water yield increases of 2.5 mm (0.1 in) per percent of forest cover removed in humid regions was reported by Neary and others (1982). Harvesting operations can also result in increased scarification of the forest floor, exposing mineral soil. The combination of conditions resulting from harvesting have been reported to increase the amount of sediment and nutrients transported to water systems (Leaf, 1970; Troendle, 1983; Troendle and King, 1987; Harr and Fredriksen, 1988; Brown et al., 1973; Kochenderfer and Wendel, 1983).

Site preparation attempts to remediate compaction resulting from harvesting and reduce seedling competition for resources. However, this operation typically results in suppression of understory vegetation (weed competition) and/or disturbance of the forest floor. Similar to the harvesting prescription, site preparation can result in decreased evapotranspiration in combination with an unprotected soil surface, which creates conditions for accelerated erosion rates. There are numerous reports citing that forest operations increase soil erosion and suspended sediments in draining waters in diverse geographical regions in the United States (Patric, 1978; Yoho, 1980; Harr and Fredriksen, 1988; Blackburn et al., 1986; Beasley, 1979; Riekerk et al., 1989).

Intensive forest management activities continue to increase to meet the escalating need for forest products, resulting in some level of disturbance. Harvesting, site preparation, and other management activities utilized in intensive forest management systems often involve mechanized equipment and access roads often resulting in increased forest floor scarification, compaction, and rutting. Accelerated erosion is likely to follow these operations because storm energy has increased potential to detach and transport soil particles. Harvesting and site preparation are necessary elements in forest management. However, potential adverse environmental impacts should be recognized and addressed. Realization of environmentally sustainable forest management systems requires quantifying the impact of forest operations on the forest ecosystem. One prerequisite to developing models as planning tools in forest management is obtaining better information on the magnitude of erosion losses as a result of forest operations.

Methods and Materials

This investigation was undertaken to quantify the effect of harvesting and site preparation, operations commonly employed in intensive management, on sediment and runoff yield from a 20-year-old loblolly pine (*Pinus taeda* L.) plantation. The purpose of this paper is to report the findings of an investigation into the soil erosion and runoff yields associated with two common intensive forest management strategies. Soil erosion and runoff yields from harvest/plant and harvest/site prep/plant treatments were compared for each treatment to test the null hypothesis that

Figure 1

General location of the loblolly pine plantation study site, topography, and relative locations of study areas in the Southern Piedmont of central Alabama (Lee County, Alabama) (Map courtesy of the U.S. Geological Survey and TerraServer USA, 4 meter resolution quadrangle, Section 29 of Waverly, Alabama).

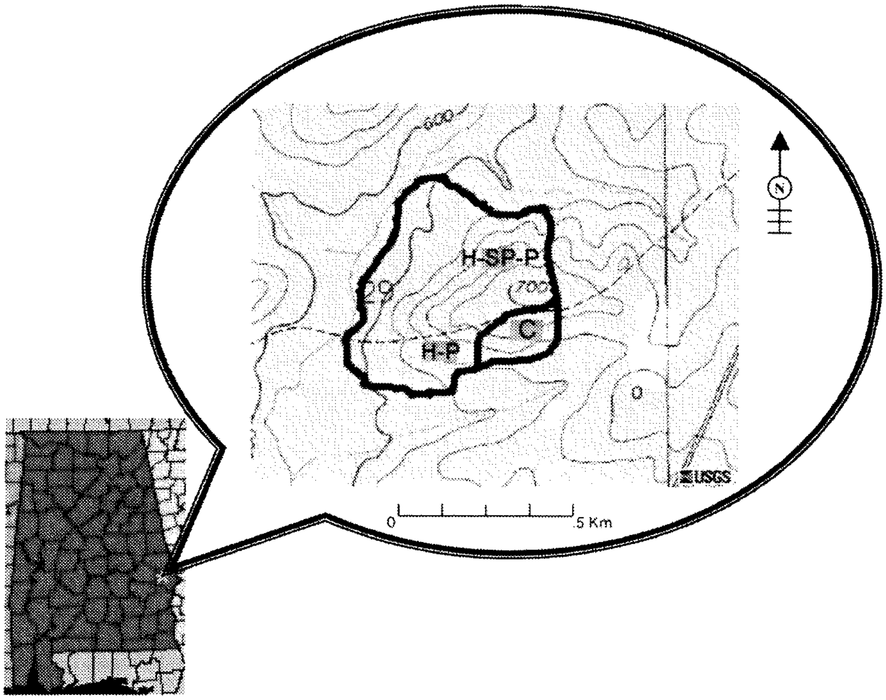
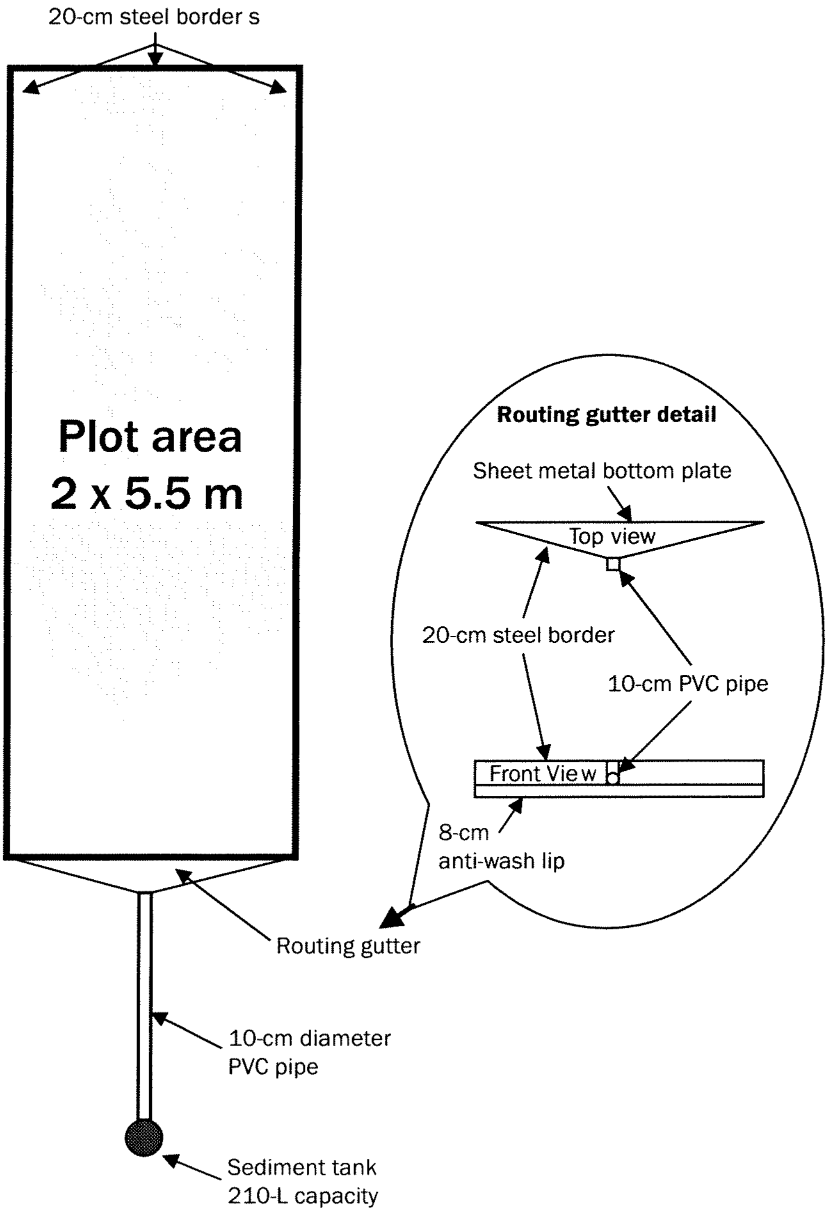


Figure 2
Erosion plot design for the North Auburn Study including routing gutter detail.



there are no differences in soil erosion and runoff emanating from treatments.

The study area was a 25 ha (62 ac) 20-year-old loblolly pine (*Pinus taeda* L.) plantation owned by Mead Coated Board, Inc. in the Southern Piedmont of central Alabama (Lee County, Alabama near Auburn, Alabama) (Figure 1). Pre-harvest basal area of loblolly pine was estimated at 27.5 m^2/ha (120 ft^2/ac). Soils on the study tract (North Auburn Study) were primarily Gwinnett sandy loam soils and classified as clayey, kaolinitic, thermic Rhodic Kanhapludults (Soil Conservation Service, 1981). Slopes on the North Auburn Study watershed ranged from three to 15 percent. Long-term mean annual precipitation in the study area is about 1370 mm (54 in).

A mechanical clear-cut harvest was applied to treatments on the North Auburn study tract during the winter/spring of 1998. The following two treatments were investigated:

1). *H-SP-P.* Treatment area was clear-cut harvested, sheared, ripped, bedded, and machine planted on contour. Average bed height was 30 cm with 4 m spacing (between contours).

2). *H-P.* Treatment area was clear-cut harvested and machine planted on contour [4 m (13.1 ft) spacing].

Nine experimental subplots with similar topography (10 percent slope), soils, and drainage were installed following harvesting operations. The general topography, location of the study site, and relative locations of study areas are illustrated in Figure 1. Three subplots were located within each study area, which included the harvest/site prep/plant treatment, the harvest /plant, and an undisturbed control.

Primary and secondary skid trails traversed the 25 ha (62 ac) site as is the case when you harvest using ground based systems. However, plots were bound and isolated from the surrounding slopes (Figure 2). Plots were designed to remove the effect of concentrated flow from skid trails (upslope or adjacent) on comparisons of treatments. Only runoff and soil transport resulting from precipitation falling in the 11-m^2 (120-ft^2) plots was possible. Monitoring of study plots began during the fall of 1998 and continued through October 1999 before removal for site preparation and planting operations. In December 1999, study plots were reinstalled following planting and monitored through August 2000.

Storm events were defined as precipitation events producing surface runoff. Runoff volume was determined following each storm event by measuring the volume of stormwater collected in sediment tanks. Grab samples, 500 ml (17 oz), were taken from each container following each event and processed for gravimetric analysis using methods defined by Greenberg et al. (1992) to determine total suspended solids. Deposited sediment fraction was quantified for each associated plot by draining container top water and collecting, drying, and weighing sediment deposited in sediment tanks. Total delivered sediment from each associated treatment was determined as the amount of suspended and deposited sediment in collection tanks for each associated treatment. Precipitation amount and duration were recorded by a tipping bucket rain gauge located on-site.

The treatment effect on soil erosion and runoff yield was determined by comparing soil erosion and runoff from treatment plots to that of the undisturbed controls using SAS general linear modeling procedures (SAS, 1998). Response variables in this investigation were soil erosion and runoff yield. The independent variable considered in the statistical analysis was treatment method. Duncan's Multiple Range Test was used to test for differences in treatment means ($\alpha = 0.05$), where analysis of variance indicated significant differences.

Results and Discussion

Thirty-five storm events, which resulted in runoff were recorded at the study site during the 20-month study period. The total accumulated precipitation during this period was 1715 mm (67.6 in) (Table 1). Sampling events, collected within 24 hours of the conclusion of a storm, consisted of single storm events for this investigation. Precipitation, in the form of rain, observed at the study site for individual sampling events ranged from 8.6 to 252.9 mm (0.34 to 10.0 in).

The control's runoff yield, totaling 58.1 mm (2.3 in), was significantly less ($p<0.0001$) than runoff yield from the treatments (Table 2). Total runoff yield from harvest/site preparation/plant and harvest/plant treatments was 137 and 228 mm (5.4 and 9.0 in), respectively during the study period. Based on this analysis, the harvest/plant treatment had significantly greater runoff yield than the harvest/site preparation/plant treatment and the control. Mean runoff yield for individual storm events for the harvest/plant treatment was 66 and 421 percent greater than the harvest/site preparation/plant treatment and the control runoff yield, respectively. The harvest/site preparation/plant treatment had less runoff yield than the control during events with low runoff yield (< 1.0 mm (0.04 in) (Figure 3). The greater surface roughness of the site prepared area compensated for the lack of cover resulting in reduced runoff yields in comparison to the control. Raised beds allowed for greater infiltration, which directly reduced the resulting runoff.

Soil erosion was greater for treatments than for the undisturbed control for all but four events (events 11, 15, 19, and 28) (Figure 4). The difference in mean soil erosion losses between the control and treatments during these events were less than 1 g (0.04 oz) (<0.00 t/ha). Event 28 was an early spring storm, which resulted in the greatest runoff for the control (Figure 3). Event 28 had a greater impact on the control by producing 41 percent of the cumulative soil erosion total for the control. The same event only accounted for 17 and 12 percent of cumulative soil erosion totals for harvest/site preparation/plant and harvest/plant treatments, respectively.

Table 1. North Auburn study precipitation for each sampling event.

Sampling event	Sampling date	Precipitation (mm)
1	12/15/98	24.1
2	1/7/99	53.3
3	1/27/99	41.9
4	2/2/99	68.6
5	3/8/99	64.5
6	3/19/99	54.9
7	3/30/99	24.4
8	4/7/99	14.7
9	5/11/99	47.8
10	5/18/99	34.9
11	6/9/99	45.8
12	6/21/99	66.1
13	6/29/99	252.9
14	7/6/99	20.3
15	7/8/99	18.8
16	7/20/99	72
17	8/27/99	75.8
18	9/10/99	50.1
19	9/30/99	46.9
20	10/6/99	14.7
21	10/12/99	88.9
22	12/29/99	26.7
23	1/18/00	73.7
24	1/26/00	44.5
25	2/29/00	18.3
26	3/9/00	8.6
27	3/15/00	19.8
28	3/23/00	60.5
29	4/4/00	56.4
30	4/18/00	22.9
31	5/22/00	74.2
32	6/23/00	27.9
33	7/24/00	38.6
34	8/4/00	43.9
35	8/11/00	17.8
Accumulated total precipitation		**1715**

Table 2. Mean sediment and runoff yields for the harvest/site preparation/plant (H-SP-P), harvest/plant (H-P), and control subplots for storm events in the North Auburn study. Values in parenthesis are sediment yields in t/ha/yr.

Parameter	Treatment	N	Mean*	Standard deviation
Sediment yield (g)†				
	H-SP-P	80	6.7 (0.004)b	7.5 (0.004)
	H-P	89	41.4 (0.022)a	72.6 (0.039)
	Control	58	3.0 (0.002)c	10.8 (0.006)
Runoff yield (mm)†				
	H-SP-P	80	4.9b	5.9
	H-P	90	7.4a	6.8
	Control	58	2.5c	4.7

* **Means with different letters are significantly different at the 5 percent significance level using Duncan's Multiple Range Test (sediment and runoff yield comparisons performed independently).**

† **Mean values are presented for each treatment per storm event.**

Figure 3
Runoff yield for the harvest/site preparation/plant (H-SP-P), harvest/plant (H-P), and the undisturbed control treatments during each storm event of the North Auburn study.

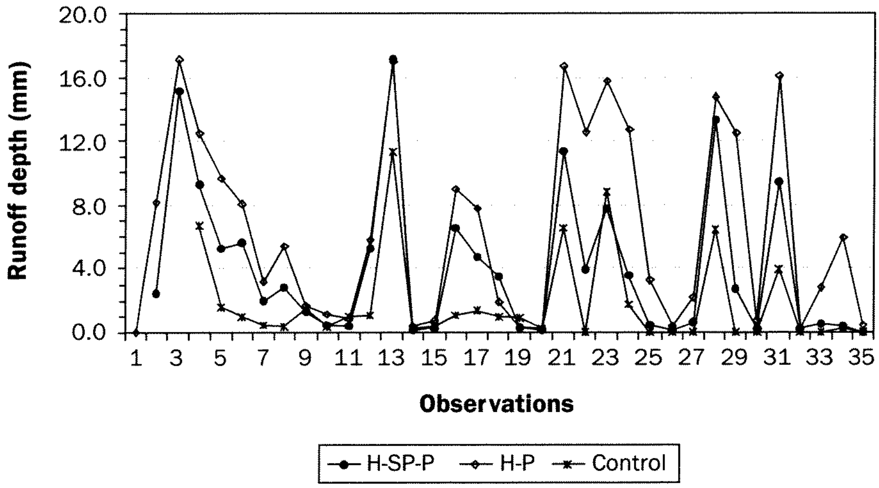
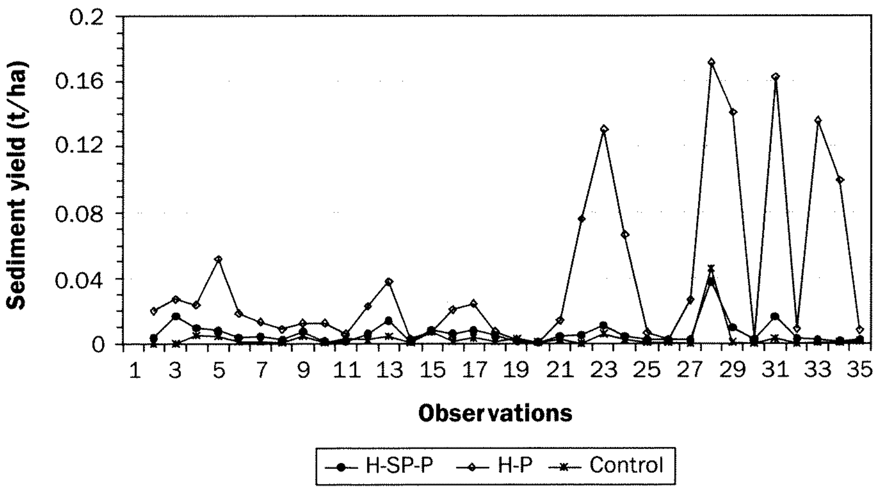


Figure 4
Sediment yield for the harvest/site preparation/plant (H-SP-P), harvest/plant (H-P), and the undisturbed control treatments during each storm event of the North Auburn study.



During the period covered by this study (20 months), the control had a total soil loss of 100.5 g (0.22 lb) (representing 0.11 t/ha) (0.07 t/ha/yr); nearly half was produced during one storm (Event 28). Excluding event 28, the control yielded 59.1 g (0.13 lb) (representing 0.07 t/ha (0.20 ton/acre)) of soil. Mean soil erosion losses were 2 and 12 times greater than the control for the H-SP-P and harvest/plant treatments, respectively. During the study, the harvest/site preparation/plant treatment yielded a total soil loss of 197.3 g (0.43 lb) [representing 0.22 t/ha (0.60 ton/acre)] (0.13 t/ha/yr) and the harvest/plant treatment yielded 1249.6 g (2.7 lbs) [representing 1.37 t/ha (3.7 t/ac)] (0.82 t/ha/yr).

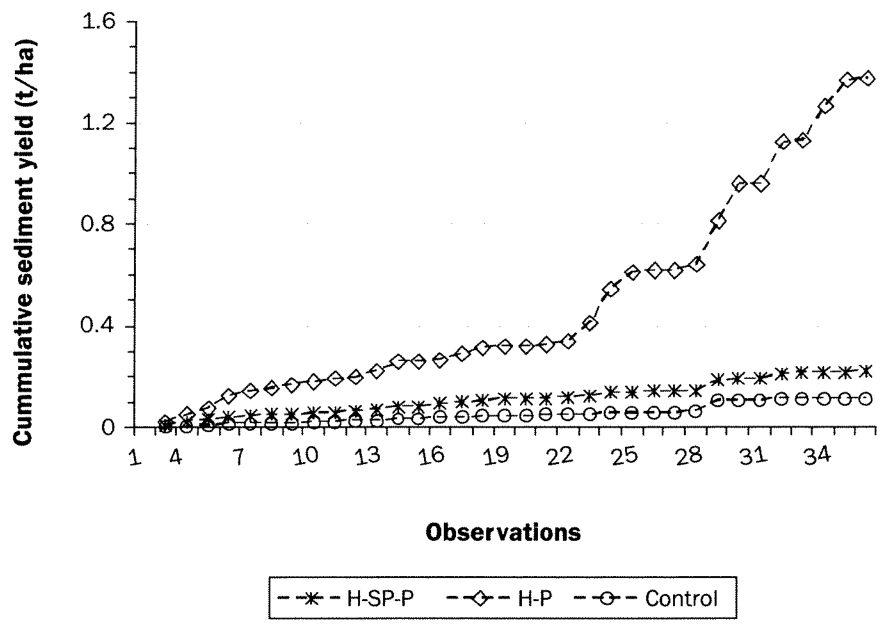
Soil erosion from the control and the harvest/site preparation/plant treatment remained relatively constant throughout the study period (Figure 5). Cumulative loss charts show similar trends between the control and the harvest/site preparation/plant treatment during the study period. However, the harvest/plant treatment had periods of accelerated soil erosion following high-energy storms during the study period. These patterns are consistent with patterns in erosion losses observed by the investigator in earlier work (Grace, 2000; 2002a; 2002b). Differences in the soil erosion patterns could be expected due to differences in cover and surface roughness between the treatments and the control. Reduced surface cover and roughness encountered following forest operations often result in less protection from the impacts of storm energy.

Soil losses from the treatment areas were detected as significantly greater than control soil loss over the study period ($p<0.0001$) (Table 2). harvest/site preparation/plant treatment soil loss was significantly less than harvest/plant treatment ($p<0.0001$). Differences in soil erosion between treatments can likely be attributed to the differences in the prescriptions. The harvest/site preparation/plant treatment had a greater surface roughness than the harvest/plant treatment due to the site preparation operation, which resulted in raised beds for seedling establishment. The beds allowed for greater storage of runoff resulting from storms in the investigation. The raised beds likely reduced transport of sediment due to greater infiltration and by providing areas for deposition of detached sediment.

The impact of forest operations on forest soil and water has received greater attention in the past 10 years. At the same time, the demand for forest products and pressure on forest resources continue to escalate. In an attempt to meet future demand, forest managers often utilize intensive forest management practices to improve site productivity. Site preparation has become a common and effective operation to improve seedling survival and establishment and shorten rotations (Gent et al., 1983). However, increased environmental awareness has focused attention on potential impacts of harvesting and site preparation on forest soil and water quality.

Erosion losses from the undisturbed control used in this study was well within the range of values expected for undisturbed forestlands (Yoho, 1980). In fact, soil erosion observed from the control used here was on the lower end of the range [trace to 0.30 t/ha/yr (0.82 t/ac/yr)] typically observed on undisturbed forests (Smith and Stamey, 1965). Soil erosion from the harvest/plant and harvest/site prep/plant treatments were greater than from the undisturbed control over the period covered by this study. However, only the harvest/plant treatment with 0.82 t/ha/yr (2.2 t/ac/yr) was greater than rates typically

Figure 5
Cumulative sediment yield for the harvest/site preparation/plant (H-SP-P), harvest/plant (H-P), and the undisturbed control treatments during the North Auburn study.



observed on undisturbed forestlands. Erosion rates observed during this study were greater than those reported for a roller chopping and burning treatment and lower than shearing, windrowing, and burning treatment in East Texas (Blackburn et al., 1986). In addition, erosion rates were lower than rates (0.27 - 9.9 t/ha/yr) (0.73 - 27 t/ac/yr) reported in studies of more intensive site preparation techniques in Mississippi (Beasley, 1979), North Carolina (Douglass and Goodwin, 1980), and Arkansas (Beasley and Granillo, 1982).

Mechanical site preparation in this study was similar to that used for agricultural row crops only varying by preparation intensity and power requirements. Soil amendment, as a result of the site preparation treatment (ripping), likely improved infiltration following harvesting. Raised beds contributed to runoff yield reductions by increasing surface water storage capacity. The beds constructed on contour also reduced slope lengths, thereby reducing the erosion energy of surface runoff emanating from treatment areas. Site preparation likely provided some soil erosion mitigation benefit by reducing the surface runoff. However, the author recognizes that experimental units in this study were small scale (11 m^2) (120 ft^2) and effects observed may be different from larger scale units with identical treatment due to mechanisms involved in the erosion process. In addition, results reported in this investigation are based on multiple samples (subsamples) of single experimental units (treatments). However, errors and misinterpretation of analysis can result from experiments involving unreplicated treatments (Hurlbert, 1984). The design utilized in this study was used to detect differences in treatment areas (harvest/site preparation/plant, harvest/plant, and control areas), but cannot implicitly attribute these differences to treatment effects. That is, observed differences in treatment areas may exist independently of the treatment method; i.e. inherent differences in the treatment areas may have influenced results of the analysis.

Summary and Conclusion

In this investigation, soil erosion increases were observed for both silvicultural treatment areas. Soil loss increases of two-fold and 30-fold were observed from the harvest/site preparation/plant and harvest/plant treatments, respectively. However, only the harvest/plant treatment with 0.82 t/ha/yr (2.2 t/ac/yr) was greater than rates typically observed on undisturbed forestlands (0.30 t/ha/yr (0.82 t/ac/yr)) (Smith and Stamey, 1965;Yoho, 1980). Cumulative soil loss from the control and the harvest/site preparation/plant treatment remained relatively constant throughout the study period. However, the harvest/plant treatment was more responsive to storm energy with dramatic increases in soil erosion following high-energy storms. Runoff yield results were similar to trends observed with soil loss. The control had significantly less runoff yield than treatments in the investigation. The harvest/site preparation/plant treatment soil erosion and runoff yields were likely less than the harvest/plant treatment due to the presence of beds which aided in infiltration and reducing surface runoff.

Little information is available which quantifies the influence of site preparation on soil erosion at multiple scales. Additional information is needed to assess the impact of site preparation on forest soil erosion and water quality at the watershed and landscape scale. A better understanding of the nature and extent of impacts of site preparation is critical for continued development of water quality standards and limits related to forest operations. Data are also critical to aid in modeling and mitigation efforts concerning the impacts of forest operations.

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