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Impact of Harvesting on Sediment and Runoff Production On a Piedmont Site in Alabama

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Abstract:

This study was performed in Lee County, Alabama to investigate the impact of harvesting a 20-year-old loblolly pine (Pinus taeda L.) plantation on sediment and runoff yield. Sediment and runoff yield responses on harvest areas was compared to that of undisturbed areas. Impacts were evaluated by establishing and monitoring isolated small plots, 2-m by 5.5-m, over a lo-month period following the harvest prescription. Statistically significant sediment yield increases greater than 3-fold (360 percent) were observed from harvest areas in comparison to undisturbed areas. Similar to sediment yield increases, runoff yield increased 3-fold (350 percent) on harvest areas in comparison to undisturbed areas. The rate of sediment yield increase from undisturbed areas remained constant over the study period, whereas sediment yield from harvest areas increased dramatically following high-energy storms.

Keywords:

Forest operations, Soil Erosion, Surface Runoff, Hat-vesting

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Introduction

Forest management operations can disturb natural processes in a forest ecosystem. In recent years, increased concern has focused on the effects of management operations on forestlands primarily because disturbances can initiate change in the forest dynamics that range from negligible to drastic. Forest operations warranting detailed investigations are generally operations that scarify the forest floor or modify the soil physical properties. The soil physical properties are altered primarily by compaction from heavy mechanized equipment used to perform management prescriptions. Harvesting and site preparation, two primary operations of concern, are operations often involving mechanized equipment resulting in increased forest floor scarification, compaction, and rutting. Scarification of the forest floor can prove beneficial in improving infiltration, thus reducing surface runoff volumes. By the same mechanisms, scarification of the forest floor causes increased erosion due to lack of surface cover to protect soil from raindrop splash and greater potential for soil transport by surface runoff.

In the South, demand for increased production of pine has initiated employment of methods similar to those practiced in agriculture. Shorter rotations increase the frequency of harvesting, which can result in accelerated erosion losses and potential for water quality problems. Harvesting is a necessary element in order to meet the demand for timber, but degrading impacts are not necessary. Literature reports harvesting as a major source of sediment yield and sedimentation on forested lands. Quantifying the effect of harvesting and other forest operations is a necessity in design of environmentally sensitive timber management systems. The study reported here is a two-phase effort to quantify the effect of harvesting on sediment and runoff yield from a 20-year-old Loblolly pine (*Pinus taeda L.*) plantation in central Alabama. The first phase of the study, for which this paper reports, will assess the effect of harvesting on sediment and runoff yield with the second phase assessing the effects of site preparation on the same response variables.

Literature Review

Forest operations such as timber harvesting, reforestation, site preparation, silvilcultural activities, and road construction and maintenance are necessary management practices that contribute to sediment delivery to streams. Sedimentation has been reported to lower the quality of pristine forest streams, which in turn adversely affects habitat. Sediment produced from forest roads, harvesting, and site preparation have the greatest potential for nonpoint source pollution of water from forestland (Douglass 1977). Harvesting often disrupts the litter cover, thus exposing the mineral soil to erosive action by rainfall.

Beasley (1979) found that watersheds on the Gulf Coast Plain sediment losses increased as much as 24 times for the first year after harvesting and site preparation treatments of chopping, shearing, and bedding. Sediment concentrations showed small increases to 2,471, 2,837, and 2,808 mg/L from the undisturbed concentration of 2,127 mg/L. Sediment tosses from site prepared watersheds during the second year after treatment were as much as 55 times the undisturbed control watershed. Second-year sediment concentrations were as much as 6 times the undisturbed' watershed. In relation to total precipitation, stormflow decreased on all site preparation treated watersheds the second year after treatment. The experiment was un-replicated and therefore had no statistical basis, but it did identify an area needing more intensive study.

In another study by Swank and others (1987), timber management practices were examined to determine effects on soil and water. This investigation looked at the effect of management practices on various forest types in the US. The findings showed intensive management practices could have a significant impact on watershed soil and water. Mechanical harvesting and site preparation methods can cause elevated soil losses and have a damaging impact both on- and off-site. Harvesting interrupts the natural cycles of nutrients and the effect of this management activity was reported to be site-specific. Carling and others (1993) found that sites at the highest risk for erosion damage include mineral soils derived from sandy or loamy parent materials on steep slopes.

In a study on the Horse Creek watershed in north central portion of Idaho, King and Gonsior (1980) observed a low flow sediment concentration range of 1 to 10 mg/l at road crossings. This concentration increased by one to two orders of magnitude during high intensity rainstorms. Vowel1 (1985) reported annual sediment yields from four test segments of road in Oklahoma's Ouachita Mountains of 183, 109, 125, and 31 tons/mi respectively. The annual yields were high particularly when compared to silvilcultural activities soil losses. In another study of road sediment production and delivery by Miller et al. (1985) sediment loss was 25 ton/ac; with 58 and 42 percent suspended and deposited, respectively. Sediment delivery to streams was 1114 ton/yr with 1004 ton/yr suspended at the collection point in stream.

Troendle and Olsen (1993) report the basic response of watersheds to timber harvest is conceptually similar. Timber harvesting reduces soil water depletion, canopy interception, and evapotranspiration. This generally results in more water available to drain from the soil toward channels, which in turn increases soil moisture levels. Sediment introduction into streams is increased following timber harvest due to sediment accumulation and transport is highly correlated with flow. Hoover (1952) reported that the amount of streamflow could be manipulated by controlling vegetation.

Objectives

An evaluation of forest harvesting operations influence on sediment and runoff yield on a Piedmont site will be presented in this work. A commonly prescribed clear-cut harvesting technique will be examined to compare sediment and runoff yields to undisturbed levels. Harvesting effects on surface runoff and sediment yield were evaluated and quantified in an attempt to better understand site impacts.

Methodology

Nine experimental plots with similar topography (10 percent slope), soils, and drainage were located on a Mead Coated Board, Inc. site in Lee County, Alabama near Auburn, Alabama. The 25-hectare study site was a 20-year-old Loblolly pine (*Pinus taeda* L.) plantation with a basal area estimated at 28 m^2 per hectare. Soils on the site were classified as clayey, kaolinitic, thermic belonging to the Rhodic Kanhapludult family. The harvesting treatments were newly prescribed to sites to assess the true effect of harvesting on soil and water. Six replications of clear-cut harvesting and three replications of an undisturbed control were used in this experiment.

Plots were designed to insure runoff within each plot was isolated from the surrounding landscape (Figure 1). Borders, 20-cm high, were installed to bound plots and define treatment areas. Plot area was 11 m^2 with dimensions 2 m in width x 5.5 m in length, exactly one-fourth the standard USLE plot. Runoff from each plot was collected in a sediment tank, 210-liter capacity, placed at the bottom of each experimental unit. Runoff volume was determined following each event by measuring volume of stormwater collected in sediment tanks. Sediment movement was quantified for each associated plot by 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. Treatment effect on soil movement and runoff was determined by comparing sediment yields and runoff characteristics from harvesting plots to that of undisturbed controls. Rainfall amount and duration were recorded by a recording rain gauge located on the study site.

Response variables for the examination were analyzed using SAS general 'linear modeling procedures. The hypothesis for this comparison was that treatment means were equal in resulting sediment yield and runoff production. Sediment and runoff yield were used as dependent variables for the investigation. The independent variable considered in the statistical analysis was treatment method. Duncan's Multiple Range Test was used to test treatment means ($\alpha = 0.05$), where analysis of variance indicated significant differences.

Results and Discussion

Twenty-one sampling events were recorded during the first ten months of the study (Table 1). Only seventeen sampling events provided for direct comparisons between the control and treatment in the study. Four events at the beginning of the study had incompiete data due to installation problems and were not included in statistical comparisons. Sample collections followed individual storm events in this investigation.' Precipitation, in the form of rain, received during individual sampling events ranged from 14.7 to 252.9 mm. Accumulated precipitation during the 10-month study totaled 1181.4 mm.

Sediment yield was greater for the harvest treatment than for the undisturbed control for each of the seventeen sampling events used in this comparison (Figure 2). Consistent with previous literature, sampling events coinciding with high intensity storms did show greater sediment yield increases than low intensity storms (Wischmeier and Smith 1978). Sediment yield increases attributed to the harvest areas in this experiment ranged from 71 to 630 percent in comparison to the undisturbed areas. The average sediment yield increase following harvest was ,360 percent over undisturbed controls. Over the period observed in this study, the experimental harvest areas produced a total of 155.5 g (representing 0.14 t/ha) and undisturbed areas produced 34.7 g (representing 0.03 t/ha) of sediment at the sampling point. ANOVA detected treatment effects at the 0.05 significance level on sediment yield as significant over the study period (Table 2). Harvest area sediment yield was detected as significantly greater than control sediment yield ($p>0.0001$).

Runoff yield, exhibiting the same trend as seen with sediment yield, was greater for the harvest treatment than for the control for fourteen of the seventeen sampling events (Figure 2). ANOVA detected significant treatments effects, substantiating the observed trends, on runoff yield over the study period (Table 2). Harvest area runoff yield was significantly greater than the control runoff yield ($p>0.0001$). Based on this analysis, harvesting increased runoff yield from a mean of 2.1-mm to 6.3-mm during the study period.

Sampling events with low runoff yield (< 11.0-L or 1 .0-mm) were events that the control had g-eater runoff yield than the harvest area. The greater surface roughness of the harvest area likely allowed for greater infiltration than the control during the low intensity storms represented by these sampling events. Runoff yield from the harvest area ranged from 2- to 187-L with a total of 984-L during the study period. Runoff yield increases attributed to the harvest ranged from 34 to 1200 percent in comparison to the undisturbed control. Consistent with results from sediment yield the average runoff yield increase following the harvest was also 3-fold (350 percent increase). Harvest clearly increased runoff yield in this experiment, although runoff yield was still relatively low for a disturbed area. Harvest area runoff yields from storms recorded in the experiment averaged less than 6 percent of the total precipitation.

Sediment yield from the undisturbed area (control) was relatively constant throughout the study, which is evident by looking at cumulative sediment yield during the 11 -month study period (Figure 3). Cumulative sediment yield gradually increased for the control at a constant rate regardless of the storm size. A different trend was observed for cumulative sediment yield on the harvest area. The harvest area sediment yield was strongly influenced by storm events during the study period, which is illustrated by the increases in slope of the cumulative sediment graph. Dramatic increases in sediment yield from the harvest area were observed following large high intensity storms, particularly on elapsed day 199 (252.9-mm). Sediment continued to be iost at an accelerated rate for several sampling events (events 14-16) following this large event which is consistent with patterns in erosion losses observed by the investigators in previous work (Grace et al. 1998, Grace 1999, Grace 2000). High storm energy not only produces elevated sediment yields, but also detaches soil particles, which can be easily transported by subsequent low energy storms. Based on this mechanism, subsequent low intensity storms can also produce accelerated erosion losses.

Conclusions

Harvesting impacts on forest soil and water have become an area of increased concern in recent years coinciding with increased environmental awareness. This increased concern has spawned a critical need for experimental data to aid in prediction and mitigation efforts. Scientific data on varying soil types and climatic regions is required to first assess the impact of harvesting operations, and secondly aid modelers in predicting.effects for planning toots. The research presented here is an effort to provide additional site-specific data on the impact of timber harvesting on sediment and runoff yield.

Runoff yield following harvesting accelerated sediment yield from the Piedmont soil site in this investigation. Runoff yield was increased in most sampling events observed, with low intensity events being the exception. Runoff yield increases as much as 1200 percent over the undisturbed control were observed. The average yield increase from harvest areas compared to the control for all sampling events in the experiment was 350 percent. Even with this dramatic increase in runoff yield from harvest areas the collected runoff was less than 6 percent of the precipitation on the area.

Sediment yield from the harvest area was significantly greater than that from the control **area.** Harvest area sediment yield was greater than control yield for each of the sampling events in the investigation. Greater than a 3-fold increase in sediment yield for the harvest area in relation to the control was observed in this small plot experiment. Cumulative sediment yield for the harvest area dramatically increased following high-energy storms, whereas cumulative sediment yield for the control remained constant throughout the study period. Sediment yield for the harvest area showed no reductions as the study progressed and continued to be accelerated at the end of this initial study period. The harvest area sediment yields reported in this work were accelerated over that of the control, but are still lower than the estimated normal rate of geologic erosion (0.40 to 0.60 t/ha/yr) reported by Smith and Stamey (1965).

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Table 1. Accumulated precipitation for each sampling event during the North Auburn study.

Sampling Event	Sampling Date	Elapsed Days	Precipitation (mm)
1	12/15/98	3	24.1
2	1/7/99	26	53.3
3	1/27/99	46	41.9
4	2/2/99	52	68.6
5	3/8/99	86	64.5
6	3/19/99	97	54.9
7	3/30/99	108	24.4
8	4/7/99	116	14.7
9	5/11/99	150	47.8
10	5/18/99	157	34.9
11	6/9/99	179	45.8
12	6/21/99	191	66.1
13	6/29/99	199	252.9
14	7/6/99	206	20.3
15	7/8/99	208	18.8
16	7/20/99	220	72.0
17	8/27/99	258	75.8
18	9/10/99	272	50.1
19	9/30/99	292	46.9
20	10/6/99	299	14.7
21	10/12/99	305	88.9
Total Accumulated Precipitation			1181.4

Table 2. Comparison of mean sediment and runoff yield between harvest treatment and undisturbed condition.

Parameter	Treatment	N	Mean*	Std. Dev.
Sediment Yield (g)				
	Harvest	109	8.2a	10.2
	Undisturbed	52	1.9b	1.3
Runoff Yield (L)				
	Harvest	104	6.3a	6.4
	Undisturbed	50	2.2b	4.3

*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 separately).

Figure 1. Plot design for the North Auburn Study.

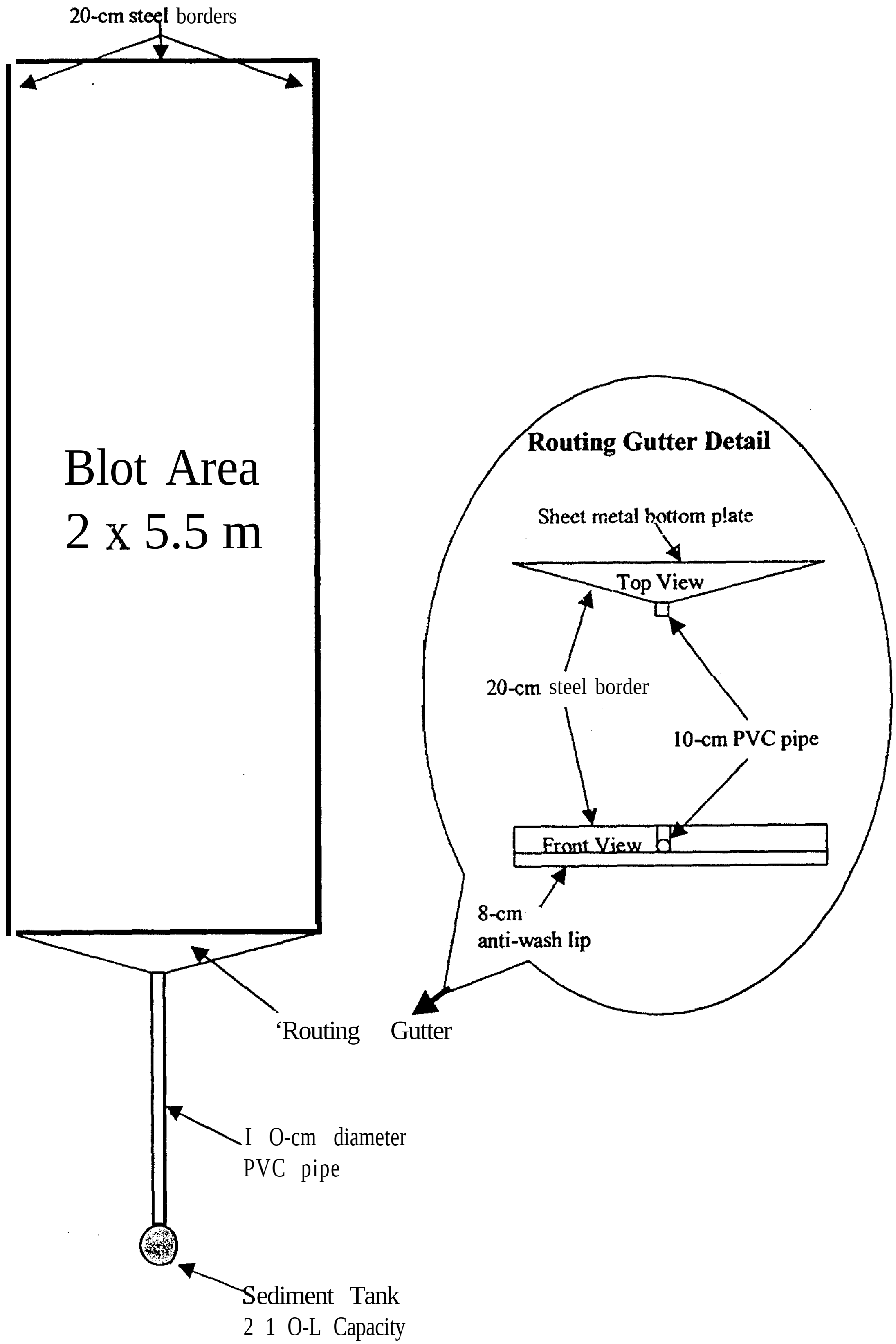

Figure 2. Observed sediment and runoff yield during the North Auburn study.

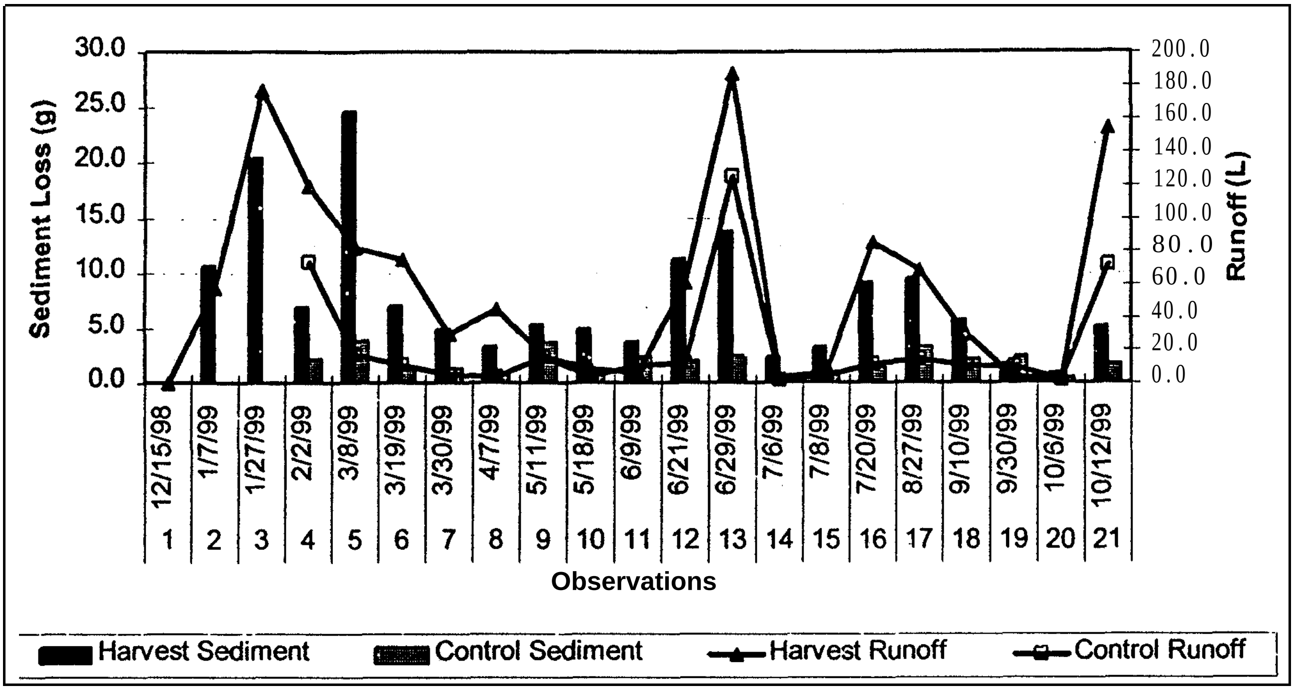

Figure 3. Cumulative sediment yield following North Auburn study initiation.