Infiltration and runoff water quality response to silvicultural and grazing treatments on a longleaf pine forest

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Abstract

The impacts of intensive vs. extensive silviculture, and moderate continuous livestock grazing vs. no livestock grazing as they relate to infiltration and runoff water quality were evaluated using rainfall simulation. Study sites were located in the Vernon District of the Kisatchie National Forest, Louisiana. Infiltration was greater, and interrill erosion, suspension-solution phase total nitrogen concentrations, and suspension-solution phase total phosphate concentrations were less from areas under extensive silviculture and no livestock grazing than from areas under intensive silviculture and livestock grazing, respectively. Intensive silviculture exposed more bare soil than extensive treatments. Litter cover and litter biomass were significantly reduced by the intensive silvicultural treatment. Livestock grazing also exposed more bare soil mainly resulting from a removal of grass cover and biomass.

Key Words: interrill erosion, nitrogen, phosphorus

Southeastern forests currently produce more than half of the nation's wood supply and are potential major livestock producing areas (Ursic 1975, Grelen 1978). The effects of silvicultural and livestock grazing practices on infiltration, interrill erosion, and runoff water quality are largely undocumented. Such information is needed for state and federal agencies to make sound resource management decisions. Likewise, maintaining site productivity by minimizing interrill erosion and nutrient export is a concern to private and public forest managers.

Intensive forest management practices of tree harvesting, site preparation, and livestock grazing have been identified as potential causes of declining site productivity and nonpoint pollution Bormann et al. 1968, Feller and Kimmins 1984, Patric and Helvey 1986). Natural erosion rates from undisturbed forestlands in the Southeast are low, ranging from a trace to 720 kg ha^{-1} $year^{-1}$ (Schreiber et al. 1980, Yoho 1980, Blackburn et al. 1986). Tree harvesting and site preparation increase the potential for soil erosion and nutrient export by disturbing the protective surface layers of the forest floor, thus reducing infiltration rates and increasing surface runoff (Moehring and Rawls 1970, Hewlett and Troendle 1975, Douglass 1975, Blackburn et al. 1986). For watersheds in northern Mississippi, Beasley (1979) reported first year sediment losses of 12,540 kg ha^{-1} following clearcut harvesting and roller chopping in a watershed in comparison to 620 kg ha^{-1} for an undisturbed watershed. However, sediment losses and concentrations were similar from clearcut harvested and roller chopped, and undisturbed watersheds near Alto, Texas (Blackburn et al. 1986).

Stoeckeler (1959) reported infiltration rates of an ungrazed oak woodland 150 times greater than an adjacent heavily grazed woodland. Infiltration rates of heavily grazed, moderately grazed, and ungrazed longleaf pine *(Pinus palustris)*-bluestem (*Andropogon* spp., *Schizachyrium* spp.) range were reported by Duvall and Linnartz (1967) to be 20, 30, and 46 mm hr^{-1}, respectively. Because of a long history of overgrazing forest, and lack of forest hydrology research applicable to grazing, the conservation-minded public perceives forest grazing as a significant environmental problem (Lee 1980, Johnson 1952, Adams 1975, Blackburn 1984, Patric and Helvey 1986).

The objective of this research was to assess the impact of intensive vs. extensive silvicultural practices, and moderate continuous livestock grazing vs. no livestock grazing on infiltration rates and runoff water quality.

Materials and Methods

Study Area and Treatments

The study area was located 48 km southeast of Leesville, Louisiana on the Fullerton Allotment, Vernon Ranger District, Kisatchie National Forest. Normal annual rainfall is 1,379 mm and the average annual temperature is 18.8° C. The mean frost-free period is 245 days, from the end of March to mid-November. Gentle rolling topography, intersected by numerous drainages, characterize the areas. Elevation ranges from 55 to 135 m above sea level. Vegetation consists mainly of a longleaf pine overstory with a bluestem and panicum (*Panicum* spp., *Diachanthelium* spp.) grass understory. Soils are of the Malbis series, which is a fine-loamy, siliceous, thermic Plinthic Paleudult. Soils are deep and moderately well drained and occur on side slopes and gently sloping ridgetops of less than 5%.

Six study sites (replications) were located within the Fullerton Allotment. Each study site consisted of a fenced exclosure (100 m × 150 m) and an adjacent similar size non-fenced area. The exclosure and the grazed area were partitioned into 10 × 15 m subsections which were randomly assigned a sample date. Two silvicultural management practices, i.e., seedtree harvesting or thinning, were equally represented in the exclosure and adjacent nonfenced area. Each sample date was represented by 6 replications of 4 treatments with 2 subsamples per treatment. Seedtree harvesting was considered an intensive silvicultural practice and involved the removal of all but 4 to 6 m^2 basal area per hectare of seed trees. After harvesting, the areas were site-prepared using a drum chopper or rake harrow (a railroad tie with spikes 8 to 10 cm dragged behind a tractor) and broadcast-burned to remove debris. After pine seedlings were established, all remaining seed trees were harvested. Forest thinning was considered an extensive silvicultural practice with minimal management conducted over a large area. The study sites were thinned to an average basal area of 14 m^2 ha^{-1}, using chain saws and rubber tire skidders. Treatment dates for each study site are summarized in Table 1. Silvicultural study sites were located with seed tree harvest and thinning treatments directly adjacent to each other.

Cattle had free access to the Fullerton Allotment from 1967 to 1977. In 1977 the allotment was cross-fenced into individual range units (RU). Two study sites were located in 3 RU's which contained

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Research reported here is a contribution from the USDA-ARS, Northwest Watershed Research Center, Texas Agricultural Experiment Station, and the USDA-Forest Service. The cooperation and financial support of the Forest Service are gratefully acknowledged. The assistance of C.E. Gates, statistician, Texas Agricultural Experiment Station, College Station, with the experimental design and statistical analysis is acknowledged along with the data collection and laboratory analysis efforts of Andrew Weichert and Pat Fazio.

Manuscript accepted 28 February 1989.

Table 1. Silvicultural treatment schedules for the 6 study sites, Vernon District, Kisatchie National Forest, Louisiana.

Study site	Seedtree harvest	Thinning
1	February 1980	March 1978
2	February 1982	March 1978
3	February 1980	March 1980
4	February 1980	March 1980
5	February 1977	March 1980
6	February 1977	March 1980

535, 511, and 675 ha. Control of animal stocking rates and grazing systems was not initiated on the sites until 1981. From 1967 through 1980, moderate stocking rates averaged 15 ha AU^{-1}. From 1981 through 1985, 2 RU's were grazed continually from 1 March to 15 November and deferred from 16 November to 28 February, and the third RU was continuously grazed yearlong. The yearlong continuously grazed RU was stocked at 13 ha AU^{-1}, and the seasonally grazed RU's were stocked at 15 and 19 ha AU^{-1}, respectively (Pearson et al. 1987). Initially 3 grazing treatments (seasonal continuous grazing, yearlong continuous grazing, and no grazing) were analyzed for statistical differences. Because no significant differences were found between seasonal and yearlong continuous grazing, they were analyzed together as one treatment (continuous grazing) in the final analysis.

Construction of livestock exclosures at each study site was not completed until 1982 just prior to the second sampling period. For this reason both sampling periods in 1982 were treated as grazed conditions. Although the grazing treatments compared were continuous livestock grazing and no livestock grazing, this was not a long-term study and therefore represents a comparison of continuous livestock grazing with the removal of livestock from areas previously grazed.

Methods

Study sites were sampled in June and August/September of 1982–1984, and for a final time in September 1985. A rainfall simulator similar to the one described by Meyer and Harman (1979) was used to determine infiltration and runoff water quality over 1-m^2 plots isolated with metal plot frames. Simulated rainfall had a normal raindrop size distribution from 0 to 6 mm with an average drop diameter of 2.5 mm. Impact energy was 2.75 kJ ha-mm^{-1}. In order to reduce variability attributable to antecedent soil water content, the plots were pre-wet by a sprinkler system that used an agricultural full-cone mist-type nozzle under a plastic cone. An area 1.5 m diameter was prewet with 42 *l* of water at a rate of 190 *l* hr^{-1}. The nozzle tip was located 1.2 m above the soil. The plots were then covered with plastic to reduce evaporation. About 24 hours later, simulated rainfall was applied at a rate of 127 mm hr^{-1} for 30 minutes to insure runoff from all plots. Water used to simulate rainfall was sampled and used to correct nutrient concentrations in runoff samples. Runoff from each plot was regularly pumped into tared containers. At the end of the 30-minute simulated rainfall event, the cumulative runoff was weighed and a 30-minute infiltration rate (mm hr^{-1}) was calculated by determining the difference between applied rainfall and the quantity of runoff. Upon termination of each simulated rainfall event, l-liter and 0.5-liter subsamples were obtained from a thoroughly agitated collection of runoff. The 1-liter subsamples were filtered through a #1 Whatman filter paper, dried at 105° C for 24 hr, weighed, and converted to sediment loss in kg ha^{-1}. Sediment loss was used as an index of interrill erosion. The unfiltered 0.5-liter water samples were frozen and analyzed, within 2 months, for the suspension-solution phase total nitrogen and total phosphorus using a Technicon Auto Analyzer II. Total nitrogen, which includes organic and ammonium nitrogen, was measured ($\mu g\ l^{-1}$) using the ammonia/salicylate complex method after digestion with a salt/acid catalyst mixture (APHA et al. 1976). Total phosphorus samples were digested using the persulfate digestion method, and concentrations ($\mu g\ l^{-1}$) were determined by the ascorbic acid reduction method (APHA et al. 1976).

For each plot, the foliar cover (%) of grasses, forbs, litter, rock, and bare ground was determined by ocular estimation. Standing grass (live and dead) and standing forbs were clipped and litter was collected from each plot. This material was dried at 60° C, weighed, and reported in kg ha^{-1}. Prior to the start of each simulated rainfall event, 51 mm diameter soil cores were collected adjacent to each runoff plot at 0–50 and 50–100 mm depths for analysis of soil bulk density and moisture (Black 1965). Following each simulated rainfall event, a soil sample of the surface 50 mm was taken from each plot and analyzed for organic carbon content by acid dichromate digestion (Black 1965).

Statistical Analysis

Because no significant interaction was found, treatments were separated and statistical significance pertains individually to either silvicultural or grazing treatment means. Analyses of variance were used to test for significant treatment differences which were separated using Duncan's new multiple range test (Steel and Torrie 1980). Statistical significance was expressed at the 0.05 level.

Results

Silviculture

Silvicultural treatment did not significantly affect vegetative cover or biomass (Table 2). Bare ground (%) was significantly less

Table 2. Vegetation and soil variable means for all sample dates combined, Kisatchie National Forest, Louisiana.

Variable	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
Bare ground (%)	17a*	6b	13a	8b
Grass cover (%)	51a	45a	42b	60a
Forb cover (%)	10a	9a	10a	8a
Litter cover (%)	22b	38a	34a	23b
Woody cover (%)	1a	2a	1a	1a
Grass biomass (kg ha^{-1})	1322a	1229a	1035b	1708a
Forb biomass (kg ha^{-1})	242a	178a	207a	217a
Litter accumulation (kg ha^{-1})	3081b	6805a	5166a	4522a
Soil bulk density 0–50 mm (mg m^{-3})	1.37a	1.33b	1.36a	1.33a
Soil bulk density 50–100 mm (mg m^{-3})	1.45a	1.42a	1.43a	1.44a
Antecedent soil moisture 0–50 mm (%)	17.3a	17.5a	17.2a	17.9a
Antecedent soil moisture 50–100 mm (%)	14.6a	15.3a	14.9a	14.8a
Soil organic matter content (%)	3.7a	3.5a	3.7a	3.4a

*Silviculture or grazing treatment means for each variable followed by the same letter are not significantly different at the 0.05 level.

Table 3. Mean 30 minute infiltration rate (kg ha^{-1}) by sample date and for all sample dates combined, Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	43.9a*	48.0a	46.0	——[1]
Sept. 1982	47.7a	49.3a	48.5	——
June 1983	44.4a	58.4a	47.4a	55.4a
Aug. 1983	37.4a	41.4a	39.6a	39.1a
June 1984	45.6a	54.0a	45.0a	54.6a
Aug. 1984	35.4a	50.8a	42.7a	43.4a
Sept. 1985	50.4a	58.4a	45.8b	63.1a
Combined mean	43.5b	51.5a	45.4b	51.1a

*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.
[1]No sample date treatment mean.

on extensive treatments than on intensive treatments where harvesting and site preparation exposed areas of bare soil. While grass, forb, and woody cover were similar for both treatments, litter cover and accumulation were significantly greater on extensive treatments than on intensive treatments.

Measured soil variables were similar for both silvicultural treatments, with the exception of surface soil bulk density, which was significantly greater for intensive silvicultural treatments than for extensive treatments.

There was a nonsignificant trend for infiltration rates and runoff water quality to decline for both silvicultural treatments as the season progressed from late spring to fall. Infiltration rates were statistically similar between treatments for all individual sampling dates, but were significantly greater from extensive treatments than from intensive treatments when all sample dates were combined (Table 3).

Interrill erosion as well as total nitrogen and phosphorus concentrations in runoff were significantly greater from intensive silvicultural treatments than from extensive silvicultural treatments for the August 1984 sampling date and for all sample dates combined (Tables 4, 5, and 6).

Livestock Grazing

Surface soil cover and biomass revealed some differences between grazing treatments (Table 2). As would be expected, cover and biomass of grass were significantly greater on treatments with no livestock grazing than on treatments with grazing. Bare ground and litter cover were significantly greater on grazed areas than on areas excluded from grazing.

All measured soil variables were similar for both grazed and ungrazed treatments (Table 2). As with the silvicultural treatments, infiltration rates and runoff water quality from grazing treatments displayed a nonsignificant trend of decreasing infiltration and runoff water quality as the seasons progressed from late spring to fall. Mean infiltration rates were significantly greater on treatments excluded from livestock grazing than on grazed treatments for the September 1985 sample date and for all sample dates combined (Table 3). Sediment production, as a measure of interrill erosion, was significantly greater from livestock grazing treatments than from treatments with no livestock grazing for the August 1983 and September 1985 sampling dates, and for all sample dates combined. Total nitrogen concentration was greater from the grazed treatments than from the treatments without grazing for the August 1984 sampling date and for all dates combined (Table 5). Concentrations of total phosphorus were low and similar from both grazing treatments at each sampling date and for all dates combined (Table 6).

Table 4. Mean interrill erosion (kg ha^{-1}) by sample date and for all sample dates combined, Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	49.9a*	54.2a	52.0	——[1]
Sept. 1982	312.4a	274.4a	293.4	——
June 1983	72.5a	82.5a	86.4a	68.6a
Aug. 1983	223.2a	159.6a	244.9a	137.0b
June 1984	47.9a	69.2a	63.4a	53.7a
Aug. 1984	209.3a	108.5b	139.7a	178.1a
Sept. 1985	208.8a	68.5a	200.0a	83.5b
Combined mean	158.7a	115.1b	155.6a	104.1b

*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.
[1]No sample date treatment mean.

Table 5. Mean suspension-solution phase total nitrogen concentrations ($\mu g l^{-1}$) by sample date and for all sample dates combined. Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	——[1]	——	——	——
Sept. 1982	980a*	1227a	1103	——
June 1983	1204a	1640a	1519a	1325a
Aug. 1983	3112a	2227a	2767a	2616a
June 1984	1691a	1558a	1677a	1571a
Aug. 1984	2775a	1327b	2401a	1632b
Sept. 1985	1243a	694a	1123a	813a
Combined mean	1777a	1403b	1643a	1514b

[1]No sample date treatment mean.
*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.

Discussion and Conclusions

Nitrogen and phosphorus are often closely associated with sediments (Schreiber et al. 1980, Duffy et al. 1978); therefore, it follows that runoff concentrations of total nitrogen and phosphorus would exhibit a similar trend to interrill erosion or sediment loss. A small watershed study near Alto, Texas, reported similar stormflow water quality from undistrubed watersheds and watersheds that had been clearcut harvested and site prepared by roller chopping (Blackburn et al. 1986). Another small watershed study near Broaddus, Texas, reported only minimal impact on sediment loss and stormflow from continuous livestock grazing when compared to no livestock grazing (Blackburn et al. 1987).

The primary potential impacts on infiltration and runoff water

Table 6. Mean suspension-solution phase total phosphate concentrations ($\mu g l^{-1}$) by sample date for all sample dates combined, Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	——[1]	——	——	——
Sept. 1982	402a*	424a	413	——
June 1983	136a	140a	148a	128a
Aug. 1983	166a	172a	176a	163a
June 1984	136a	98a	117a	116a
Aug. 1984	233a	136b	178a	196a
Sept. 1985	189a	111a	177a	123a
Combined mean	209a	178b	229a	144a

[1]No sample date treatment mean.
*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.

quality attributable to silviculture or grazing treatment are predominately related to the removal of protective vegetation and disturbances of the surface soil.

Surface cover and bulk density were influenced most by the silvicultural treatments. Intensive silvicultural treatments exposed greater amounts of bare soil than the extensive treatment, causing the sites to be more vulnerable to the detrimental influences of raindrop impact and overland flow. Litter cover and accumulation were the only cover variables that were significantly influenced by the intensive silvicultural treatments and were probably most important. Surface soil bulk density was only slightly greater on intensively managed silvicultural treatments than on extensively managed areas; however, differences were significant. The greater surface soil bulk density and percent bare ground on intensive silvicultural treatments are probably related to harvesting and site preparation practices.

Grass cover and biomass were significantly different between treatments, and were most influenced by grazing treatments. Although litter cover was significantly different between grazing treatments, this difference was probably due mostly to the indirect reduction of grasses by cattle grazing, thus exposing additional litter. The reduction of grass cover and grass biomass by livestock grazing exposed greater amounts of bare soil to the detrimental influences of raindrop impact and overland flow. Livestock grazing did not greatly influence soil conditions since all of the soil variables measured were found to be similar for treatments with or without livestock grazing.

Under the prevailing climatic, soil, and vegetative conditions of the study area, the impacts of applied silvicultural and grazing practices on infiltration and runoff water quality, although significant, should not present a problem to management or site productivity.

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