Forest clearcutting and site preparation on a saline soil in East Texas: impact on sediment losses

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Abstract Three plot-watersheds of 0.02 ha each were installed on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas to study sediment losses from three different forest conditions for 2 water-years. A total of 118 storms and 2593 mm of rainfall were recorded during the 2-year period. Annual surface runoff was about 3, 6, and 36% of annual rainfall for the undisturbed forest, commercial clearcut, and clearcut with stumps sheared and windrowed plots, respectively. Sediment losses for the three plots, in the same order, were 65, 355, and 2,559 kg ha^{-1} yr^{-1}. Losses were highly correlated with rainfall, surface runoff, soil moisture, and site disturbance. For the occurrence of surface runoff, an average storm rainfall of at least 20, 18, and 13 mm was required for the three forest conditions. Using the universal soil loss equation with the cover-management factor (C) adopted from three different studies to four various sizes of storms in the study, the results agree with a previous study that sediment loss in disturbed forests is more difficult to estimate than that in undisturbed forests. The C values proposed in the US Agriculture Handbook #537 are least satisfactory for estimating soil losses in commercial clearcut sites and in clearcut sites with all stumps sheared and windrowed.

INTRODUCTION

Commercial clearcutting is the most common type of forest activity in East Texas (McWilliams & Lord, 1988). After a forest is cleared, mechanical site preparation is performed to enhance forest regeneration. Because of the intensity of site disturbance, these activities have caused great concern about their impacts on soil physical (Gent *et al.*, 1985; Alegre *et al.*, 1986) and chemical (Mroz *et al.*, 1985; Snyder & Harter, 1985) properties, nutrient losses (Clayton & Kennedy, 1985; Muda *et al.*, 1989), and erosion problems (Beasley & Granillo, 1988; Chang *et al.*, 1982; Miller, 1984; Riekerk, 1983).

There are more than 120 000 ha of somewhat poorly drained, upland saline soils dominated by mature loblolly and shortleaf pines with scattered hardwoods in 6 counties in central East Texas. The soils contain a high concentration of aeolian sediments deposited over impervious mudstone high in pyroclastic sediments. Recently, it was found that artificial pine regeneration (as many as three attempts in some areas) is extremely difficult following clearcutting on these soils. Information on how forestry activities affect water, soil and salt movement is urgently needed for proper forest and water resources management. Reported here are some preliminary results on soil and water losses caused by intensive site preparations on a saline soil in East Texas.

The study was conducted in the Davy Crockett National Forest near Apple Springs, Texas, about 200 km north of Houston and 250 km southeast of Dallas. The area has a humid subtropical climate and is characterized by gentle rolling hills with slopes ranging from 2-10%. The soil is Fuller fine sandy loam, a member of the fine loamy siliceous, thermic family of Albic Glossic Natraqualfs. Vegetation density of the mature southern pine stand was about 21.81 m^2 ha^{-1}.

METHODS AND PROCEDURES

Three treatments were used in the study: (1) undisturbed forest with full crown closure used as the control, (2) commercial clearcut with all merchantable timber removed, other vegetation left intact, and (3) clearcut, all vegetation removed, stumps sheared with V-blade, and windrowed, vegetation growth was prevented by shearing with no soil disturbance for 2 years. All treatments were located in close proximity to each other (about 60 m apart) for comparable environmental conditions. Budget constraints prevented replication of treatments. A surface plot (9.14 m x 22.13 m) was centrally located in each of the treatments to monitor surface runoff and soil erosion. Each plot was bounded by a plywood barrier extending 8 cm below and 7 cm above the ground surface. At the end of each plot, an apron, an approach section, a 15.4 cm H-flume, a stilling well equipped with an FW-1 water level recorder, a Coshocton N-1 runoff sampler, and a storage tank were sequentially connected together. The runoff sampler diverted about 1% of the surface runoff into a small storage tank with compartments for sediment concentration analysis. The small tank is confined in a larger storage tank designed to accommodate surface runoff generated by 48-h 50-year storms. Soil loss generated from each storm was the sum of the soil deposited in the apron and approach section plus the suspended particles in runoff water collected in both storage tanks. Sediment suspended in the water was gravimetrically determined in the laboratory.

Soil moisture at 5 depth levels was measured weekly using a CPN #503 Hydroprobe, a neutron scattering instrument, through three access tubes installed in each plot. To account for abundant organic matter and roots in forest environment, the instrument was recalibrated for the study site by the gravimetric method. A nonrecording and a recording raingage were installed beside the sheared plot. Data read from the raingage charts were used to calculate the rainfall energy (R) of the universal soil loss equation, using the procedures given by Wischmeier & Smith (1978).

After treatments, canopy density, understories, litter cover, debris, root system, organic matter, soil texture, permeability and soil structure were examined and analyzed for the determination of the cover-management (C) factor proposed by Dissmeyer & Foster (1984) and the K factor of the universal soil loss equation. The C values thus determined were compared with values proposed by Wischmeier & Smith (1978) and Chang *et al.* (1982) for estimating soil losses generated from single storms in the study area.

RESULTS AND DISCUSSION

Forest harvesting and site preparation were conducted on 22-23 July 1988. The plot-watersheds and all monitoring instruments were completely installed in September and data collection began in October 1988. Results reported below are based on data collected between 1 October 1988 and January 1991.

Rainfall and runoff

A total 63 storms and 1244 mm of rainfall were observed during the first water year, 55 storms and 1349 mm during the second water year. Rainfall in both years was considerably higher than the normal rainfall (1951-1980) of 1054 mm reported at Lufkin Airport, about 22 km northeast of the study area. Monthly rainfall at the study site ranged from 6 (August) to 349 (June) mm for the water year 1989 and from 33 (November) to 374 (May) for the water year 1990. However, the monthly normal rainfall at Lufkin Airport ranged from 62 (August) to 109 (May) mm. Apparently, rainfall amount, intensity, and variation during the study period, especially in the second year, were much greater than normal. Annual surface runoff generated from rainfall was 382 (31%), 61 (5%), and 15 (1%) mm, for the sheared, commercial cut, and control plots, respectively, during the first year, and 550 (41), 105 (8%) and 63 (5%) during the second year (Table 1). The sheared plot removed all vegetation, stumps, and debris from the ground and the soil was compacted by heavy machinery, resulting in a reduction in both transpiration and interception losses, an increase in soil moisture content, and a decrease in infiltration rate and capacity. This translated into more surface runoff than that observed on the other two test plots.

These results reveal a correlation between rainfall and runoff, and the effects of forest cover on runoff occurrence. This correlation has led us to use this simple empirical model for runoff estimation:

$$Q = b\,P_t - I_a \tag{1}$$

Table 1 Annual rainfall, surface runoff, and sediment losses for three forest conditions near Apple Springs, Texas, water year 1989-1990.

Variables	1989	1990	Average
Rainfall (mm)	1244	1349	1297
Surface runoff (mm):			
Forested	15	63	39
Clearcut	61	105	83
Sheared	382	55	466
Sediment loss (kg ha^{-1}):			
Forested	57	73	65
Clearcut	426	283	355
Sheared	2301	2817	2559

where Q is runoff, P_t is rainfall, b is runoff coefficient, and I_a is constant which can be considered as the watershed initial abstraction. For a positive Q or occurrence of runoff, $b\ P_t$ must be greater than I_a, or

$$P_t > (I_a)/b \tag{2}$$

Of the 118 storm events recorded in the two post-treatment year (October 1988-September 1990), 38, 57, and 76 events generated surface runoff for the control, commercial clearcut, and sheared plots, respectively. Using the rainfall-runoff data to fit equation (1), the results show that about 10, 15, and 64% of storm rainfall were generated into surface runoff and a storm rainfall of at least 20, 18, and 13 mm is required to generate surface runoff for the control, clearcut, and sheared plots, respectively. Note that these minimum storm sizes are the average values from fitted equations, variation in soil moisture, vegetation cover and weather conditions will make the initial abstraction different for each storm. Because of the complex environmental relations, rainfall alone only explains 50% of the runoff variation for the control plot with a standard error of estimate as high as 331% of the observed mean.

Using rainfall squared to fit equation (1) greatly improved the predictability of surface runoff. The coefficient of determination (R^2) increased from 0.50 to 0.74 for the control plot, and from 0.84 to 0.91 for the sheared plot. The developed models (Fig. 1) clearly illustrated differences in surface runoff among the three forest site conditions, especially for large storms on the sheared plot. In the commercial clearcut plot, all hardwoods, small diameter pines, debris, and stumps were left untouched. This made surface runoff in the clearcut plot only slightly greater than the control plot. No interpretations with respect to b and I_a were made due to the transformation nature of the data used in the analysis.

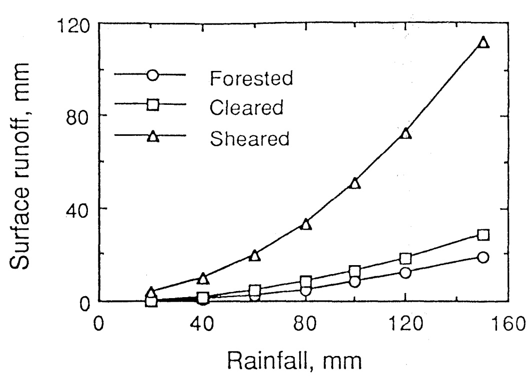

Fig. 1 Storm rainfall versus surface runoff for three forest conditions near Apple Springs, Texas.

Soil moisture

The mean soil moisture contents of the whole soil profile (0-120 cm) during the 2 year period were 0.271, 0.282, and 0.323 g cm^{-3} for the control, cleared, and sheared plots, respectively. It increased with depth from the surface and decreased with increasing canopy density. Differences among treatments were highly significant at the

0.01 alpha level, especially during the May-October period, reflecting evapotranspiration losses in the control plot.

Total sediment loss

Differences in soil loss were highly significant among treatments. In the first year, total soil losses were 57, 426, and 2301 kg ha^{-1} for the control, cleared, and sheared plots, respectively. In other words, shearing and commercial cutting increased soil losses by 40 and 8 times, respectively, over that observed in the control forest. The losses in the 2nd year, in the same order, were 73, 283, and 2817 kg ha^{-1} (Table 1). These data reveal the association of soil loss with the severity of forest and ground disturbance, rainfall, and surface runoff.

Compared to the first year, total sediment loss in the 2nd year increased by 28 and 22%, respectively, for the control and sheared plots, but declined slightly in the commercial clearcut plot. The decrease in soil loss of the cleared plot reflected the regrowth of vegetation as an effective medium in controlling erosion and sediment transport, despite a 10% increase in rainfall. Since the surface of the sheared plot was kept barren during the entire 2 year period, the comparatively higher soil loss in the 2nd year was attributed to rainfall amount and intensity. As for the control plot, the increase was attributed to about a 50% opening of canopy caused by a tornado on 19 January 1990. Since the tornado, three very large storms occurred in the study area,

Table 2 The first year runoff and sediment losses caused by forest site preparations in the southern United States.

Location	Variables	Forest	Clearcut	Sheared	References
Monticello, AK	Rainfall, mm		51	1204	Beasley &
	Runoff, mm	10	13	132	Granillo
	Sediment (kg/ha)	4		264	(1988)
Starke, FL	Rainfall			1261	Riekerk
	Runoff	175		161	(1983)
	Sediment	3.1		6.4	
Northern MS	Rainfall			1356	Beasley
	Runoff	290		451	(1979)
	Sediment	620		12800	
McCurtain Co.	Rainfall			1420	Miller (1984)
OK	Runoff	139		225	
	Sediment	36		282	
San Augustine	Rainfall	1358	1341	1317	Blackburn
Co., E. TX	Runoff	86	224	343	*et al.* (1990)
	Sediment	36	170	306	
Etoile, E. TX[a]	Rainfall	360	430	459	Chang *et al.*
	Runoff	7	42	137	(1982)
	Sediment	11	156	3462	

[a] Covered only nine months (28 May 1980-27 February 1981).

one of 93 mm (29 March 1990), one of 151 mm (3 May 1990), and one of 155 mm (30 May 1990). Total sediment generated by the three storms was 41, 184, and 1574 kg ha^{-1} which accounted for about 56, 70, 56% of the annual total loss for the control, clearcut, and sheared plots, respectively.

Compared to other studies in the southeastern USA, sediment losses from the undisturbed forest were much lower than that of northern Mississippi, and were slightly higher than that of 5 other studies (Table 2). The greater sediment losses in northern Mississippi might be attributed to 30-50% slopes and loess soils with weakly developed fragipans in the watersheds. For sheared sites, this study was lower than the studies in northern Mississippi and at Etoile, Texas, only 60 km northeast of the study area, but it was much higher than the other four studies, including the one in San Augustine County, Texas, about 110 km northeast of the study area.

Watershed sediment loss is a complex process due to diversified topographic configuration, surface roughness, and drainage systems. A soil particle may be trapped or deposited in a micro-depression, at a site with changes in slope, besides debris, or at the bottom of a creek for days, weeks, or even years before it is monitored at the gaging station. The three Texas studies were conducted within a distance of 110 km. Topography, climate, and vegetation among the three study sites are quite similar. The great soil loss of this study and the Etoile study, compared to the San Augustine study, might be attributed to the plot-watershed monitoring system. These plot watersheds were installed in the middle slopes. Their slopes are quite uniform as compared to the complex slope configuration of the entire watersheds used in the San Augustine study.

The universal soil loss equation

The universal soil loss equation (USLE) estimates the average annual soil loss from agricultural land, A, as the product of six variables reflecting rainfall energy R, soil erodibility K, slope length L, slope steepness S, cover and cropping management C, and conservation practices P, or

$$A = RKLSCP \tag{3}$$

Procedures for determination of the 6 variables in equation (3) are available in US Department of Agriculture Handbook #537 (Wischmeier & Smith, 1978). Application of the USLE in forested areas requires special evaluation of the C factor due to the characteristic forest canopy, litter floor and soil conditions (Wischmeier, 1975). Although the Handbook suggested some C values for use in forested areas, they were based on experienced judgement with very limited field observations. The C values of the three study plots determined by Dissmeyer & Foster (1984) along with that proposed in the USDA Handbook #537 and field observations made at Etoile, Texas (Chang *et al.*, 1982) are given in Table 3.

Equation (3) has been separately employed with the three sets of C values to estimate annual as well as single-storm soil losses recorded between October 1988 and September 1990 in the study areas (Chang *et al.*, 1992). The same procedures were repeated again to test the applicability of the three sets of C values for estimating soil losses generated by four single-storms recorded between October 1990 and January 1991. Figure 2 indicates that sediment loss in disturbed forests is more difficult to

Table 3 The cover-management factors of the USLE proposed by different authors for three forest site conditions.

Authors	Forested	Commercial clearcut	Sheared
Wischmeier & Smith (1978)	0.00055	0.00600	0.85000
Dissmeyer & Foster (1984)	0.00016	0.00096	0.02756
Chang *et al.* (1982)	0.00014	0.00165	0.02420

estimate than that in undisturbed forests. The *C* values proposed in the USDA Handbook are the least appropriate for estimating soil losses in the cleared and sheared plots. The estimates made using Dissmeyer & Smith (1984) and Chang *et al.* (1982) *C* values for the disturbed plots agreed with the observed data much better than that using the USDA Handbook *C* values. The results agreed with the previous study reported earlier (Chang *et al.*, 1992).

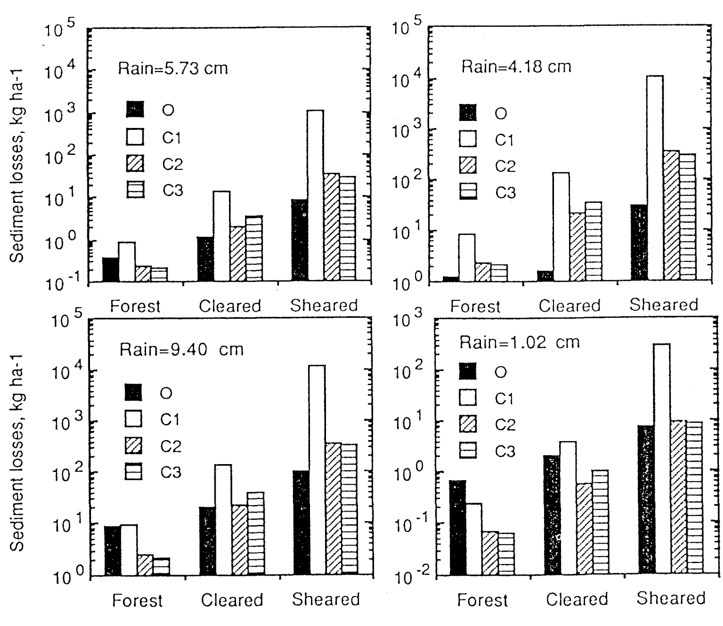

Fig. 2 Observed (O) and estimated soil losses using the USLE with a *C* factor computed from three published studies and applied to four storms near Apple Springs, Texas (C1: Wischmeier & Smith, 1978; C2: Dissmeyer & Foster, 1984; C3: Chang *et al.*, 1982).

CONCLUSIONS

Soil losses were highly correlated with rainfall, surface runoff, soil moisture, and forest disturbance. Forest treatments caused significant differences in surface runoff and soil losses among test plots, especially for the clearcut with shearing. However, the erosion problems did not seem to be serious enough to adversely affect land productivity. For the occurrence of surface runoff, a storm rainfall must be, on the average, greater than 20, 18, and 13 mm in the undisturbed forest, commercial clearcut, and sheared areas, respectively. About 10, 15, and 64% of storm rainfall for the control, clearcut, and sheared plots, respectively, resulted in surface runoff. Sediment loss was more difficult to estimate in disturbed forests than undisturbed forests. Of the three sets of the USLE's *C* values tested, the USDA Handbook values were the least appropriate for estimating soil losses in the disturbed forests.

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