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Forest Clearcutting and Site-Preparation on a Saline Soil in East Texas: Impacts on Water Quality

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FOREST CLEARCUTTING AND SITE PREPARATION ON A SALINE SOIL IN EAST TEXAS: IMPACTS ON WATER QUALITY

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Abstract—Three 0.02 hectare plot-watersheds were installed on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas. Each plot was installed with an H-flume, FW-1 automatic water level recorder, Coshocton N-1 runoff sampler, and two storage tanks. One watershed was undisturbed forested and served a control, one was clearcut without any site-preparation, and the third was clearcut, V-blade sheared, windrowed, and vegetation regrowth was prevented for the first 2 years. A total of 274 storms were recorded during the four-year study period, 1989-1992. Average annual sediment losses for the study period were 55, 197, and 1,530 kilograms per hectare per year for the control, commercial clearcut, and sheared plots, respectively. These losses are about average for most studies conducted in East Texas and the Southeast and are well below average losses for all land uses in the Southeast. Sediment losses and surface runoff were significantly greater from the sheared plot-watershed than from the control and the commercial clearcut plots. Employing Wischmeier and Smith's (1978) long-term average R-value for the USLE overestimated annual sediment yield for the study period, while two shortcut models developed in the United States resulted in more accurate predictions and are good substitutes for the long-term R-value. Total losses in surface runoff of PO_4, NO_3, NO_2, TKN, K, Ca, Mg, Na, Al, Fe, Zn, and Cu were higher on the site-prepared plot watershed than the other two. Losses of PO_4, TKN, and NO_2 were higher on the commercial clearcut plot than the control. Losses were not high enough to adversely affect forest productivity. Concentrations of elements were generally below established USEPA surface water quality standards and were not high enough to adversely affect plant growth.

INTRODUCTION

Commercial clearcutting is the most common silvicultural system employed for the regeneration of upland forests in East Texas. Following harvest, sites are usually prepared for planting by mechanical techniques such as shearing, chopping, bedding, ripping or some combination of these activities. Concern has arisen regarding possible degradation of site productivity over time and possible degradation of water quality (USEPA 1993).

There are more than 120,000 hectares of somewhat poorly drained, upland saline soils in central East Texas (between Sam Rayburn Reservoir and Livingston Reservoir). These soils have high salt concentrations, low permeability, and are frequently saturated. Upland vegetation is predominately mixed pine/hardwood, with loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pine dominating the overstory. Conversion of these natural stands to plantations can be difficult, reporting as many as three attempts with no success in some areas. J-rooting and limited lateral root development at about 15 centimeters below the surface is frequently observed on theses sites. High mortality rates are thought to be the result of a rise in the water table following harvest, seedlings experiencing salt toxicities, nutrient imbalances, or some combination of these factors. Surface runoff from clearcut sites on these soils could negatively impact water quality as well.

This study was initiated in 1988 to examine the impacts of clearcutting and site preparation on sediment movement and water quality from a saline soil in East Texas. The results from the first two years were presented in Sayok and others (1993a and 1993b) on sediment and element movements and Chang and others (1992) on applications of the universal soil loss equation. Effects on soil properties were reported in Chang and others (1994). This report summarizes the results of all four years of data collection.

METHODS AND PROCEDURES

Study Area

This study was conducted during the water years 1989 through 1992 in the Davy Crockett National Forest near Apple Springs, Texas, about 200 kilometers north of Houston and 250 kilometers southeast of Dallas. The area is characterized by a humid subtropical climate with prevailing winds from a southerly direction. Precipitation is fairly evenly distributed throughout the year. Winter precipitation is associated with frontal activity while summer precipitation is dominated by convective storms of high intensity, low frequency and short duration. Precipitation during the study period was 1,119 millimeters, 1,236 millimeters, 1,295 millimeters, and 1,208 millimeters for the 1989, 1990, 1991, and 1992 water years (October-September), respectively. These amounts were much

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Table 1—Annual rainfall, surface runoff, and sediment losses for three forested conditions near Apple Springs, Texas for water years 1989-1992[a]

	Water Year				
Parameters	1989	1990	1991	1992	Average
Rainfall (Pt mm)	1,119	1,236	1,295	1,208	1,215
Number of Storms	63	55	77	79	69
Surface Runoff (Ro mm)					
Forested	14 A	68 A	31 A	9 A	31 A
Clearcut	60 B	107 B	59 A	38 A	66 B
Sheared	299 C	577 C	404 B	375 B	414 C
Runoff/Rainfall (Ro/Pt percent)					
Forested	1.2	5.5	2.4	0.8	2.5
Clearcut	5.4	8.6	4.5	3.1	5.4
Sheared	26.7	46.7	31.2	31.0	34.1
Sediment Loss (kg ha^{-1})					
Forested	56 A	72 A	33 AB	61 B	55 A
Clearcut	422 B	287 B	50 B	33 A	198 B
Sheared	2,374 C	2,916 C	725 A	116 B	1,533 C

[a] Different letters in a given year indicate that the means of all events are significantly different at $\alpha \leq 0.05$

higher than the normal (1951-1980) annual precipitation of 1,077 millimeters observed at the Lufkin Airport about 22 kilometers east of the study site.

The area is characterized by gently rolling topography with slopes averaging 2 to 10 percent. Severe erosion can occur on slopes above 2 percent. The soil of the study site is Fuller fine sandy loam, a member of the fine loamy siliceous, thermic family of Albic Glossic Natraqualfs. The salinity of these soils results from volcanic ash blown from the Cook Mountain Formation during the Eocene epoch and deposited on siltstones or mudstones. The area was inundated by ocean water and the volcanic ash was compacted. Silty materials were blown from the west and settled on the compacted ash.

Loblolly and shortleaf pines dominated the overstory with a mixture of post oak (*Quercus stellata*), red oak (*Quercus falcata*), white oak (*Quercus alba*), sweetgum (*Liquidambar styraciflua*), and hickories (*Carya* spp.). Merchantable

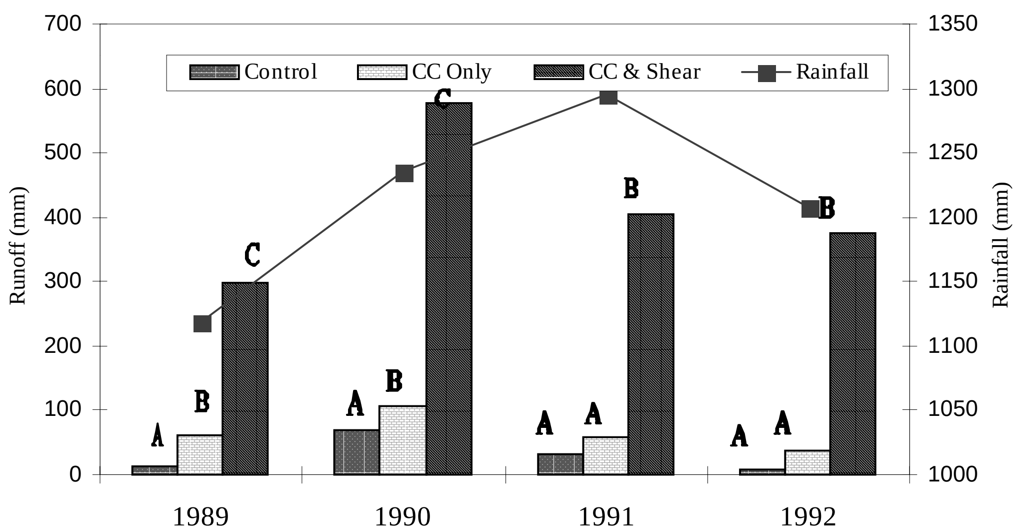

Figure 1—Surface runoff and rainfall by treatment and water year for Apple Springs, Texas

trees ranged from 30 to 55 years of age in 1988 with an average height of 28.5 meters, diameter at breast height of 25 centimeters, site index (50) of 27 meters, and basal area of 21.81 square meters per hectare.

Treatments

Three treatments were employed in this study: 1) undisturbed forest with full crown closure as a control, 2) commercial clearcut with all merchantable timber removed, other vegetation and logging debris left intact, and 3) commercial clearcut with all vegetation removed, stumps sheared with V-blade D6 crawler tractor, and all debris windrowed. Vegetation was prevented from regrowing by hand shearing with no soil disturbance for the first two years following treatment. To avoid potential edge effects, the distance from the sides of the plots to the surrounding stand was at least 30 meters. Harvesting was conducted on July 23-24, 1988 and site preparation on August 26, 1988. Due to budget constraints, treatments were not replicated.

Plot Watersheds and Data Analysis

Each plot was 0.02 hectares in size (9.14 meters by 22.13 meters) and was located in each treatment area to monitor surface runoff and soil and element losses generated by storm events. All plots were located within a 3.24 hectare area, with comparable environmental conditions regarding vegetation, soils, slope, and aspect. A plywood barrier 8 centimeters below and 7 centimeters above the ground bordered each plot. At the lower end of each plot an approach apron, a 15.4 centimeter H-flume, a stilling well with an FW-1 water level recorder, a Coshocton N-1 runoff sampler, and a storage tank were sequentially connected together. The Coshocton wheel diverted about 1 percent of the surface runoff into a small storage tank. The small tank was confined in a larger tank designed to accommodate surface runoff generated by 48-hour 50-year storms. Total soil loss from each storm runoff event was the sum of sediment deposited in the apron and approach section plus suspended sediment collected in the storage tank. Volumes of surface runoff were directly measured from the storage tank and also interpreted from the charts of the water-level recorders.

The volume of surface runoff generated from each runoff event was converted to depth. Samples were collected after each runoff event and were transported to the Stephen F. Austin State University Arthur Temple College of Forestry Forest Hydrology Laboratory for chemical analyses of 19 water quality parameters. Methods and procedures for water quality analyses were reported in Sayok (1991) and Sayok and others (1993b).

USEPA's (1986) water quality standards were used as a reference to evaluate surface runoff water quality conditions. Data failed to meet the assumption of normality for parametric statistical analyses. Therefore, the nonparametric Kruskall-Wallis test as described by Hollander and Wolfe (1999) and SAS Institute, Inc (1999) was employed to determine differences in concentrations among the three treatments. The Wilcoxon's rank sum procedure was used to evaluate multiple comparisons where the Kruskall-Wallis test found differences to be significant at a $\leq$ 0.05.

The data were also stratified into summer- (May – October) and winter- (November – April) half years for testing seasonal effects on surface water quality. Seasonal differences were determined using the Wilcoxon's rank sum procedure.

RESULTS AND DISCUSSION

Rainfall and Runoff

Rainfall during the four year study period was considerably higher than the average rainfall (1951-1980) of 1,077 millimeters reported at the Lufkin Airport about 22 kilometers east of the study area (table 1). Highest precipitation occurred in water year 1991 with 218 millimeters or 20 percent more precipitation than normal.

Annual surface runoff generated from the plots varied considerably with treatment and by water year (table 1). Since all vegetation, stumps, and debris were removed and no regrowth of vegetation was allowed for the first two years, the sheared plot had the least transpiration and interception loss among the three plots. Furthermore, the soil was compacted by the heavy machinery, resulting in a decrease in infiltration rate and an increase in soil moisture content. Bulk densities were found to be greater following treatment (Chang and others 1994). This translated to more total surface runoff from the sheared plot and greater runoff efficiency. Average runoff as a percent of rainfall (Ro/Pt) for the four-year period was 34 on the sheared plot and only 3 and 5 on the control and commercial clearcut plots, respectively. The percent Ro/Pt ratio for the clearcut plot (5) was about the same as reported by two other East Texas studies: 6 in Cherokee County (Blackburn and others 1986) and 8 in Nacogdoches County (Chang and others 1982). However, percent Ro/Pt ratio for the sheared plot was higher (34) than values reported in Nacogdoches (29) and Cherokee (11) counties. Runoff as a percent of precipitation did not decline significantly on the sheared plot during the study period. Ro/Pt was 31 percent during year four, whereas it was 27 percent during year one. This may be due to the lower permeability and higher soil moisture content of the saline soil.

Using the Kruskall-Wallis test and Wilcoxon's rank sum, the sheared plot were found to be significantly different from the control at a $\leq$ 0.05 for all four years (figure 1). During water years 1989 and 1990, all three plots were significantly different from one another. However, during water years 1991 and 1992, the commercial clearcut plot was not significantly different from the control plot (figure 1).

Sediment Losses

Annual Losses—Sediment losses were highly significant among treatments. First year sediment losses were 56, 422, 2,347 kilograms per hectare for the control, cleared, and sheared plots, respectively (table 1). Losses among plots were significantly different the second year following treatment as well. This difference is due to greater soil disturbance on the shear treatment, resulting in more exposed bare soil. By the third year, the control and cleared plots were no longer significantly different, although the losses of sediment on the sheared plot remained

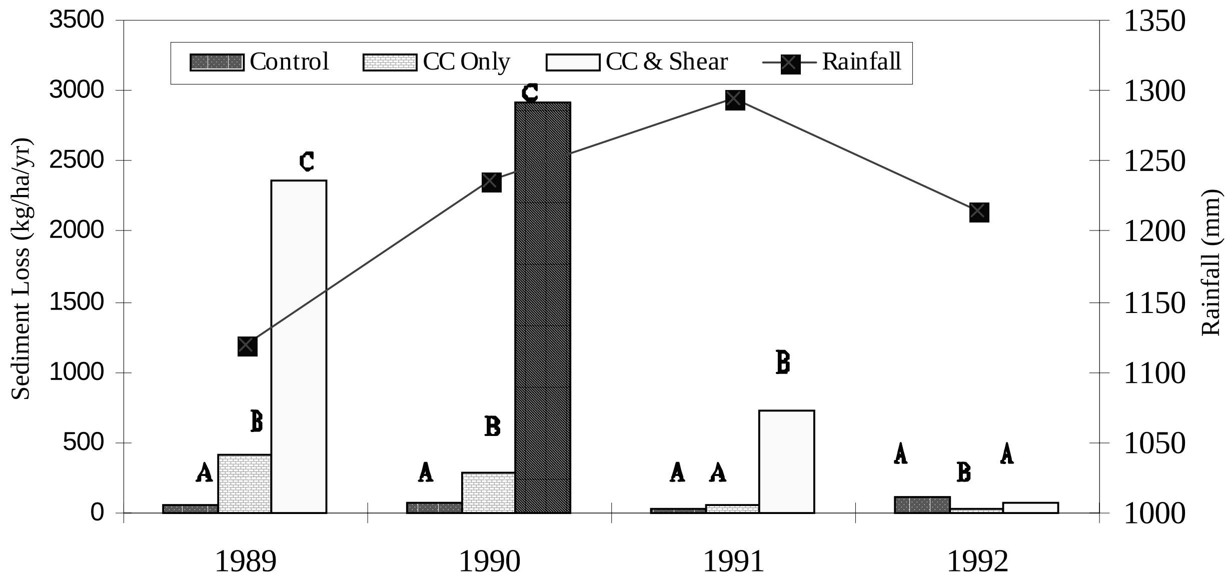

Figure 2—Sediment loss and rainfall by treatment and water year for Apple Springs, Texas.

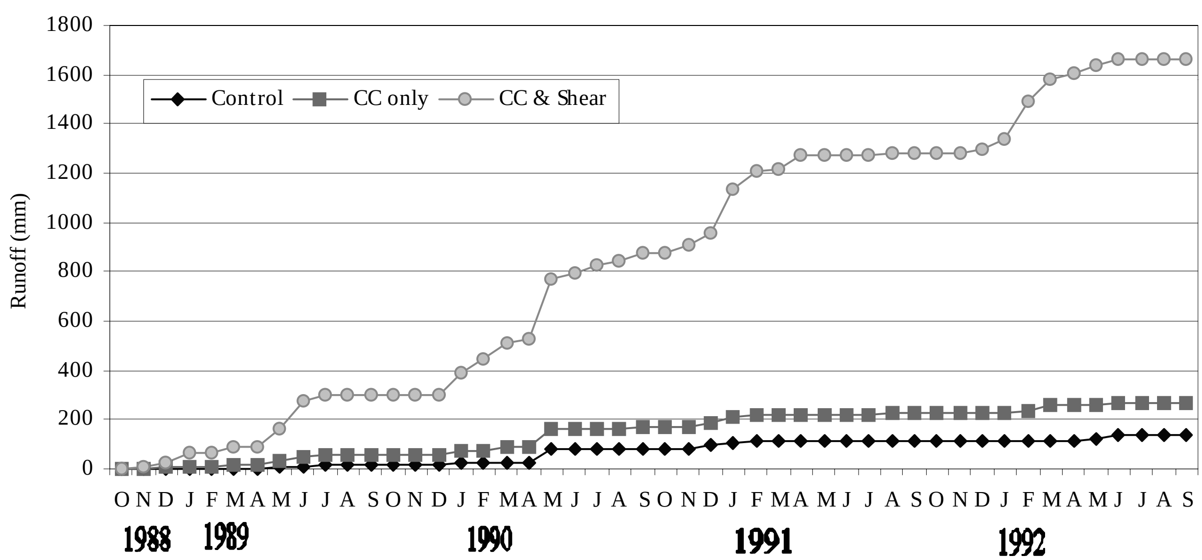

Figure 3—Cumulative runoff for three forest treatments at Apple Springs, Texas.

significantly different. By the fourth year, the sheared and control plots were no longer significantly different. Overall, the sheared plot generated about 28 times more sediment than the commercial clearcut plot and 8 times more than the forested plot. About 44, 70, 79, and 54 percent of the total annual sediment loss was produced from the five largest storms for water years 1989, 1990, 1991, and 1992, respectively.

Soil losses decreased over time on the two treatment plots throughout the study period. On the commercial clearcut plot, this was due to rapid vegetative regrowth following harvest, an indication that vegetation is an effective medium in controlling erosion and sediment transport, despite a 10 percent increase in rainfall from the first year to the second. On the sheared plot vegetative regrowth was prevented for the first two years, and sediment losses remained high during this time (figure 2). During the second year following harvest, the 10 percent increase in rainfall might account for the increase in total sediment loss. Vegetation was allowed to regrow during years three and four, and sediment losses declined until by year four in which sediment losses were no longer significantly different from the control plot. Sediment losses were slightly higher on the control plot during the second year. This could be due to the increase in rainfall. Also, a tornado occurred on January 19, 1990 that resulted in about a 50 percent opening in the canopy. Following the tornado, three large storms occurred that resulted increased sediment yield from the control plot. Greater sediment losses were associated with late winter and early spring when rainfall and runoff rates were greatest (figures 3 and 4).

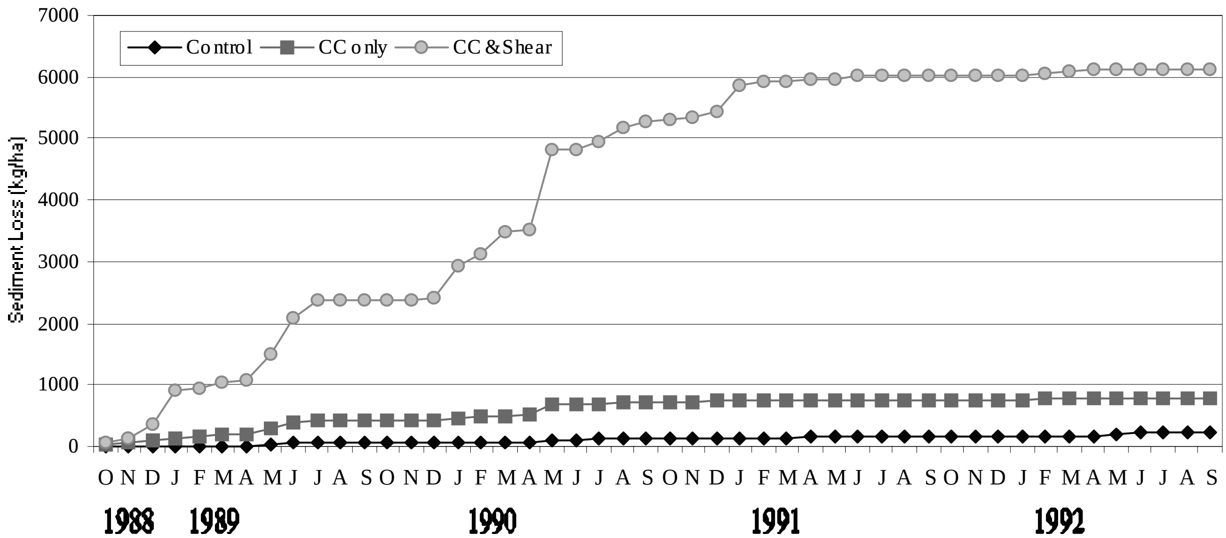

Figure 4—Cumulative sediment loss for three forest treatmnts at Apple Springs, Texas.

Comparison to Other Studies

Based on 16 other studies throughout the southeast USA, Yoho (1980) reported that sediment losses ranged from 2 to 717 kilograms per hectare per year for undisturbed forested watersheds. Sediment losses from the control plot are within the lower end of this range. First year sediment loss for the sheared plot was also within the range of losses reported for other studies in East Texas, 3,462 kilograms per hectare near Etoile, (Chang and others 1982), 2,937 kilograms per hectare near Alto (Blackburn and others 1986), and 306 kilograms per hectare in San Augustine County (Blackburn and others 1990). In this study, first year losses observed from the sheared plot were below those observed near Etoile and Alto, but greater that those observed in San Augustine County.

Several studies have also reported that about 3-4 years are required for sediment losses from sheared plots to return to observed levels on undisturbed areas in the southeast (Blackburn and others 1986; Blackburn and others 1990; Miller 1984). In this study, losses were no longer significant by year four. This period could have been shorter had vegetation regrowth not been prevented during the first two years of the study.

Sediment Estimates

The Universal Soil Loss Equation (USLE) was employed to estimate average sediment losses for the study plots during the study period. The equation estimates sediment A = RKLSCP in which the six factors are related to rainfall, soil, slope length, slope steepness, vegetation/management, and conservation practices, respectively. The C-factor employed was based on values observed for East Texas forests (Chang and others 1982) as they were found to be the most accurate estimates for the East Texas environment (Chang and others 1992). However, the C-value for the sheared plot during the last two years was obtained from Wischmeier and Smith (1978) to account for vegetation regrowth. Thus the long-term C-value for the sheared plot was estimated by averaging the C-values from these two sources. Values of KLSP were based on the standard procedure given by Wischmeier and Smith (1978). R-values were obtained by using the standard Wischmeier and Smith (1978) procedure along with eight other shortcut models developed in various regions (table 2). The standard EI_{30} (kinetic energy x 30 minute intensity) method for calculating R-values requires rainfall intensity information for all runoff-producing storms. This information may not be available and calculations are tedious. If the shortcut methods, generally using annual rainfall to correlate with EI_{30} values, can provide satisfactory estimates, then the use of USLE would be greatly facilitated for stations with only total rainfall.

Estimating sediment losses using R-values obtained from Wischmeier and Smith's (1978) long-term average (US Agricultural Handbook No 537) resulted in about a 143 and a 118 percent overestimation of sediment losses for the shear and commercial clearcut plots, respectively (table 3). However, the two shortcut models developed in the United States (Models 4 and 9) provided sediment estimates for these two plots within 23 percent of those from the observed values. Also, reasonable estimates for these two sites could be obtained from the two models developed in the two tropical regions (Models 3 and 5) with errors less than 50 percent. All estimates by these four models of sediment losses for the forested plot resulted in greater percent errors than for the treatment plots. Because of the relatively small magnitudes of losses from forested areas, these errors are of less concern.

Element Losses

Concentrations of elements were generally below USEPA surface water quality standards and not significantly

Table 2—Ten different models for calculating R-values (metric ton m/ha/hr per yr) for the USLE

Model	Location	Reference
1 $R = [\Sigma^N \Sigma^M (EI_{30})]/(100N) * 1.735$	United States	Wischmeier and Smith (1978)
2 $R = 0.5 (P) * 1.735$	West Africa	Roose (1975)
3 $R = (9.28(P) - 8838 \times I30) * 0.001$	Malaysia	Morgan (1974)
4 $R = 0.276 P \times I30 \times 0.01$	United States	Foster and others (1981)
5 $R = (38.46 + 3.48P) \times 0.1$	Hawaii	Lo and others (1985)
6 $R = (0.264 * ((\sum_{i=1}^{12} p_i^2)/P)^{1.50})$	Morocco	Arnoldus (1977)
7 $R = (0.04830 P^{1.610}) * 0.1$	United States	Renard and Freimund (1994)
8 $R = (587.8 - 1.219P + 0.004105P^2) * 0.1$	United States	Renard and Freimund (1994)
9 $R = (0.07397 * ((\sum_{i=1}^{12} p_i^2)/P)^{1.847}) * 0.1$	United States	Renard and Freimund (1994)

Note: E = storm kinetic energy (metric ton-m ha^{-1} cm^{-1}), I_{30} = maximum 30 minute storm intensity (cm hr^{-1}), I30 = maximum annual maximum 30 minute rainfall intensity (assumed to be 75 mm hr^{-1}), P = mean annual rainfall (1989-1992) in mm, p_i = mean monthly rainfall (1989-1992), N = number of years, and M = number of storms in each year.

Table 3—Observed and estimated average sediment losses (kg/ha/yr) by the USLE with R-values obtained by nine different models in Apple Springs, Texas

	Forest		Clearcut		Shear	
Source	Loss	Diff[a]	Loss	Diff[a]	Loss	Diff[a]
Observed	55	0	198	0	1,533	0
Estimated						
Model 1	37	-33	431	118	3,729	143
Model 2	54	-1	639	223	5,520	260
Model 3	10	-83	113	-43	976	-36
Model 4	13	-76	152	-23	1,316	-14
Model 5	22	-59	264	33	2,278	49
Model 6	68	23	799	303	6,903	351
Model 7	23	-57	276	39	2,385	56
Model 8	27	-51	319	61	2,760	180
Model 9	14	-75	160	19	1,381	-10

[a]Percent difference where diff = ((obs-est)/obs)*100

Table 4—Mean concentrations (mg/L) and mass losses (g/ha) for 17 elements in the study area for water years 1989-1992[a]

	Mass Losses[b]			Concentrations[b]		
Parameter	Control	Clearcut	Shear	Control	Clearcut	Shear
PO_3	28.46 A	35.76 B	194.52 C	2.92 A	3.44 A	2.61 A
NO_3	3.11 A	4.44 A	42.77 B	0.31 A	0.29 A	0.29 A
NO_2	1.32 A	6.95 AB	10.18 B	0.09 A	1.52 A	0.19 A
NH_4	38.41 A	76.77 B	264.48 C	3.16 A	3.25 A	2.53 A
TKN	99.90 A	123.50 B	448.60 C	5.71 A	5.13 A	4.26 A
K	45.41 A	85.64 A	347.38 B	5.73 A	6.74 A	7.55 A
Cl	208.20 A	253.10 A	1331.80 B	15.57 A	15.42 A	15.34 A
Na	124.40 A	204.51 A	730.12 B	21.07 A	16.92 A	10.91 A
Ca	36.25 A	55.98 A	212.86 B	3.43 A	3.72 A	3.12 A
Mg	44.20 A	43.93 A	168.78 B	2.17 A	2.42 A	2.49 A
Al	4.35 A	6.03 A	49.98 B	0.25 A	0.45 A	1.20 A
Mn	7.20 A	7.74 A	18.92 A	0.01 A	0.26 A	0.27 A
Fe	8.30 A	15.39 A	53.90 B	0.37 A	0.61 A	0.49 A
Zn	23.37 A	42.59 A	105.31 B	0.62 A	1.38 A	1.61 A
Cu	2.19 A	4.25 A	30.45 B	0.28 A	0.27 A	0.36 A
SO_4	188.00 A	243.20 A	993.70 A	26.05 A	20.65 B	12.90 B
HCO_3	325.00 A	543.00 A	957.60 B	45.29 A	55.43 B	38.08 A

[a] Nutrient parameters (PO_4, NO_3, NO_2, NH_4, and TKN) were only measured during water years 1989 and 1990.
[b] Mean values with different letters in a given year are significantly different at $\alpha \leq 0.05$.

different between treatments (table 4). This is due to the dilution effect of greater runoff volume from the treatment plots. However, when concentrations are converted to mass per unit area, elements were found to be different between treatments. Mass losses in grams per hectare were greater from the sheared plot than from the commercial clearcut or the control (table 4). Losses of sodium (Na), chloride (Cl), Calcium (Ca), magnesium (Mg), and aluminum (Al) were especially high. Elements were generally not significantly different between the control and the clearcut plot. However, nutrient parameters such as ortho-phosphorus ($PO_{4)}$, ammonia ($NH_{4)}$, and total Kjeldahl nitrogen (TKN) were significantly greater on the commercial clearcut plot than the control plot.

A comparison of element losses by water year illustrates a general attenuation trend with time. Losses of elements such as Na, Cl, Ca, Mg, and Al were greater from the sheared plot than the control in water year 1989 and 1990. After regrowth of vegetation, only Na and Cl losses remained higher on the sheared plot. Sodium losses following shearing in other East Texas studies were 343 grams per hectare (Blackburn and others 1986) and 380 grams per hectare (Muda and others 1989), much lower than losses observed in this study, 730 grams per hectare. Higher rates of export of Na and Cl would be expected from a saline soil. Vegetative regrowth resulted in reduced rates of Ca and Mg export.

CONCLUSION

Harvesting and mechanical site-preparation greatly reduced evapotranspiration, disturbed soil structure, and increased soil moisture content, resulting in greater runoff volumes and losses of sediment, nutrients, and elements. However, erosion problems did not seem to be serious enough to adversely affect land productivity. Following regrowth of vegetation, losses decreased dramatically until by the fourth year following treatment no differences were observed between the treatments and the control. Neither treatment plot was reforested by artificial means, yet after two years of vegetation regrowth, runoff volumes and sediment losses were no longer different from the undisturbed forest plot. Wischmeier and Smith's (1978) long-term average R-value for the USLE overestimated annual sediment yield for the study period. Two shortcut models developed in the United States for estimating the rainfall factor resulted in more accurate predictions and are good substitutes for the EI_{30} factor in the study area.

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