Soil Loss, Runoff, and Water Quality of Seeded and Unseeded Steep Watersheds Following Prescribed Burning

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Abstract

Seeding of steep slopes (37 to 61%) after burning on the Edwards Plateau in central Texas reduced soil losses 78 to 93%. Moreover, the major impact of burning on soil losses was significantly reduced in 3 months on burned and seeded watersheds, but not for 15 to 18 months on unseeded watersheds. Stability (soil losses comparable to pretreatment levels) was reached in 6 months on burned and seeded watersheds. Soil loss rates stabilized when cover (live vegetation plus litter) reached 64 to 72% during normal to wet years or 53 to 60% during dry years. Thus, amount of precipitation and cover are closely tied to soil losses. Overland flow stabilized in 4 to 5 years on unseeded watershed and in 1 to 2 years on seeded watersheds. Water quality, lowered slightly by burning, returned to preburn levels within 2 years after seeding. Without seeding it took 4 years to reach preburn levels. Overall, water quality change following burning was not considered to be serious.

Ashe juniper *(Juniperus ashei)* has invaded extensive areas of the mixed prairie in central Texas and reduced grazing capacities from 1 animal unit/6 ha to 1 animal unit/20 ha. A recommended range management practice is to remove the tall green junipers by knocking the trees down individually with a tractor (dozing) or dragging an anchor chain over them that is attached between two tractors (chaining). This allows the native grasses to recover, but it leaves piles of debris over 22% of the land area (devoid of grass), enhances germination of Ashe juniper seed, and does not kill the young trees (Wink and Wright 1973).

Prescribed burning removes the piles of debris, kills the young Ashe juniper trees, and creates an unfavorable environment for the establishment of Ashe juniper seedlings (Wright 1978), but before recommendation to use by ranchers, we needed to know whether soil losses following burning were significant. In 1971 we initiated a study to determine how long it would take for runoff, soil loss, vegetative cover (live vegetation plus litter), and water quality to return to preburn status on level (0 to 4%), moderate (8 to 20%), and steep (37 to 61%) slopes. The study revealed that soil losses and changes in water quality were not serious on level and moderate slopes (Wright et al. 1976). However, adverse effects lasted for 15 to 30 or more months on steep slopes.

Soil losses are influenced by intensity of storms (Orr 1970), size and frequency of bare areas (Packer 1951), and soil, topography, and plant cover (Smith and Wischmeier 1962). Among these factors vegetative cover and slope are the most important (Meeuwig 1971). Meeuwig (1971) found that as cover decreases, slope becomes increasingly important for soils that vary from sandy loams to clay loams. For example, a 40% cover on a 5% slope is as effective as an 80% cover on a 35% slope. At less than 50% cover, erosion rates double for each 10% increase of slope within the range of 5 to 35%. Thus, cover will account for as much as 76% of the variance of the logarithm of the weight of eroded soil (Meeuwig 1970). A cover of 60 to 70% is necessary for soil stability on slopes that range from 30 to 60% (Bailey and Copeland 1961, Packer 1963, Orr 1970, Wright et al. 1976). However, as the size of bare areas increases within a specific percentage cover category, the influence of ground cover decreases (Packer 1951). Fine-textured soils such as clay loams are far less erodible than coarse-textured soils such as loamy sand or sandy loam (Swanston and Dyrness 1973).

Following burning, unseeded chaparral of brushy watersheds with average slopes of 30 to 60% lose as much as 52 to 116 metric tons/ha of soil during the first year, particularly on granitic, sandstone, and shale-derived soils (Pase and Ingebo 1965, Pase and Lindenmuth 1971, Pitt et al. 1978). Four years are generally required for such slopes to become stabilized with natural shrub vegetation (Pase and Ingebo 1965, Orr 1970, DeByle and Packer 1972, Anderson and Brooks 1975). On limestone-derived soils in central Texas, however, Wright et al. (1976) recorded total soil losses of only 16 to 22 metric tons/ha over 2.5 years on 45 to 53% slopes, but a portion of these watersheds was covered with native grasses before burning. Thus, slope, soil texture, duration and intensity of storms, and amount of native grass cover are key factors that will affect total soil loss.

Seeding a burned watershed in the Black Hills of South Dakota reduced soil loss to 22% of that on unseeded areas (Orr 1970). Recovery of seeded watersheds (60% cover) took 1 to 4 years. In Oregon, Anderson and Brooks (1975) found that a burned forest had a satisfactory vegetative cover the first year after seeding, whereas natural vegetation did not provide a satisfactory cover in 4 years. Sometimes seedings are unsuccessful and soil losses continue (Corbett and Green 1965).

Brush to grass conversions usually increase runoff in the California and Arizona chaparral zones (Rowe 1948, Pase and Ingebo 1965, Baldwin 1968, Brown 1970, Fox 1970, Pitt et al. 1978), but the increased water yield is highly variable and unpredictable depending on vegetation and total precipitation (Pitt et al. 1978). Soil properties and vegetation before conversion to grass have been shown to be especially important in subsequent water yields. For example, conversions in chaparral are more likely to increase water yields than conversions in juniper vegetation. Baldwin (1968) found that brush to grass conversions in a 38- to 64-cm precipitation zone in Arizona chaparral usually increased surface runoff from relatively "low" amounts of 4–15 surface centimeters per year. By contrast, in a 66-cm rainfall zone of Ashe juniper in central Texas, brush to grass conversion increased average water yields

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from only 0.05 to 2.87 surface centimeters the first year after burning. This increase declined steadily to preburn water yields within 3 to 5 years. In general, conversion practices in pinyon-juniper communities with 30 to 50 cm of annual precipitation rarely increase water yields (Baker et al. 1971, Myrick 1971, Branson et al. 1972, Gifford 1973). Thus type of vegetation and its associated soil properties, before conversion to grass, are very influential on subsequent runoff yields.

Sediment is the major pollutant that lowers water quality following disturbance on agricultural lands (Grant 1971, Robinson 1971), but total hardness (calcium and magnesium content) is also an important component of water quality (Hem 1970). Hardness is acceptable until it reaches 100 mg/liter (Hem 1970). Research by Wright et al. (1976) on limestone-derived soils showed that water quality, primarily turbidity and total hardness, was related to plant cover. Following burning, water was soft (0 to 60 mg/liter) from level areas, moderately hard (61 to 120 mg/liter) for 6 months on 15 to 20% slopes, and moderately hard for more than 30 months on a 53% slope. Water from burned watersheds was more turbid than water from controls for 1.5 years on moderate slopes and for at least 2.5 years on steep slopes. Water quality increased significantly when plant cover reached 63 to 68% and soil loss rates were reduced to 0.5 metric ton/ha/year (Wright et al. 1976). Sodium was usually less than 1.0 mg/liter, and pH increased only slightly after burning moderate and steep watersheds.

This study was initiated in 1975 as a followup to previous watershed research (Wright et al. 1976) to determine whether the seeding of "hot spots" (pile areas) after burning on steep watersheds would reduce soil losses and lessen the time for cover and other factors on steep slopes to reach a preburn status. Soil loss rates, overland flow, water quality, and cover were compared on seeded and unseeded watersheds following prescribed burning.

Study Areas and Methods

This study was conducted on the Beckham Ranch in Callahan County, Texas, 23 km southeast of Baird. The area is on limestone-derived soils in the southern mixed prairie on the north end of the Edwards Plateau in central Texas. Average annual precipitation is 66 cm. Topography of the general area is level to undulating with slopes up to 60% at an elevation of 430 to 640 m above sea level. The average minimum January temperature is -5° C; average maximum July temperature is 35° C. The growing season averages 232 days.

Native vegetation consists of mixed prairie grasses interspersed with Ashe juniper and several species of oak (*Quercus* sp.). Little bluestem *(Schizachyrium scoparium)* and sideoats grama *(Bouteloua curtipendula)* are the dominant decreasers. Buffalograss *(Buchloe dactyloides)*, vine-mesquite *(Panicum obtusum)*, Texas wintergrass *(Stipa leucotricha)*, tall grama *(B. pectinata)*, and meadow dropseed *(Sporobolus asper* var. *hookeri)* are important increasers. All large juniper trees were dozed in piles of 1 to 4 trees in 1967.

Four watersheds (each 0.10 to 0.19 ha in size) were used to conduct the study beginning January 1, 1972. They are adjacent to each other with slopes that average 45% with an east aspect and are characterized by Somervell gravelly clay loam. The Somervell series is a member of a loamy-skeletal, carbonatic, thermic family of Ustochrepts. They contain over 50% gravel and cobble-size limestone fragments throughout the A and B horizons.

Initially, the watersheds were paired (W.S. 9 and 10, and W.S. 11 and 12, respectively) and one (No. 12) was burned in March, 1972 and one (No. 10) was burned in December, 1972. Neither of these burned watersheds were seeded. The unburned watersheds (9 and 11) served as controls until March, 1975 (No. 11) and February, 1977 (No. 9) at which time they were burned and seeded. The pretreatment yearly averages of all water quality measurements, cover, soil loss, and runoff on the two control watersheds (one for 3 years and one for 5 years) served as baseline control data (Year 0 in Table 1; W.S. 9 and 11 in Fig. 1 and 2) for both the seeded and unseeded watersheds. All watersheds were burned without any prepared firelines when the wind was 6 to 10 km/h, relative humidity was 26 to 60%, and air temperature was 2 to 10° C.

Seed mixture for the burned and seeded watersheds contained little bluestem, sideoats grama, King Range bluestem *(Bothriochloa ischaemum)*, kleingrass *(Panicum coloratum)*, and sorghum almum *(Sorghum almum)*. Only "hot spots" beneath burned piles (about 25% of each watershed area) were broadcast seeded at a rate of 11 to 22 kg/ha. If high winds blew the ash and seed off the burned areas, the pile areas were seeded a second time. Areas around the hot spots had a good stand of little bluestem, sideoats grama, and buffalograss.

At the base of all watersheds, a metal dyke was installed. Flush with the soil surface, a 0.09 m^2 opening in the dyke was connected to a trough that led to a collection tank. Each collection tank had a capacity of 11,363 liters. Standard rain gauges were installed in August, 1971 between each set of initially paired watersheds (W.S. 9 and 10 and W.S. 11 and 12) to determine quantity of rainfall on the watersheds. A recording rain gauge with weekly recording charts was installed nearby to determine intensity of rainfall.

Following each major storm, water samples were collected 12 to 24 hr later in 1/4-liter jars for analysis. Volume of runoff was calculated after each major storm by measuring depth of water in tanks, subtracting the correction for rainfall (tanks and troughs were not covered) and then calculating centimeters of runoff per hectare. After measurement of runoff, the water was pumped out of the tanks. Depending on the frequency of storms, sediment in the tanks and sediment samples were collected every 1 to 3 months after excess moisture had evaporated. Sediment was weighed in the field, corrected for water content, based on laboratory samples, and then calculated as metric tons/ha. Data collections began on January 1, 1972, and ended on September 30, 1978.

Table 1. Water quality and vegetative cover on burned (B) and burned and seeded (S) watersheds[1].

Year after treatment	Turbidity (ppm)		Turbidity (J.U.)[2]		Hardness[3]		pH		Cover (%)	
	B	S	B	S	B	S	B	S	B	S
0	1.1	1.0	12	12	25	25	7.1	7.1	71	78
1	3.7*[5]	3.7*	162*	72*	95*	92*	7.7*	7.3	56*	70
2	3.1*	1.4	147*	27*	78*	39	7.7*	7.0	64	70
3	2.1*	0.1	48*	8	70*	21	7.3	7.1	67	69[4]
4	1.8*	0.3	36*	10	50*	24	7.1	7.0	72	69[4]
5	0.6	—	23	—	32	—	7.2	—	64[4]	—
6	0.5	—	22	—	20	—	7.1	—	59[4]	

[1]Each water quality figure is based on 18 to 31 values (combined from two replicates).
[2]Jackson Units (Rainwater and Thatcher 1960).
[3]Mg/liter of Ca × 2.497 plus mg/liter of Mg × 4.116.
[4]Figures are associated with drought years.
[5]*Values differ from controls at 0.10 level of probability.

Water samples were analyzed for calcium, magnesium, sodium, turbidity, hardness, and pH. Calcium and sodium were determined as mg/l on a flame photometer. Calcium plus magnesium (mg/l) was determined by the official methods of analysis (Association of Official Analytical Chemists 1970, p. 671). Then mg/l of magnesium was determined by subtracting mg/l of calcium from mg/l of calcium + magnesium. Using these data, water hardness was calculated from the following formula: mg/l of Ca × 2.497 plus mg/l of Mg × 4.116. Turbidity was measured in ppm and in Jackson units (Rainwater and Thatcher 1960) on a scale of 0 to 400 using a UV-Vis spectrophotometer. A reading of 0 would be obtained using distilled water with 100% transmittance, whereas a reading of 400 would be for very turbid water with almost no transmittance of light. pH was determined with a Sargent-Selch model LSX pH meter.

Sediment samples were oven dried for 24 hr at 100°C and analyzed for organic matter, nitrogen, phosphorus, and potassium. Organic matter was determined using the potassium dichromate method. Phosphorus and potassium were read on a photoelectric colormeter using quinaldine red indicator for potassium. Parts per million of nitrogen were determined by a standard formula: (percentage organic matter/2) × 1,000. This formula assumes an organic matter to nitrogen ratio of 20:1 (Buckman and Brady 1961).

Cover (live vegetation plus litter), rock and bare soil were determined by a vertical ocular estimate using fifty 1/4-m² plots on each watershed. These data were taken before treatment and were continued after the spring and fall growing seasons each year.

Data were analyzed using several methods. Cover data of paired watersheds were compared using the standard *t*-test for independent samples (Snedecor and Cochran 1967). Soil losses and runoff were considered significant if they exceeded maximum annual losses from untreated watersheds during the period of January 1, 1972, to January 1, 1977.

Results and Discussion

Rapid soil loss rates (more than 1.6 metric tons/ha/year) following prescribed burning on seeded steep slopes (W.S. 9 and 11 in Fig. 1) slowed significantly in 3 months, although it took 6 months for these soil loss rates to reach pretreatment levels (range 0.01 to 0.06 metric tons/ha/year). Without seeding (W.S. 10 and 12), it took 15 to 18 months for soil loss rates to slow significantly and 33 to 42 months to reach pretreatment levels (Fig. 1).

Stabilized soil loss rates were generally associated with cover that ranged from 64 to 72% (Table 1) during the average to "wet" years (i.e. late summer of 1974 and spring and summer of 1976 in

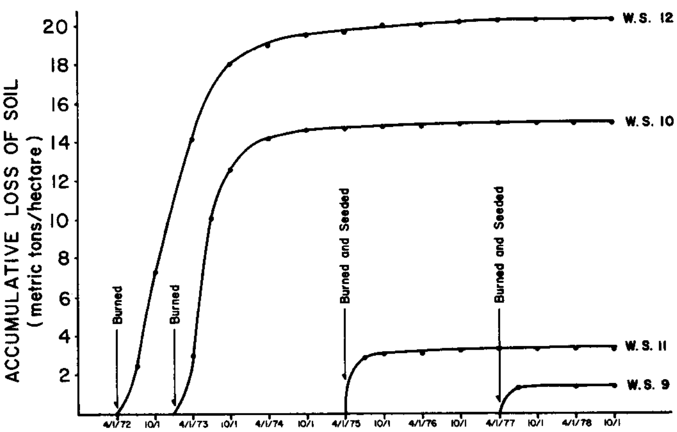

Fig. 1. *Accumulative loss of soil from steep slopes (average 45%) on (1) burned and (2) burned and seeded watersheds. All watersheds have been monitored since January 1, 1972, but only traces of sediment were lost before treatment.*

Table 2. Precipitation and storm data from April 1, 1972, to September 30, 1978, on Beckham Ranch in central Texas.

Date	Total ppt. (cm)	Centimeters of high intensity[1]	Maximum intensity Cm/hr	Maximum intensity Amount (cm)
4/1 - 9/30/72	33.0	5.1	3.8	1.9
10/1/72-3/31/73	35.3	11.7	6.4	2.4
4/1-9/30/73	32.5	6.1	4.3	4.3
10/1/73-3/31/74	21.3	4.3	2.8	2.0
4/1-9/30/74	55.4	14.2	6.1	2.0
10/1/74-3/31/75	34.3	15.0	3.3	2.0
4/1-9/30/75	33.8	7.9	6.1	3.0
10/1/75-3/31/76	17.0	3.6	2.0	1.9
4/1-9/30/76	47.5	19.8	3.6	6.9
10/1/76-3/31/77	30.2	12.7	3.3	3.3
4/1-9/30/77	29.5	15.7	5.1	2.5
10/1/77-3/31/78	15.0	2.5	1.0	2.4
4/1-9/30/78	38.1	17.8	3.8	2.5

[1]Centimeters of rainfall from storms with at least 1.5 cm that fell with an intensity of at least 1.3 cm/hr.

Table 2). During "dry" cycles (i.e. winter and spring of 1974 and 1978), cover values of 53 to 60% were adequate to hold soil losses at pretreatment levels. Following the rapid soil loss rate periods, there was no significant change in cover (Table 1) of watersheds as the soil loss rates were gradually reduced to pretreatment levels (Fig. 1). The slight, but significant soil loss during the latter half of the recovery period implies that factors other than cover were involved for the burned watersheds to become as stable as the untreated watersheds.

Most sediment from unseeded watersheds (W.S. 10 and 12) came from loose piles of soil on bare areas following the burning of dozed juniper. Seeding these pile areas on watersheds 9 and 11 slowed the rate of soil loss, although soil movement from the burned pile areas to the draws within the watersheds was apparent. Seed germinated rapidly, however, and stabilized much of the soil in the draws before it could leave the watersheds. There was no noticeable gully erosion because the gullies were well-covered with native perennial grasses.

Losses of N, P, K, and organic matter (O.M.) were less than 0.6% for N and O.M. and less than 2% for P and K from the upper 15 cm of the soil mantle losses as accumulated sediment. Seeding reduced nutrient losses 60 to 91% in accumulated sediment (Table 3). Phosphorus was the element most susceptible to loss.

Overland flow increased from a range of 0.036 to 0.183 surface centimeter/year on untreated watersheds to about 2.5 cm per year during the first year after burning on watersheds 10 and 12 (Fig. 2). Thereafter, overland flow continued to be moderately higher (1.2

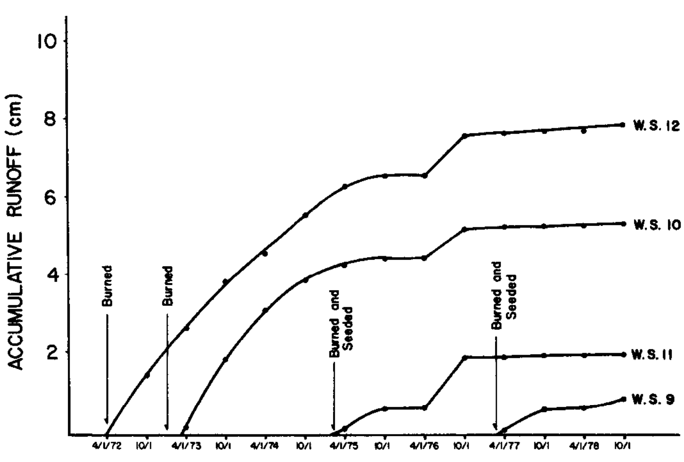

Fig. 2. *Accumulative runoff from steep slopes (average 45%) on (1) burned and (2) burned and seeded watersheds.*

Table 3. Nutrient and organic matter losses (kg/ha) due to erosion of soil following burning or burning and seeding.[1]

Treatment	Element N	P	K	O.M.
Burned				
Rep 1	24.8[2]	0.86	1.02	379.8
Rep 2	33.3	0.83	1.15	714.9
Burned and Seeded				
Rep 1	2.8	0.11	0.06	57.2
Rep 2	7.7	0.17	0.26	154.5

[1]No nutrient losses on untreated watersheds exceeded 0.037 kg/ha over a 5-year period and organic matter losses did not exceed 0.76 kg/ha.

[2]Each of these figures represent total nutrient losses in accumulated sediment until soil losses were comparable to pretreatment levels. Time for each watershed to become completely stabilized varied from 6 to 42 months, depending on treatment and weather after treatment.

to 2.0 cm/year) than control watersheds for 1.5 to 3 years, depending on quantity of precipitation (Table 2). Stability (runoff rates measured on unburned watersheds—0.036 to 0.183 surface centimeters/year), however, was not reached until 4 to 5 years after burning on unseeded watersheds. Burned and seeded watersheds (W.S. 9 and 11) stabilized in 1 to 2 years, depending on the weather patterns that followed (Fig. 2).

Quality of water (turbidity, hardness, and pH) also improved on burns when seeding followed burning (Table 1). Turbidity and total hardness reached pretreatment levels in 4 years on unseeded watersheds and in 2 years on seeded watersheds. However, burning did not affect water hardness seriously. Average total hardness was never above 95 and it was below 60 after 3 years on unseeded watersheds and 1 year on seeded watersheds. Thus burning caused the runoff water to be moderately hard for a short period of time, but if followed by seeding, it was soft (<60) within a year. Sodium concentrations varied from 0.2 to 6.3 mg/l but were usually less than 1.0 mg/l in runoff water from these limestone-derived soils (Wright et al. 1976).

pH of runoff water from burned and seeded watersheds rose as high as 7.6 during the first 6 months after treatment, but was comparable to untreated watersheds thereafter (Table 1). On unseeded watersheds, pH did not drop to preburn levels until 2 years after the burning treatments.

Management Implications

Seeding of steep slopes (37 to 61%) after prescribed burning in mixed brush and grass communities will reduce the major impacts of prescribed burning to 3 months compared to 15 to 18 months for unseeded watersheds. However, it took 6 months for soil loss rates to reach pretreatment levels on burned and seeded watersheds and 33 to 42 months to reach pretreatment levels on burned and unseeded watersheds. Nevertheless, seeding of hot spots after burning reduced total soil losses 78 to 93% on the burned and seeded watersheds. Stability of soil loss rates on steep slopes was generally related to cover (live vegetation plus litter) that ranged from 64 to 72% during wet years (average or better than average precipitation) and 53 to 60% during dry years (below average precipitation).

Thus, when steep slopes are tree-dozed, they should be seeded after burning to minimize soil loss and to reach the desired plant cover within 1 year. As a management alternative, steep slopes might be left alone and used for wildlife cover to preserve the watershed values of the range. Burning will not seriously affect water quality, although seeding after a burn will return water quality to preburn levels within 2 years instead of the usual 4 years.

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