Soil Loss from Long-term Winter-wheat/Summer Fallow Residue and Nutrient Management Experiment at Columbia Basin Agricultural Research Center, Pendleton, Oregon

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Abstract

Changes in soil property resulting from crop production practices are not often readily apparent after a few years or decades. The objective of the research reported here was to evaluate soil erodibility in treatments representing past and current cultural practices in a winter wheat-fallow field experiment established in 1931 near Pendleton, Oregon. Five treatments were evaluated: 1) fall-burned residue/0 lb N/acre/crop (no fertilizer); 2) spring-burned residue/0 lb N/acre/crop (no fertilizer); 3) spring-burned residue /80 lb N/acre/crop commercial fertilizer; 4) residue not burned/80 lb N/acre/crop commercial fertilizer; and 5) residue not burned/100 lb N/acre/crop from manure. All treatments were moldboard plowed by multiple passes with secondary tillage equipment. Weirs, stage recorders, and sediment samplers were used to collect data from January through March of 1998, 1999, and 2000. Grab samples (1 qt) were collected to confirm digital stage data. Measured soil erosion increased from plots with standing stubble (0.04 tons/acre/year), to plots in crop with manure and commercial fertilizer amendments with and without the crop residue burned (0.38 tons/acre/year), to plots in crop with crop residue burned and no fertilizer (1.47 tons/acre/year). These results provide direct evidence of the relationship between reduced soil organic matter and increasing erodibility, and demonstrate the importance of maintaining soil organic matter levels in semiarid dryland soils.

Keywords: cropping systems, erodibility, fallow, silt loam, soil loss, soil resource

Dryland winter wheat (*Triticum aestivum* L.) is the predominant crop throughout the low 10- to 13-inch and intermediate 13- to 18-inch precipitation areas on the Columbia Plateau of the inland Pacific Northwest, and grain yields average from 17 to 70 bu/acre (Rasmussen and Parton 1994, Papendick 1996). Between 1995 and 2005, 10 percent of the small grain producing acreage was in no-till, but the adoption rate has slowed, and mechanical tillage remains the practice for soil water, weed, and disease control (Smiley et al. 2005, Kok 2007). Generally, crop rotations in this region correspond to three annual precipitation zones: winter wheat-fallow, less than 13 inches, winter wheat-spring cereal-fallow in 13 to 18 inches, and annual cropping with a range of crops (small grains, pulses, and oil seed crops) in more than 18 inches. A notable exception to this distribution occurs in the southeastern area of the region near Pendleton, Oregon, where winter wheat-fallow is predominately practiced through the intermediate precipitation zones. Economic stability and consistent yields (Schillinger et al. 2006) contribute to the popularity of this rotation. In this Mediterranean climate, where 88 percent of the precipitation falls from September through May, many producers still use mechanical tillage (disk, chisel, and moldboard plows) to prepare summer fallow, manage residue, and control weeds. Typically, wheat is harvested in July, stubble is left standing over winter and primary tillage takes place in spring, with secondary tillage to control weeds used as needed. Fields are sown to winter wheat in the autumn. Soils fallowed in this manner are nearly devoid of surface residue when the next crop is planted. Soil loss from recurrent wind and water erosion is often in excess of tens of tons per acre (Papendick 1996).

The combination of winter precipitation, frozen soil, poor soil condition, and lack of surface residue contribute to high rates of soil erosion. Zuzel (1994) observed up to seven events per year where warm low intensity rain contributed to rapid snowmelt, runoff, and considerable soil loss. Soils in this semiarid region are loess derived with silt loam textures. They have low soil organic matter (SOM) and weak soil structure, and few water stable peds. Soil macropores are especially vulnerable to destruction by mechanical disturbance. Many of the soils in this region are less than 3 ft deep, and soils can reach field capacity by late fall or early winter of the crop year.

Several options available to growers can counter these conditions. Annual cropping, marginally successful in the intermediate rainfall zone, slows or reverses SOM loss because it returns crop residues each year and uses soil water effectively (Rasmussen and Parton 1994). Planting spring crops leaves fields covered with stubble through the winter when soils are most prone to water erosion, but annual-cropped spring wheat yields are significantly lower than those of winter wheat after summer fallow (Schillinger et al. 2006). No-till management reduces soil loss (Williams et al. 2004), but adoption is hampered by problems of soil water availability in the seed-zone at planting, and weed and disease control. It is likely that the winter wheat-fallow system will continue as the cropping system of choice in many regions on the Columbia Plateau.

Evidence of effect of management practice impact on semiarid croplands is slow to emerge, as demonstrated by a number of long-term experiments conducted in western the United States and Canada (Rasmussen et al. 1989, Campbell et al. 1991, Rasmussen and Parton 1994, Dormaar et al.1997, Rasmussen et al. 1998, Rickman et al. 2001). Consistently, these authors reported that intensive tillage combined with fallow depleted soil organic matter and nitrogen. The objective of this research was to evaluate the erodibility of soils cultivated for nearly seven decades using five different combinations of residue and nutrient amendment treatments in the intermediate precipitation zone of the Columbia Plateau.

Materials and Methods

Study Site

This research was conducted at the USDA-Agricultural Research Service (ARS) Columbia Plateau Conservation Research Center (CPCRC) and Oregon State University Columbia Basin Agricultural Research Center (CBARC), located approximately 9 miles northeast of Pendleton, Oregon (45°43’N, 118°38’W). The elevation at the site is 1,500 ft.

Meteorological Records and Soil.

Meteorological records at the CPCRC/CBARC show minimum, maximum, and mean annual air temperatures of -29°F, 115°F, and 52°F, respectively. Annually, 135 to 170 days are frost-free. Approximately 70 percent of precipitation occurs between November and April and results from maritime fronts that produce low intensity storms with a median duration of 3 hours, and 50 percent with duration ranging from 1 to 7 hours. The maximum recorded 1-hour storm intensity is 0.51 inch/hour and median rainfall of 0.06 inch occurring at 0.02 inch/hour (Brown et al.

1983). Seventy years of records at CPCRC/CBARC show mean annual precipitation is 16.61 inches, with extremes of 9.57 inches (minimum) and 22.95 inches (maximum) at the research site. Snow water equivalent depends upon whether the storm developed from continental or maritime fronts. Snow cover is transient and subject to rapid melting by frequent, warm maritime fronts. A meteorological station immediately adjacent to the plots recorded precipitation, wind speed and direction, solar radiation, relative humidity, and air and soil temperature each crop year, (1 September-31 August), of this study. Soil frost tubes were used to measure soil-freezing depth (Ricard et al. 1976).

The soil type is a Walla Walla silt loam (coarse-silty, mixed, mesic, superactive Typic Haploxerolls-US; Kastanozems-FAO). Slope ranges from 2 to 6 percent on a northeast aspect. (Johnson and Makinson 1988). As found at CBARC, these soils are deeper than 3 ft. Ground cover comprised of current year's growth and previous year's residue was measured in February, 2000 using a digital adaptation of the cross-hair frame method developed by Floyd and Anderson (1982).

Cropping System and Tillage Operations

Initiated in 1931, the intent of the long-term crop residue and nutrient management (LTCR) experiment was to determine the influence of residue management and nutrient amendments on grain yields and soil fertility. The LTCR experiment is described in detail by Rasmussen and Parton (1994). Plot dimensions are 39 ft by 131 ft. Five combinations of residue management and fertilizer application were evaluated during the crop phase of the winter wheat-fallow rotation (Fig. 1): 1) fall-burned residue/0 lb N/acre/crop (no fertilizer); 2) spring-burned residue/0 lb N acre/crop (no fertilizer); 3) spring-burned residue/80 lb N/acre/crop commercial fertilizer; 4) residue not burned/80 lb N/acre/crop commercial fertilizer; and 5) residue not burned/100 lb N/acre/crop from manure (Table 1). Evaluation of the fallow phase of the rotation included treatments 4 and 5, but not burn or no-fertilizer treatments 1, 2, or 3 described above. These treatments were chosen because they represent extremes in nutrient additions and residue management and potential for water and soil loss or conservation in the original LTCR experiment. A local cattle feed lot has supplied partially dried, mixed straw and manure for the manure treatment since 1931, which has been applied at a rate of 10 ton/acre/crop. These treatments represented typical farming practices in the 1930's. The crop rotation in all plots was soft white winter wheat, harvested in mid-July, followed by a fallow period of about 15 months. Primary tillage occurs in April using a moldboard plow (depth: 8-10 inches), followed by a field cultivator to smooth the plots, and then numerous (2 to 5) passes throughout the summer with a rodweeder to control weeds. Commercial fertilizer was applied as dry ammonium sulfate, dry urea, or gaseous ammonia (NH_3-H) between July and October. The same tillage and residue management practices, in combination with the 80-lb N/acre/crop commercial fertilizer application rate, are still commonly used in 2006.

Measurements

A weather station at the site recorded soil and air temperature, wind speed, and precipitation. Lister furrows (small ditches made by a single-bottom moldboard plow) separated treatments to prevent overland flow from one treatment to the next (Brakensiek et al. 1979). Lister furrows are similar to end furrows that cross and capture flow from other furrows in fields with complex slopes, and represent one part of the farming practice being investigated. An erosion event was recorded each time one or more treatments produced overland flow. Digital stage recorders fitted to drop-box weirs (Bonta 1998) at the furrow outfall recorded the depth of overland flow (Fig. 2).

Flow rates were calculated from standard stage/flow rating curves developed by Bonta (1998). Grab samples were collected in 1-liter bottles, timed using a stopwatch, and the flow and total eroded material (TEM) loss rates calculated to provide quality control for digital stage data and erosion samples collected by automated storm water samplers.

Experimental Design and Analysis

Each treatment was duplicated on two slopes, 2 percent and 6 percent (Fig. 1). In crop year 1998, 4 treatments in the crop phase of the winter wheat-fallow rotation and 1 standing stubble fallow plot were monitored, for a total of 10 plots. In crop years 1999 and 2000, 5 treatments in the crop phase of the winter wheat-fallow rotation and 2 standing stubble-fallow plots were monitored, for a total of 14 plots (Table 1). Data were analyzed in two sets; crop years 1998 through 2000, and crop years 1999 and 2000.

Analysis of values of TEM from treatments monitored for 3 years were based on 45 events, and values for 2 years were based on 28 events. Plot and treatment assignment layout from 1931 predate now standard experimental and statistical designs (Fig. 1), because treatments or crop/fallow rotations were not randomly assigned (Hurlbert 1984, Janzen 1995). With acknowledgment of these limitations and how they might violate assumptions of ANOVA, we tested data for normality, performed a log transformation to meet the assumption of normality, and conducted an analysis using ANOVA (SAS Mixed Procedure) type 3 tests of fixed effects ($P \leq 0.05$) (SAS. 1998, Williams 2004). TEM data were pooled by treatment per year, in 2-year and 3-year sets, and analyzed. Where variance was found to be significantly different among treatments, mean separation tests were performed using least squares analysis (SAS 1998). Mean separation *P* values are presented to demonstrate the comparative probability of TEM loss among treatments.

Results and Discussion

Eighty-three percent of the soil erosion events recorded from fall 1997 through spring of 2000 occurred on unfrozen soil (Table 2). With three exceptions, monthly precipitation values during the 3 years of monitoring were within the 95 percent confidence intervals established by the previous 67 years of weather data (Table 3). The exceptions were above-average precipitation in November, 1998 and February and March, 2000. Measurements of two early season overland flow events were missed during each of the 3 years of study.

Soil erosion was not significantly different among years. The lowest soil erosion values were recorded in fallow plots with standing stubble (Fig. 3). In the crop phase of the rotation, soil erosion increased as SOM (Fig. 4), ground cover (Table 4), and N application rates decreased across treatments, with the strongest statistical probabilities of differences between treatments at opposite ends of the treatment spectrum.

Previous Research on the Columbia Plateau

Zuzel et al. (1993) recorded an average of 1.20 ton eroded material/acre/year from three treatments at a research location known as the Kirk site, only 9 miles from the LTCR plots, but on a steeper slope (16 percent), with higher precipitation, and 810 ft higher elevation (2,300 ft), located in a different agronomic zone (Douglas et al. 1990), and in the southernmost extent of the Palouse geophysical region. Eroded material from 80 lb N/acre commercial fertilizer and no-burn or spring-burn residue management were, respectively, 0.33 to 0.64 ton/acre/year, or an average 0.48 ton/acre/year, 84 percent the 0.58 ton/acre/year from winter wheat-fallow recorded by Zuzel et al. (1993). In this study, the highest erosion rates, 1.20 and 1.74 ton/acre/year (Fig. 3), resulted from 0 lb N/acre, residue-burned treatments. These soil erosion values are considerably lower than the 2.41 ton/acre/year recorded by Zuzel et al. (1993) from plots kept bare with regular tillage and not seeded. All these values are lower than the long-term erosion values obtained by Nagle and Ritchie (2004), who measured field concentrations of Cesium-137 accumulated since 1963 within a 10-mile radius of the CPCRC. They reported erosion rates of 1.34 ton/acre/year from conventionally tilled fields from 5 percent slopes, 3.35 ton/acre/year from 5 percent slopes in pasture since 1971, and 2.96 ton/acre/year from 12 percent slopes that were no-tilled for 10 years. They attributed the high rates of erosion from the grass pasture and no-till field to erosion that took place before those sites were taken out of conventional management practices.

Soil erosion and frozen soil in the Pacific Northwest.

Erosion events associated with frozen soil events are often spectacular, with large amounts of soil and water flowing from fields and filling ditches and streams. In a brief period during January and February 1980, Zuzel et al. (1982) reported that 50 to 100 percent of the erosion events on the southeastern Columbia Plateau were related to frozen soils, with soil losses from 2.2 to 13.8 ton/acre/crop. Of the 46 erosion events recorded between November and April during crop years 1998 through 2000, only 12 (26 percent) occurred with frozen soil conditions. The chronic frequency of erosion events resulting from rain on nonfrozen soil in these 3 years produced more eroded material than any combination of conditions with frozen soil (Fig. 5). Fall and winter air temperatures during 1998 through 2000 were within the 95 percent confidence interval of values recorded since 1931 (Table 3). The frequency of frozen soil events reported here is similar to that recorded since soil temperature records began at CPCRC in 1963.

Residue and nutrient management, SOM, and soil erosion.

The small amount of soil erosion from standing stubble fallow and treatments 4 (no-burn, 80 lb commercial fertilizer) and 5 (no-burn, manure fertilizer), results from superior hydrologic conditions created by nearly complete ground cover, little soil moisture after the previous crop, and subsequent rapid infiltration. In the crop phase of the rotation, the effects of SOM concentrations (Fig. 4) and ground cover (Table 4) can be seen in the trend of increasing soil erosion (Fig. 3). Straw residue, responsible for at least half of the ground cover from November through March after fall seeding (Table 4), and SOC are negatively affected by low rates of N application. Since 1931, SOC loss in all but the manure treatments has been chronic (Rasmussen and Parton 1994, Rickman et al. 2001) and has resulted in the inability of crop growth to return organic matter lost by erosion and SOC mineralization (Rasmussen et al. 1989, 1998). Growers began adding fertilizer to commercial crops in the 1930's with complete adoption of the practice in the 1950's. However, the tillage practices described here, in combination with commercial fertilizer rates used in this experiment, are still common on the Columbia Plateau, and are associated with declining concentrations of total carbon, total nitrogen, and SOM (Rasmussen and Parton 1994; Rasmussen et al. 1989, 1998).

Soil nutrient levels play a substantial role in aggregate stability (Bird et al. 2007), and by extension an important role in the erodibility of soils. Rain falls on the Columbia Plateau with a relatively small drop size and low energy (Brown et al. 1983). Consequently, soil surface sealing results from slaking, or exfoliation of soil peds, not from destruction by direct raindrop impact. Working with soils from the plots used in this paper and other long-term plots managed by CBARC and CPCRC, Wuest et al. (2005) reported that aggregate stability was determined primarily by levels of total carbon and total nitrogen, and secondarily by stubble management and nitrogen fertilization rates. They showed that small differences in aggregate stability had profound effects on infiltration rates, with impaired infiltration corresponding to treatments with increased runoff (Williams 2004), and increased soil erosion (Fig. 3). The key to reducing soil erosion in the winter wheat-fallow cropping system in the low and intermediate precipitation zones of the Columbia Plateau will be the management of factors that contribute to soil aggregate stability.

Summary and Conclusions

The purpose of this research was to evaluate the long-term effects on soil erodibility of common crop residue and fertilizer amendment management found in the dryland crop area of the Columbia Plateau. My results complement the findings of previous research conducted on these specific plots and link soil ecological processes described in recent publications to small-field-scale erosion processes. Less soil was eroded from treatments with manure and commercial fertilizer amendments than from no fertility (0 lb N/acre) treatments where crop residue from the previous crop had been burned. Although the soil loss values reported here are relatively low, they represent chronic loss of a productive soil resource. Management to maintain good soil structural development and stability, as demonstrated by the manure amendment and commercial fertilizer treatments, reduces soil loss to levels not much greater than plots in stubble with 100 percent cover. These conditions increase soil water availability and provide a rich environment to maintain grain yields.

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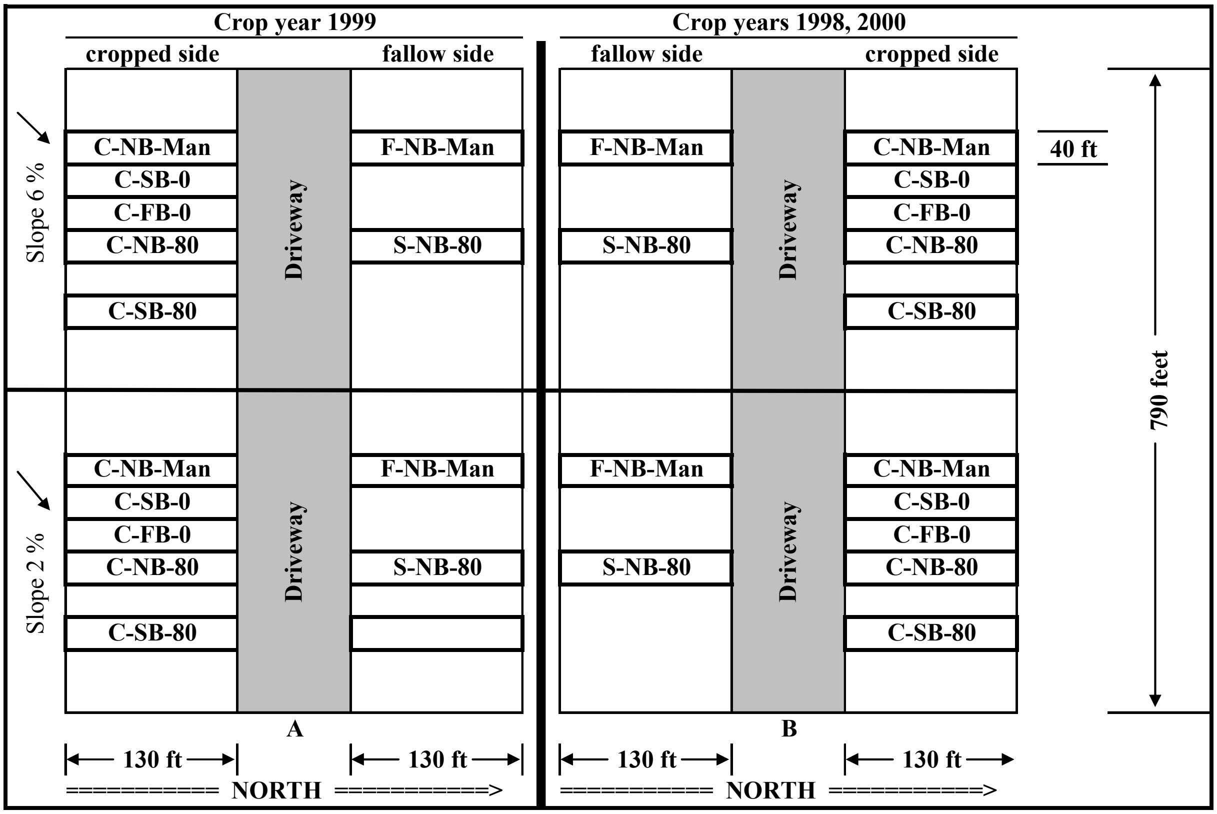
Figure 1. Treatment layout for a crop/fallow cycle in a long-term crop residue and nutrient management study, Pendleton, Oregon.



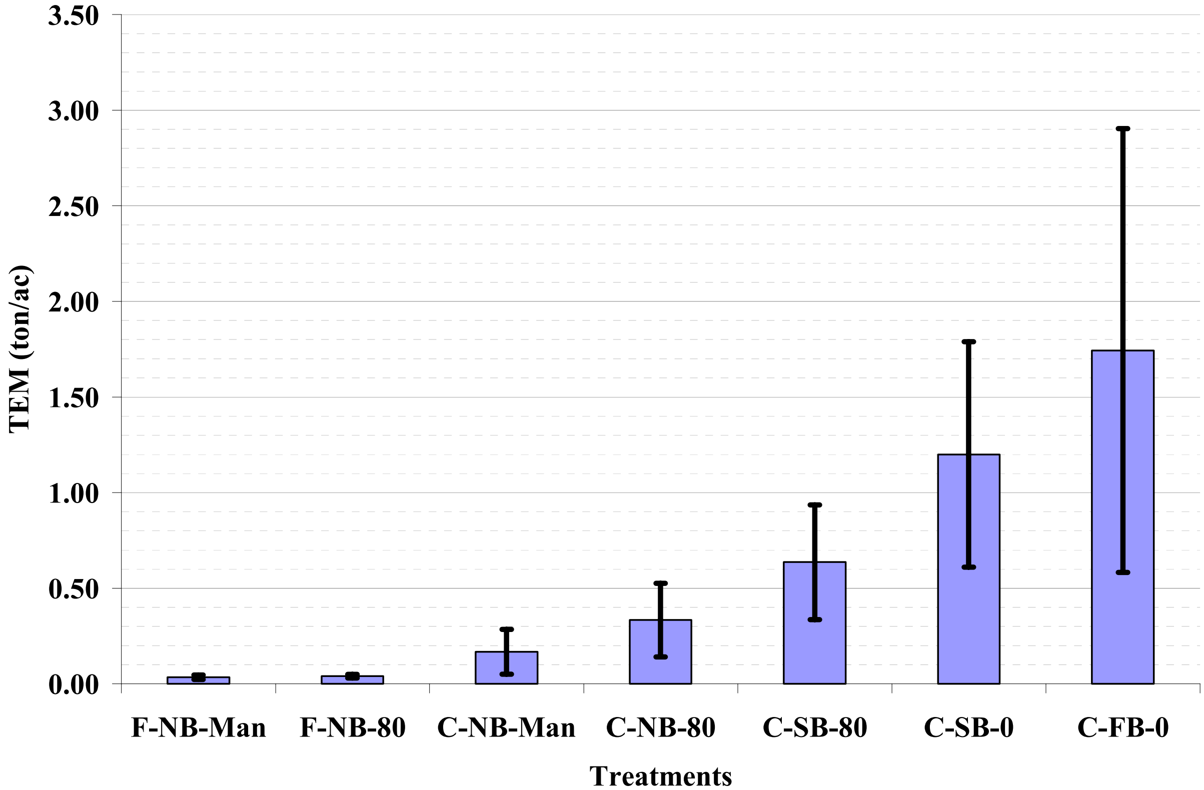
Note: Columns A and B depict the same area. Column A shows plots sampled during crop year 1999, column B shows plots sampled during 1998 and 2000. Treatments are duplicated between 2 percent and 6 percent slopes. Fallow ground has standing stubble from previous year's crop. Shaded area between crop and fallow plots is equipment traffic area.

Treatment key: C/F = crop/fallow; NB, SB, and FB = no-burn, spring-burn, and fall-burn; 0, 80, and Man are 0 lb N/acre, 80 lb N/acre commercial nitrogen, and manure (100 lb N/acre). Example: C-SB-0: C = in crop, SB = spring-burn, 0 = 0 lb N/acre. F-NB-Man and C-FB-0 were monitored 2 years (1999 and 2000 crop years), all others were monitored 3 years (1998, 1999, and 2000 crop years).

Figure 2. Lister furrow leading into drop-box weir and digital stage recorder in long-term crop residue and nutrient management study, Pendleton, Oregon.

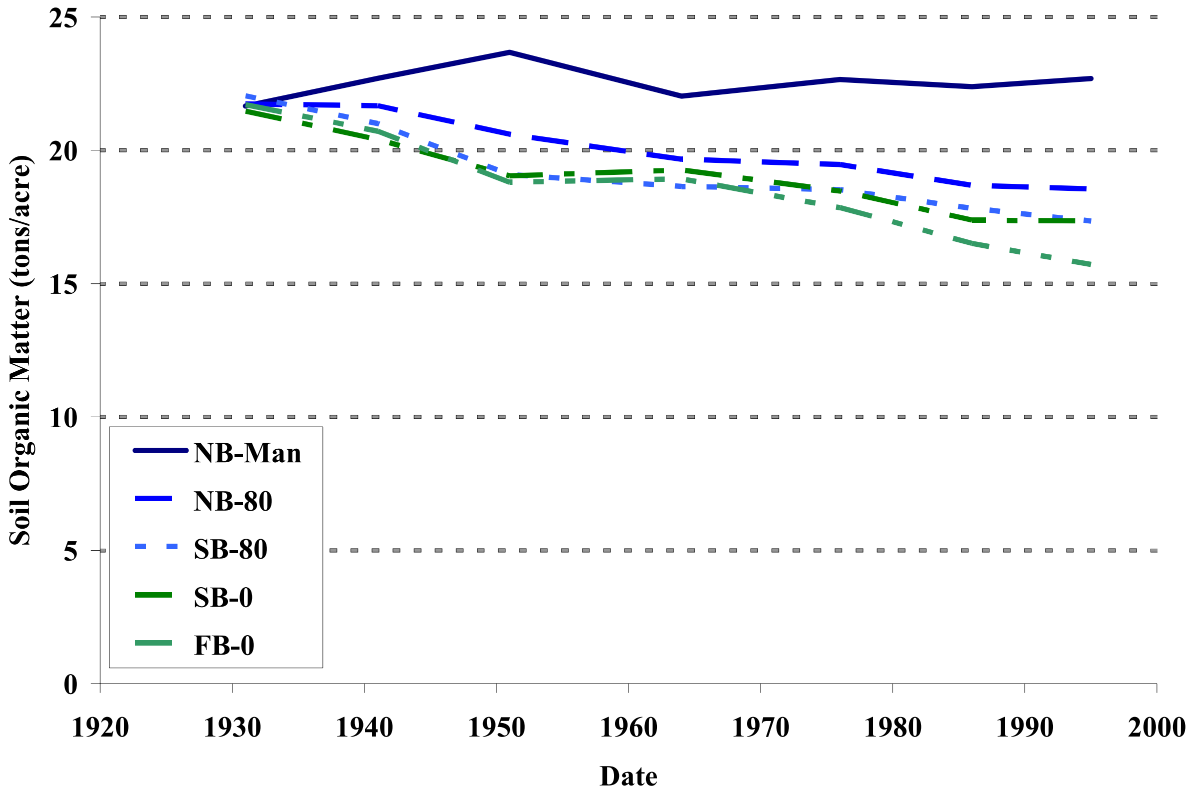
Note: Overland flow shown resulted from a rainstorm (duration 18 hours, average intensity 0.16 inch/hour, three peaks of 0.59 inch/hour intensity for a total of 10 minutes, total event 1.18 inches), on thawed soil in C-FB-0 treatment, 14 February 2000. Peak flow coincided with peak rainfall intensities in the ninth and tenth hours of the storm.

Figure 3. Average annual soil loss, measured as total eroded material (TEM) with standard error (0.05) bars from long-term crop residue and nutrient management study, Pendleton, Oregon.



Note: Treatments F-NB-Man and C-FB-0 were instrumented only during crop years 1999 and 2000, all other treatments were monitored during crop years 1998-2000.
Treatment key: C/F = crop/fallow; NB, SB, and FB = no-burn, spring-burn, and fall-burn; 0, 80, and Man = 0 lb N/acre, 80 lb N/acre commercial nitrogen, and manure (100 lb N/acre).

Figure 4. Soil organic matter decline in winter wheat-fallow cropping system.



Note: Treatment key: N, S, and F = no-burn, spring-burn, and fall-burn; 0, 80, and Man = no nutrient amendment, 80 lb N/acre commercial nitrogen, and manure (100 lb N/acre).
Source: Rasmussen and Parton, 1994; P.E. Rasmussen, unpublished data.

Figure 5. Total eroded material (TEM) from 3 years of monitoring, by erosion event type, all treatments combined, and the sum of 3 years of data, in a long-term crop residue and nutrient management study, Pendleton, Oregon.

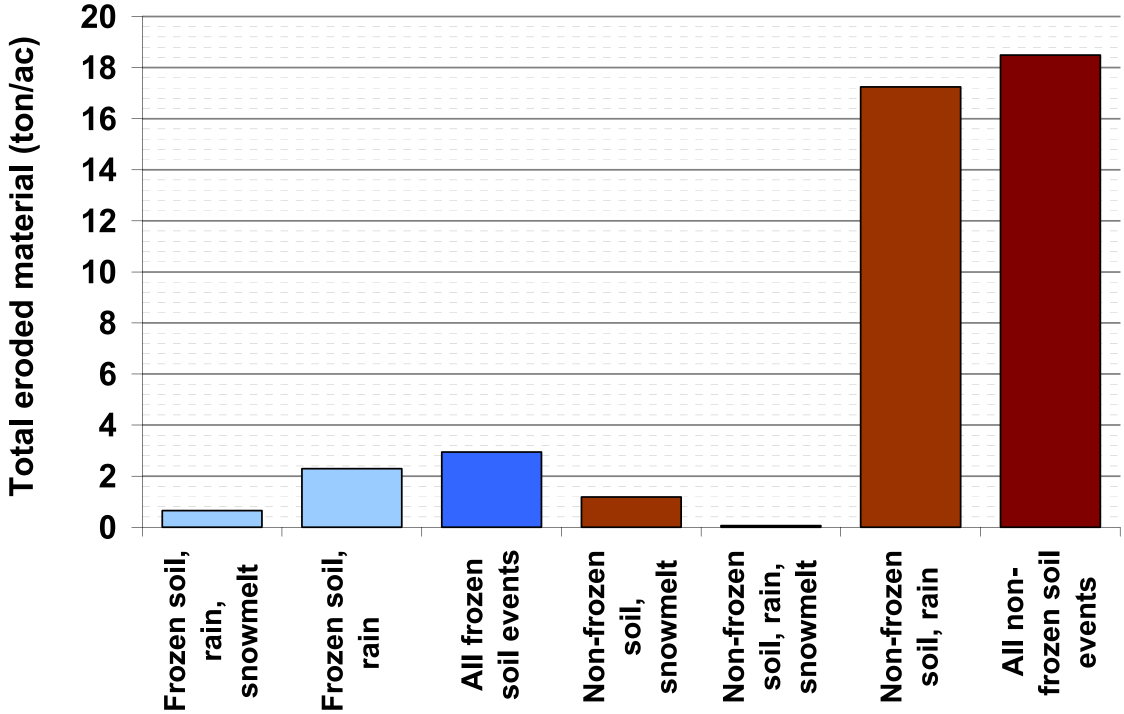


Table 1. Winter wheat-fallow treatments where overland flow was measured. Treatments were established in 1931, near Pendleton, Oregon.

Treatment	Amendments/fertilizer	Years measured
Fallow*, no burn, manure amendment	F-NB-Man†	1999, 2000
Fallow, no burn, commercial fertilizer	F-NB-80‡	1998, 1999, 2000
Crop, no burn, manure amendment	C-NB-Man	1998, 1999, 2000
Crop, no burn, commercial fertilizer	C-NB-80	1998, 1999, 2000
Crop, spring burn, commercial amendment	C-SB-80	1998, 1999, 2000
Crop, spring burn, no nutrients added	C-SB-0	1998, 1999, 2000
Crop, fall burn, no nutrients added	C-FB-0	1999, 2000

*Standing stubble following harvest.
†Manure amendments average N application of 100 lb/acre/crop year from livestock manure.
‡Commercial fertilizer average N application of 80 lb/acre/crop year, F-NB-Man, and F-NB-80 treatments were in fallow with standing stubble. These plots, in alternate years, were the C-NB-Man and C-NB-80 treatments. Overland flow was captured only during crop years in treatments C-SB-80, C-SB-0, and C-FB-0.
Treatment key: C/F = crop/fallow; N, S, and F = no-burn, spring-burn, and fall-burn; 0, 80, and Man = no nutrient amendment, 80 lb N/acre commercial nitrogen, and manure (100 lb N/acre).

Table 2. Soil and climate conditions associated with frequency of overland flow events.

Event type	Crop year			3 years
	1997-1998	1998-1999	1999-2000	
Frozen soil, snowmelt	0	0	0	0
Frozen soil, rain, snowmelt	2	2	1	5
Frozen soil, rain	1	1	0	7
Not frozen soil, snowmelt	0	0	1	1
Not frozen soil, rain, snowmelt	0	0	1	1
Not frozen soil, rain	15	11	11	32
Totals	18	14	14	46

Table 3. Total precipitation and temperature values for 67-year weather records (1930-1997) and during 1998-2000, Pendleton, Oregon.

	67-year record average	1997-98	1998-99	1999-2000
Precipitation (inches)				
November	2.09 ± 1.06	1.57	4.72*	2.17
December	2.05 ± 0.24	1.42	2.95	1.89
January	1.97 ± 0.94	2.83	1.18	2.40
February	1.54 ± 1.54	0.87	2.17	3.35 *
March	1.69 ± 1.69	1.42	1.22	3.39 *
Minimum temperature (ºF)				
November	23 ± 15	25	25	27
December	17 ± 19	28	-5*	22
January	10 ± 19	3	22	23
February	12 ± 16	23	15	25
March	19 ± 8	23	24	25
Maximum temperature (ºF)				
November	66 ± 5	67	64	78 *
December	60 ± 5	60	58	59
January	58 ± 6	59	60	57
February	61 ± 5	62	61	63
March	69 ± 5	68	66	71

Notes: Precipitation and temperature conditions averaged for the 3 years of study, or the combined erosion season (November-March), were not different from the previous 67 years of record.
* Numerical values outside of one standard deviation of 68 years of record.

Table 4. Ground cover in winter wheat-fallow cropping system, February 2000, Pendleton, Oregon.

	Cover type (percent)			
Treatment*	Bare soil	Residue	Wheat	Total cover
NB-Man	43 ± 19	43 ± 14	15 ± 5	58
NB-80	44 ± 12	44 ± 4	13 ± 8	57
SB-80	55 ± 38	29 ± 13	17 ± 27	46
SB-0	59 ± 17	21 ± 6	21 ± 12	42
FB-0	77 ± 4	10 ± 1	13 ±3	43

*Treatment key: N, S, and F = no-burn, spring-burn, and fall-burn; 0, 80, and Man = 0 lb N/acre, 80 lb N/acre commercial nitrogen, and manure (100 lb N/acre).