APPLIED RESEARCH

Soil erosion from dryland winter wheat–fallow in a long-term residue and nutrient management experiment in north-central Oregon

J.D. Williams

Abstract: Soil property changes 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 kg N ha^{-1} $crop^{-1}$ (no fertilizer); (2) spring burned residue, 0 kg N ha^{-1} $crop^{-1}$ (no fertilizer); (3) spring burned residue, 90 kg N ha^{-1} $crop^{-1}$ (80 lb N ac^{-1} $crop^{-1}$) commercial fertilizer; (4) residue not burned, 90 kg N ha^{-1} $crop^{-1}$ commercial fertilizer; and (5) residue not burned, 111 kg N ha^{-1} $crop^{-1}$ (99 lb N ac^{-1} $crop^{-1}$) from manure. All treatments were moldboard plowed with multiple subsequent 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 L [0.25 gal]) were collected to confirm digital stage data. Measured soil erosion progressively increased from plots with standing stubble (0.08 Mg ha^{-1} y^{-1} [10.04 t ac^{-1} yr^{-1}]) to plots in crop with manure and commercial fertilizer amendments with and without the crop residue burned (0.85 Mg ha^{-1} y^{-1} [0.38 t ac^{-1} yr^{-1}]), to plots in crop with crop residue burned and no fertilizer (3.30 Mg ha^{-1} y^{-1} [1.47 t ac^{-1} yr^{-1}]). These results provide direct evidence of the relationship between depleted soil quality and increasing erodibility and demonstrate the importance of maintaining nutrient levels in semiarid dryland soils.

Key words: cropping systems—erodibility—fallow—silt loam—soil loss—soil resource

Dryland winter wheat (*Triticum aestivum* L.) is the predominant crop throughout the low 250 to 340 mm (10 to 13 in) and intermediate 340 to 450 mm (13 to 18 in) precipitation areas on the Columbia Plateau of the inland Pacific Northwest, and grain yields average from 1.3 to 4.7 Mg ha^{-1} (17 to 70 bu ac^{-1}) (Rasmussen and Parton 1994; Papendick 1996). Ten percent of the small grain producing acreage was in no-till between 1995 and 2005, but the adoption rate has slowed, and mechanical tillage remains the general 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 <340 mm, winter wheat-spring cereal-fallow in 340 to 450 mm, annual cropping with wider ranges of crops (small grains, pulses, and oil seed crops) > 450 mm. A notable exception to this distribution occurs in the southeastern area of the region near Pendleton, Oregon, where winter wheat-fallow is predominantly practiced throughout the intermediate precipitation zone. Economic stability and consistent yields (Schillinger et al. 2006) contribute to its popularity. Many producers still use mechanical tillage tools, (disk, chisel, and moldboard plows), to manage residue, control weeds and diseases, and store and manage soil water in this Mediterranean climate where 88% of the precipitation falls from September through May. Fields fallowed in this manner for 13 to 14 months leaves the soil surface nearly devoid of residue when the next crop is planted in late summer or autumn. Soil loss from recurrent wind and water erosion are often excessive (Papendick 1996).

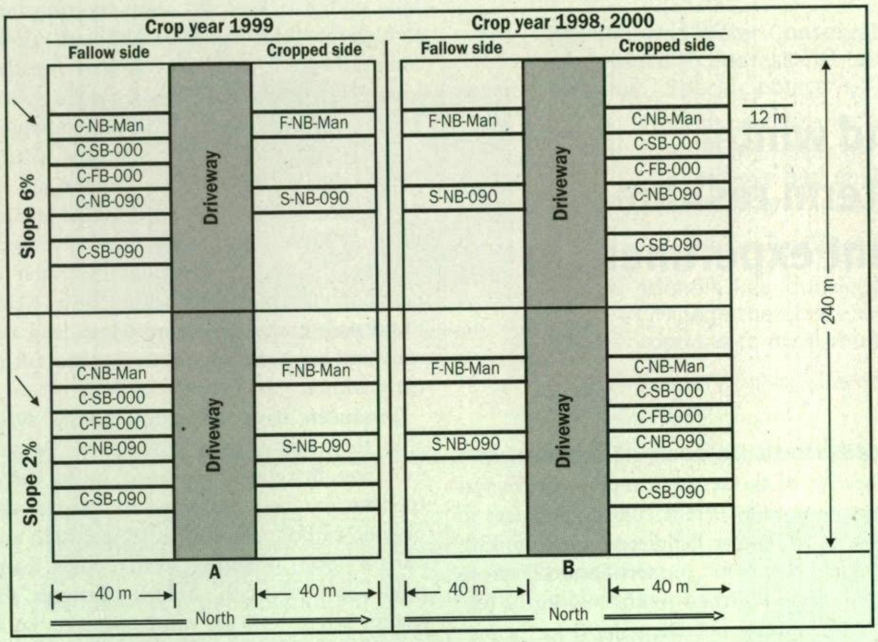
Winter weather and soil conditions combine with a lack of soil cover to contribute to high rates of soil erosion. Although rainfall intensities are low, as many as seven weather events per year have been recorded where warm rain contributes to rapid snowmelt, runoff, and considerable soil loss (Zuzel 1994). Soils in this semi-arid region are silt dominated with intrinsically low soil organic matter, soil structure, and water stable peds. Soil macropores are especially vulnerable to destruction by mechanical disturbance. Many of the soils in this region are <1 m deep, and soils can reach field capacity by late fall or early winter.

Producers have numerous options available to counter these conditions. Annual cropping, marginally successful in the intermediate rainfall zone, slows or reverses soil organic carbon (SOC) loss (Rasmussen and Parton 1994). Planting spring crops leaves fields covered with stubble through the winter when soils are most prone to water erosion, but spring wheat yields are significantly lower than from 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 at seeding and weed and disease control. For the foreseeable future, the winter wheat-fallow system will continue as the cropping system of choice in many regions on the Columbia Plateau.

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

John D. Williams is a research hydrologist at the Columbia Plateau Conservation Research Center, USDA Agricultural Research Service, Pendleton, Oregon.

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



Note: Columns A and B depict the same ground. Column A shows plots sampled during crop year 1999; column B shows plots sampled during 1998 and 2000. Treatments are duplicated between 2% and 6% 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 = crop, F = fallow; NB = no-burn, SB = spring-burn, FB = fall-burn; 000 = no nutrient amendment (000 kg N ha^{-1}), 090 = commercial nitrogen (090 kg N ha^{-1}), Man = manure (111 kg N ha^{-1}). For example, C-SB-000: C = in crop, SB = spring-burn, 000 = 0 kg N ha^{-1}. F-NB-Man and C-FB-000 were monitored two years (1999 and 2000 crop years); all others were monitored three years (1998, 1999, and 2000 crop years).

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 15 km (≈9 mi) northeast of Pendleton, Oregon (45°43'N, 118°38'W). The elevation at the site is of 458 m (1,500 ft).

Table 1
Winter wheat–fallow treatments on which overland flow was measured.

Treatment	Amendments/fertilizer	Years measured
Fallow, no-burn, manure amendment	F-NB-Man	1999, 2000
Fallow, no-burn, commercial fertilizer	F-NB-090	1998, 1999, 2000
Crop, no-burn, manure amendment	C-NB-Man	1998, 1999, 2000
Crop, no-burn, commercial fertilizer	C-NB-090	1998, 1999, 2000
Crop, spring-burn, commercial amendment	C-SB-090	1998, 1999, 2000
Crop, spring-burn, no nutrients added	C-SB-000	1998, 1999, 2000
Crop, fall-burn, no nutrients added	C-FB-000	1999, 2000

Notes: Treatments were established 1931, near Pendleton, Oregon. F-NB-Man and F-NB-090 treatments were in fallow with standing stubble. These plots, in alternate years, were the C-NB-Man and C-NB-090 treatments. Overland flow was only captured during crop years in treatments C-SB-090, C-SB-000, and C-FB-000. Treatment key: C = crop, F = fallow; NB = no-burn, SB = spring-burn, FB = fall-burn; 000 = no nutrient amendment (000 kg N ha^{-1}), 090 = commercial nitrogen (090 kg N ha^{-1}), Man = manure (111 kg N ha^{-1}).

Meteorological Records and Soils. Meteorological records at the CPCRC/CBARC show minimum, maximum, and mean annual air temperatures of –34°C (–29°F), 46°C (115°F), and 11°C (52°F), respectively. Annually, 135 to 170 days are frost-free. Approximately 70% of precipitation occurs between November and April and results from maritime fronts that produce low intensity storms with a median duration of 3 hr and 50% with duration ranging from 1 to 7 h. The maximum recorded one-hour storm intensity is 13 mm h^{-1} (0.51 in hr^{-1}) and median storm size is 1.5 mm (0.06 in) at 0.5 mm h^{-1} (0.02 in hr^{-1}) (Brown et al. 1983). Seventy years of records CPCRC/CBARC show mean annual precipitation is 422 mm (16.61 in), with extremes of 243 mm (9.57 in) minimum and 583 mm (22.95 in) 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 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 [United States], Kastanozems [Food and Agriculture Organization]). Slope ranges from 2% to 6% on a northeast aspect (Johnson and Makinson 1988). 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 sizes were 12 m × 40 m (39 ft × 131 ft). Five combinations of residue management and fertilizer application were evaluated during the in-crop phase of the winter wheat-fallow rotation (figure 1): (1) fall burned residue, 0 kg N ha^{-1} crop^{-1} (no fertilizer); (2) spring burned residue, 0 kg N ha^{-1} $crop^{-1}$ (no fertilizer); (3) spring burned residue, 90 kg N ha^{-1} $crop^{-1}$ (80 lb N ac^{-1} $crop^{-1}$) commercial fertilizer; (4) residue not burned, 90 kg N ha^{-1} $crop^{-1}$ commercial fertilizer; and (5) residue not burned/111 kg N ha^{-1} $crop^{-1}$ (99 lb N ac^{-1} $crop^{-1}$) 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 soil fertility and potential for water and soil loss or conservation in the original LTCR experiment. A local animal (bovine) feed lot has supplied partially dried, mixed straw and manure for the manure treatment since 1931, which has been applied at a rate of 22.4 Mg ha^{-1} $crop^{-1}$ (10 tn ac^{-1} $crop^{-1}$). These treatments represented farming practices in the 1930s. The crop rotation in all plots was soft, white winter wheat, harvested in mid-July and followed by a fallow period of 15 months. Primary tillage occurs in April using a moldboard plow (depth: 200 to 250 mm [8 to 10 in]), followed by a field cultivator to smooth the plots, and then numerous (2 to 5) passes throughout the summer with secondary tillage equipment to control weeds. Commercial fertilizer was applied as aqueous NH_3-N between July and October. The same tillage and residue management practices, in combination with the 90 kg N ha^{-1} $crop^{-1}$ 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 (figure 2).

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

Figure 2

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

Notes: Overland flow shown resulted from a rainstorm, (duration 18 h, average intensity 4 mm h^{-1}, three peaks of 15 mm h^{-1} intensity for a total of 10 min, total event 30 mm), on thawed soil in C-FB-000 treatment, February 14, 2000. Peak flow coincided with peak rainfall intensities in the ninth and tenth hours of the storm.

Experimental Design and Analysis. Each treatment was duplicated on two slopes, 2% and 6% (figure 1). In crop year 1998, four treatments in the crop phase of the winter wheat-fallow rotation and one standing stubble fallow plot were monitored, for a total of 10 plots. In crop years 1999 and 2000, five treatments in the crop phase of the winter wheat-fallow rotation and two standing stubble fallow plots were monitored, for a total of 14 plots (table 1). Data were analyzed in two sets: crop years 1998, 1999, and 2000, and crop years 1999 and 2000.

Analysis of values of TEM from treatments monitored for three years were based upon n = 45 events, and values for two years were based upon n = 28 events. Plot and treatment assignment layout from 1931 predate now standard experimental and statistical designs (figure 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 (Statistical Analysis Systems [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 two-year and three-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 the spring of 2000 occurred on unfrozen soil (table 2). With three exceptions, monthly precipitation values during the three years of monitoring were within the 95% confidence intervals established by the previous 67 years of weather data (table 3). The excep-

Table 2

Soil and climate conditions associated with overland flow events.

Event type	Crop year 1997 to 1998	1998 to 1999	1999 to 2000	Three years
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

tions 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 three years of study.

Soil erosion was not significantly different among years. The lowest soil erosion values were recorded in fallow plots with standing stubble (figure 3). In the crop phase of the rotation, soil erosion increased as SOC (table 4) (Rasmussen and Parton 1994; Rickman et al. 2001), ground cover (table 5), and N application rates decreased across treatments, with the strongest statistical probabilities of differences between treatments at opposite ends of the treatment spectrum (table 6).

Previous Research on the Columbia Plateau. Zuzel et al. (1993) recorded an average of 2.7 Mg ha^{-1} y^{-1} (1.20 tn ac^{-1} yr^{-1}) from three treatments at a research location known as the Kirk site, geographically near the LTCR plots (15 km [9.3 mi] distant) but on a steeper slope (16%) with higher precipitation at a 247-m (810.4-ft) higher elevation located in a different agronomic zone (Douglas et al. 1990) and technically in the southern most extent of the Palouse geophysical region. Eroded material from 90 kg N ha^{-1} (80 lb N ac^{-1}) commercial fertilizer and no-burn or spring burn residue management were respectively, 0.75 to 1.43 Mg ha^{-1} y^{-1} (0.33 to 0.64 tn ac^{-1} yr^{-1}) or an average 1.09 Mg ha^{-1} y^{-1} (0.48 tn ac^{-1} yr^{-1}), half the 1.3 Mg ha^{-1} y^{-1} (0.58 tn ac^{-1} yr^{-1}) from winter wheat-fallow recorded by Zuzel et al. (1993). In this study, the highest erosion rates resulted from treatments where no nitrogen fertilizer was added and the residue was either burned in the spring or fall following harvest, 2.69 and 3.91 Mg ha^{-1} y^{-1} (1.20 and 1.74 tn ac^{-1} yr^{-1}) (figure 3), which are both considerably lower than the 5.4 Mg ha^{-1} y^{-1} (2.41 tn ac^{-1} yr^{-1}) 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) measuring field concentrations of CS-137 accumulated since 1963 within a 15 km (10 mi) radius of the CPCRC. They reported erosion rates of 3.0 Mg ha^{-1} y^{-1} (1.34 tn ac^{-1} yr^{-1}) from conventionally tilled fields from 5% slopes, 7.5 Mg ha^{-1} y^{-1} (3.35 tn ac^{-1} yr^{-1}) from 5% slopes in pasture since 1971, and 6.6 Mg ha^{-1} y^{-1}; (2.96 tn ac^{-1} yr^{-1}) from 12% slopes that where 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 50% to 100% of the erosion events on the southeastern Columbia Plateau were related to frozen soils, with soil losses from 0.5 to 31.0 Mg ha^{-1} crop^{-1} (2.2 to 13.8 tn ac^{-1} crop^{-1}). Of the 46 erosion events recorded between November and April during crop years 1998, 1999, and 2000, only twelve (26%) occurred with frozen soil conditions. The chronic frequency of erosion events resulting from rain on nonfrozen soil in these three years produced more eroded material than any combination of conditions with frozen soil (figure 4). Fall and winter air temperatures during 1998, 1999, and 2000 were within the 95% confidence interval of values recorded since 1931 (table 3). A similar frequency of frozen soil events occurred

Table 3

Total precipitation and average temperature values for 67-year weather record (1930 to 1997) and during 1998 to 2000, Pendleton, Oregon.

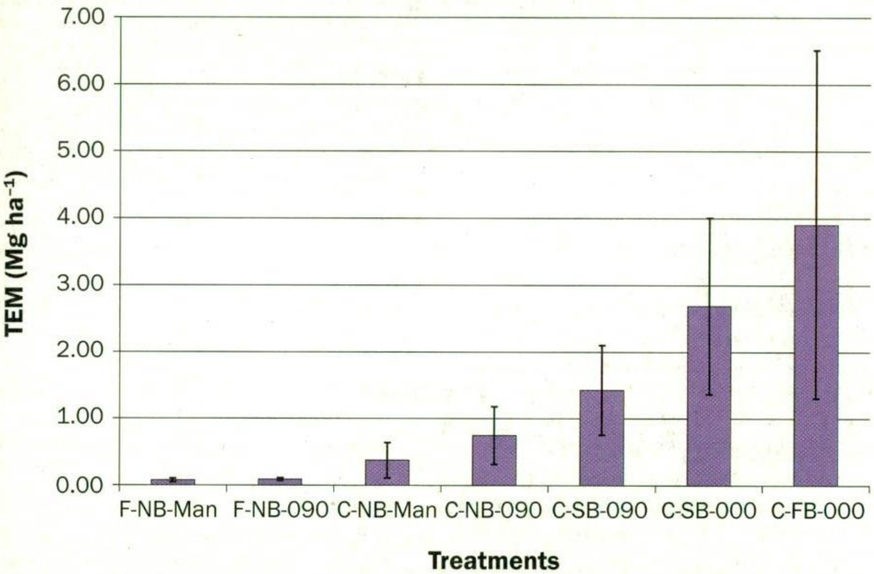
	67-year record	1997 to 1998	1998 to 1999	1999 to 2000
Precipitation (mm)				
November	53 ± 27	40	120*	55
December	52 ± 26	36	75	48
January	50 ± 24	72	30	61
February	39 ± 19	22	55	85*
March	43 ± 20	36	31	86*
Minimum temperature (°C)				
November	-5.0 ± 8.2	-3.9	-3.9	-2.8
December	-8.1 ± 9.7	-2.1	-20.6*	-5.6
January	-12.1 ± 10.8	-16.1	-5.6	-5.0
February	-11.3 ± 8.8	-5.0	-9.5	-3.9
March	-7.3 ± 4.3	-5.0	-4.4	-3.9
Maximum temperature (°C)				
November	18.9 ± 2.9	19.5	17.8	25.6*
December	15.5 ± 2.9	15.6	14.5	15.0
January	14.4 ± 3.6	15.0	15.6	13.9
February	16.3 ± 3.0	16.7	16.1	17.2
March	20.5 ± 2.5	20.0	18.9	21.7

Notes: Precipitation and temperature conditions averaged for the three years of study, or the combined erosion season (November to March), were not different from the previous 67 years of record.

*Numerical values outside of one standard deviation of 68 years of record.

Figure 3

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



Note: Treatments F-NB-111 and C-FB-000 were instrumented only during crop years 1999 and 2000; all other treatments were monitored during crop years 1998 to 2000. Treatment key: C = crop, F = fallow; NB = no-burn, SB = spring-burn, FB = fall-burn; 000 = no nutrient amendment (000 kg N ha^{-1}), 090 = commercial nitrogen (090 kg N ha^{-1}), Man = manure (111 kg N ha^{-1}).

during the research reported here as occurred since soil temperature records began at CPCRC in 1963.

Residue and Nutrient Management, Soil Organic Carbon, and Soil Erosion. The small amount of soil erosion from standing stubble fallow, NB-Man and NB-090 treatments, results from superior hydrologic conditions created by nearly complete ground cover, little soil moisture after the previous crop, and subsequent high infiltration rates. In the crop phase of the rotation, the effects of SOC concentrations (table 4) and ground cover (table 5) can be seen in the trend of increasing soil erosion (figure 3). Straw residue, responsible for half or more of the ground cover from November through March after fall seeding (table 5), 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), resulting in the inability of crop growth to return organic matter lost by erosion and SOC mineralization (Rasmussen et al. 1989, 1998). The practice of not adding commercial fertilizer to a crop ended sometime in the 1930s or 1940s. 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 C, total N, and SOC (Rasmussen and Parton 1994; Rasmussen et al. 1989,1998).

Soil nutrient levels play a substantial role in aggregate stability (Bird et al. 2997) and by extension an important role in the erodibility of soils. Rain falls on the Columbia Plateau with 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) showed aggregate stability was determined primarily by levels of total C and total N and secondarily by stubble management and N 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 (figure 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 conditions 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. The results compliment 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 the high fertility treatments with manure and commercial fertilizer amendments than from no fertility (0 kg N ha^{-1}) treatments in which crop residue from the previous crop had been burned. The importance of soil structural development and stability is demonstrated by the manure amendment treatment, in crop, with soil loss corresponding to plots in stubble with 100%

Table 4

Soil organic carbon decline in winter wheat-fallow cropping system.

	Soil organic carbon (Mg ha^{-1})				
Year	NB-Man	NB-090	SB-090	SB-000	FB-000
1931*	48.57	48.75	49.41	48.12	48.67
1941*	50.88	48.59	47.08	45.74	46.44
1951*	53.07	46.18	42.80	42.69	42.15
1964*	49.39	44.09	41.81	43.18	42.45
1976*	50.80	43.65	41.52	41.42	40.01
1986*	50.18	41.90	39.95	38.96	37.01
1995†	50.87	41.58	38.89	38.89	35.25

Treatment key: NB = no-burn, SB = spring-burn, FB = fall-burn; 000 = no nutrient amendment (000 kg N ha^{-1}), 090 = commercial nitrogen (090 kg N ha^{-1}), Man = manure (111 kg N ha^{-1}).

*From Rasmussen and Parton (1994).

†From P.E. Rasmussen, unpublished data.

Table 5

Ground cover in winter wheat-fallow cropping system, February 2000.

	Cover type (%)			
Treatment	**Bare soil**	**Residue**	**Wheat**	**Total cover**
NB-Man	43 ± 19	43 ± 14	15 ± 5	58
NB-090	44 ± 12	44 ± 4	13 ± 8	57
SB-090	55 ± 38	29 ± 13	17 ± 27	46
SB-000	59 ± 17	21 ± 6	21 ± 12	42
FB-000	77 ± 4	10 ± 1	13 ±3	43

Treatment key: NB = no-burn, SB = spring-burn, FB = fall-burn; 000 = no nutrient amendment (000 kg N ha^{-1}), 090 = commercial nitrogen (090 kg N ha^{-1}), Man = manure (111 kg N ha^{-1}).

cover. Farming practices that maintain soil nutrients create soil conditions that reduce or retard soil erosion in this region. Such soil conditions increase soil water availability and provide a rich environment to maintain grain yields.

Table 6

Least squares *p*-values means separation of total eroded material (TEM) values on an annual basis for the long-term crop residue and nutrient management study, Pendleton, Oregon.

Management practices			$p \le$
F-NB-Man	<	C-FB-000	0.01†
F-NB-Man	<	C-SB-000	0.01†
F-NB-090	<	C-SB-000	0.01†
F-NB-090	<	C-FB-000	0.01†
F-NB-Man	<	C-SB-090	0.01†
C-NB-Man	<	C-SB-000	0.02†
C-NB-Man	<	C-FB-000	0.02†
F-NB-090	<	C-SB-090	0.03†
F-NB-Man	<	C-NB-090	0.04†
C-NB-Man	<	C-SB-090	0.07†
F-NB-090	<	C-NB-090	0.09*
C-NB-090	<	C-SB-000	0.13*
C-NB-090	<	C-FB-000	0.17†
C-NB-Man	<	C-NB-090	0.18†
F-NB-Man	<	C-NB-Man	0.29†
C-NB-090	<	C-SB-090	0.38†
C-SB-090	<	C-SB-000	0.40†
C-SB-090	<	C-FB-000	0.43*
F-NB-Man	<	F-NB-090	0.53†
F-NB-090	<	C-NB-Man	0.65†
C-SB-000	<	C-FB-000	0.97†

Notes: Treatment key: C = crop, F = fallow; NB = no-burn, SB = spring-burn, FB = fall-burn; 000 = no nutrient amendment (000 kg N ha^{-1}), 090 = commercial nitrogen (090 kg N ha^{-1}), Man = manure (111 kg N ha^{-1}).

*Based on two years of data, 4 degrees of freedom.

†Based on three years of data, 6 degrees of freedom.

Acknowledgements

The USDA ARS CPCRC and Oregon State University CBARC have shared responsibility for the property and management of the long term crop residue experiment. Thanks to Steve Albrecht, Bob Correa, Clyde Douglas, Daryl Haasch, Joy Mathews, Eric Nicita, Stephan Osburn, Scott Oviatt, Ron Rickman, Dave Robertson, Dale Wilkins, and Heidi Williams for field work and data collection; Amy Baker, Tami Johlke, and Chris Roager for sample processing and laboratory analysis; and the entire CPCRC/CBARC staff for the many technical and logistical contributions. Susan Durham, Utah State University, provided statistical counseling and guidance. Darren Van Cleave, University of Utah, provided analytical meteorological expertise. This research would not have been possible without the dedication required to maintain the LTCR experiments by past and present superintendents of Oregon State University CBARC, Paul Rasmussen (retired USDA ARS soil scientist), and generous funding for data acquisition equipment provided by the USDA ARS Pacific West Area Office, Albany, California.

References

Bird, S.B., J.E. Herrick, M.M. Wander, and L. Murray. 2007. Multi-scale variability in soil aggregate stability: Implications for understanding and predicting semi-arid grassland degradation. Geoderma 140(1/2):106-118.

Bonta, J.V. 1998. Modified drop-box weir for monitoring flows from erosion plots and small watersheds. Transactions of the American Society of Agricultural Engineers 41(3):565-573.

Brakensiek, D.L., H.B. Osborn, and W.J. Rawls. 1979. Field Manual for Research in Agricultural Hydrology. US Department of Agriculture Agricultural Handbook 224. Washington DC: US Government Printing Office.

Brown, B., J.D. Istok, R.W. Katz, and A.H. Murphy. 1983. Statistical Analysis of Climatological Data to Characterize Erosion Potential: 2. Precipitation Events in Eastern Oregon/Washington. Special Report 687, Corvallis, OR: Agricultural Experiment Station, Oregon State University.

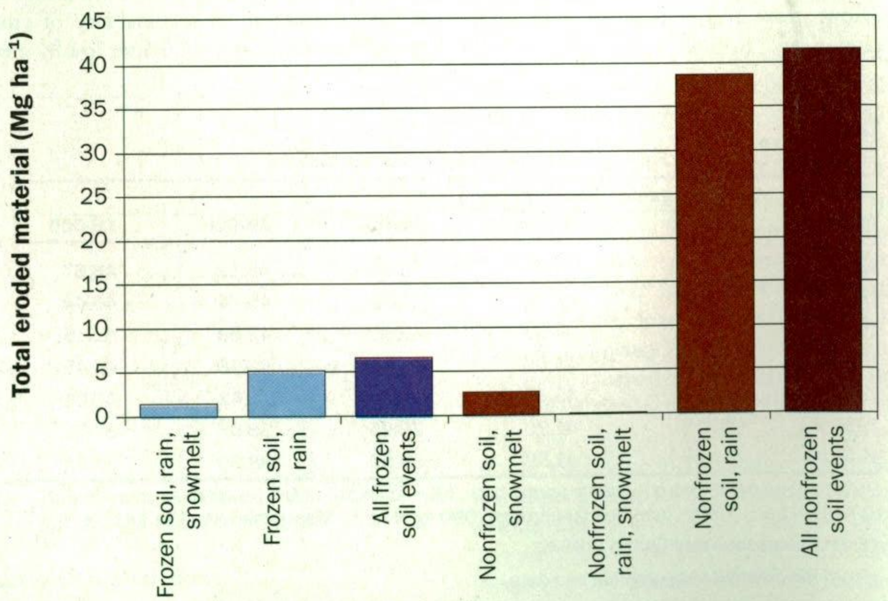
Campbell, C.A., G.P. LaFond, R.P. Zentner, and V.O. Biederbeck. 1991. Soil organic matter in a thin black Chernozem in western Canada. Soil Biology and Biochemistry 23(2):443-446.

Dormaar, J.F., C.W. Limdwall, and G.C. Kozub. 1997. Role of continuous wheat and amendments in ameliorating an artificially eroded dark brown Chernozemic under dryland conditions. Canadian Journal of Soil Science 77(2):271-279.

Douglas, C.L., D.J. Wysocki, J.F. Zuzel, R.W. Rickman, and B.L. Klepper. 1990. Agronomic zones for the dryland Pacific Northwest. Pacific Northwest Extension Publication 354:3-8.

Figure 4

Total eroded material from three years of monitoring by erosion event type with all treatments combined and the sum of three years of data.



Floyd, D.A., and J.E. Anderson. 1982. A new point interception frame for estimating cover vegetation. Vegetatio 50:185-186.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54(2):187-211.

Janzen, H.H. 1995. The role of long-term sites in agroecological research: A case study. Canadian Journal of Soil Science 75:123-133.

Johnson, D.R., and A.J. Makinson. 1988. Soil survey of Umatilla County area, Oregon. Washington DC: USDA Soil Conservation Service.

Kok, H. 2007. Helping Northwest farmers with profitable conservation technologies. Washington State University—Impact 2007. Pullman, WA: Information Department of the College of Agricultural, Human, and Natural Resource Sciences, Washington State University. http://ext.wsu.edu/impact/report/report.asp?impactID=396.

Nagle, G.N., and J.C. Ritchie. 2004. Wheat field erosion rates and channel bottom sediment sources in an intensively cropped Northeastern Oregon drainage basin. Land Degradation and Development 15(1):15-26.

Papendick, R.I. 1996. Farming systems and conservation needs in the Northwest wheat region. American Journal of Alternative Agriculture 11(2/3):52-57.

Rasmussen, P.E., and S.L. Albrecht. 1998. Crop management effects on organic carbon in semi-arid Pacific Northwest soils. *In* Management for Carbon Sequestration in Soil, ed. R. Lal, R.F. Follett, B.A. Stewart, 209-219. Boca Raton, FL: CRC Press.

Rasmussen, P.E., and W.J. Parton. 1994. Long-term effects of residue management in wheat-fallow. I. Inputs, yield, and soil organic matter. Soil Science Society America Journal 58(2):523-530.

Rasmussen, P.E., S.L. Albrecht, and R.W. Smiley. 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil and Tillage Research 47(3/4):197-205.

Rasmussen, P.E., H.P. Collins, and R.W. Smiley. 1989. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. Station Bulletin 675. Pendleton, OR: Oregon Agricultural Experiment Station.

Ricard, J.A., W.T. Tobiasson, and A. Greutorex. 1976. The Field Assembled Frost Gage. Technical note. Hanover, NH: Cold Regions Research Engingeering Laboratory, US Army Corps of Engineers.

Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht, L.G. Bundy, and J.L. Berc. 2001. CQESTR: A model to estimate carbon sequestration in agricultural soils. Journal of Soil and Water Conservation 56(3):237-242.

SAS (Statistical Analysis Systems). 1998. SAS (r) Proprietary Software Version 7 (TS P1). Licensed to USDA, Site 0038232001. SAS Institute Inc., Cary, North Carolina.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2006. Dryland cropping in the western United States. *In* Dryland Agriculture, 2nd ed. Agronomy monograph no. 23, ed. G.A. Peterson, P.W. Unger, and W.A. Payne, 365-393. Madison, WI: American Society of Agronomy, Crop Science Society America, and Soil Science Society America.

Smiley, R.W., M.C. Siemens, T.M. Gohlke, and J.K. Poore. 2005. Small Grain Acreage and Management Trends for Eastern Oregon and Washington. *In* 2005 Dryland Agricultural Research Annual Report SR 1061, ed. D.A. Long, S.E. Petrie and P.M. Frank, 30-50. Corvallis, OR: Agricultural Experiment Station, Oregon State University.

Williams, J.D. 2004. Effects of long-term winter wheat, summer fallow residue and nutrient management on field hydrology for a silt loam, north-central Oregon. Soil and Tillage Research 75(2):109-119.

Williams, J.D., D.S. Robertson, and H.S. Oviatt. 2004. Changes in storm flow responses as a result of direct seed farming practices on the Columbia Plateau croplands. *In* Eos, Transactions American Geophysical Union 85, Fall Meeting Supplement. CD-ROM. Abstract: H53A-1213.

Wuest, S.B., T. Caesar-TonThat, S.F. Wright, and J.D. Williams. 2005. Organic matter additions, N, and residue burning effects on infiltration, biological, and physical properties of an intensively tilled silt-loam soil. Soil and Tillage Research 84(2):154-167.

Zuzel, J.F. 1994. Runoff and soil erosion phenomena in the dryland grain growing region of the Pacific Northwest, USA. Trends in Hydrology 1(1):209-216.

Zuzel, J.F., R.R. Allmaras, and R.N. Greenwalt. 1982. Runoff and soil erosion on frozen soils in northeastern Oregon. Journal Soil and Water Conservation 37(6):351-354.

Zuzel, J.F., 'R.R. Allmaras, and R.N. Greenwalt. 1993. Temporal distribution of runoff and soil erosion at a site in northeastern Oregon. Journal of Soil and Water Conservation 48(4):373-378.

Effects of a regional channel stabilization project on suspended sediment yield

F.D. Shields Jr.

Abstract: Under legislation passed in 1984, three federal agencies constructed more than $300 million worth of channel erosion control measures in 16 watersheds in northern Mississippi between 1985 and 2003. Most work was completed between 1985 and 1995 and was confined to six larger watersheds. Flows of water and suspended sediment emanating from these watersheds were measured from 1986 until 1997 and for longer periods for two of these gages and one additional gage. Statistical analyses of flow-adjusted instantaneous measured concentration data failed to detect significant trends at six of the seven gages. A downward trend was noted for a watershed in which eight reservoirs were constructed. These results indicate that watershed-level effects of even large-scale erosion control measures are difficult to detect over 5 to 15 years. Evidently substantial reductions in sediment yields require changes in watershed hydrology that reduce runoff and peak flows or changes in channel bed slope.

Key words: Conservation Effects Assessment Project (CEAP)—channel incision—erosion control—sediment concentration—sediment yield—watershed

Society currently directs significant resources toward goals of watershed and stream channel management. Endeavors such as stream habitat restoration, soil conservation, water quality management, and channel erosion control require reductions in sediment yield. Despite the emphasis on in-field and edge-of-field conservation measures, most sediment leaving agricultural watersheds originates in channel boundaries (Simon and Rinaldi 2006). Although a wide range of sediment and erosion control strategies and structures are in use and design criteria are available in textbooks and handbooks, technology for assessing the effectiveness of these measures is lacking. A major objective of an ongoing national program, the Conservation Effects Assessment Project, is to measure the effects of conservation practices at the watershed scale. A previous federal program, the Demonstration Erosion Control (DEC) project, has yielded data that may be helpful in this effort, particularly in areas plagued by channel incision such as portions of the Mississippi River Valley with loessial soils (Simon and Rinaldi 2000).

The DEC project was focused on 16 watersheds in northern Mississippi (figure 1). Since the initiation of large-scale European settlement in the early 1830s, these watersheds have been plagued with elevated levels of erosion and downstream sediment deposition. Highly erodible soils, high levels of rainfall (ca. 1,500 mm y^{-1} [59 in yr^{-1}]) and poor land management have combined to produce sediment yields that are about 1,000 t km^{-2} (3,000 tn mi^{-2}) (for watersheds with areas on the order of 100 km^2 [40 mi^2]), which is twice the national average for watersheds of this size (Shields et al. 1995). Initial efforts to cultivate hillslopes led to accelerated valley sedimentation (up to 2 m [7 ft]), plugging channels (i.e., almost completely filling some reaches), and prompting subsequent efforts to clear and channelize entire stream networks (Watson et al. 1997).

F. Douglas Shields Jr. is a research hydraulic engineer at the National Sediment Laboratory, USDA Agricultural Research Service, Oxford, Mississippi.