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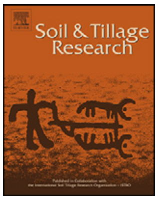

Effects of burn/low-till on erosion and soil quality

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ABSTRACT

Burn/low-till management of winter wheat (*Triticum aestivum*) is being practiced by some growers in the higher rainfall areas of the Pacific Northwestern Winter Wheat Region of the US. Residue burning eliminates the numerous seedbed tillage operations that are normally required to reduce residues and control weeds and diseases in continuous winter wheat production. The detrimental effects of burn and till systems on soil erosion are well documented. However, there is little or no data on the effects of burning with no-till or low-till annual cropping on either erosion or soil quality. A 3-year field study comparing winter season erosion resulting from burn/low-till (BLT) seeded winter wheat following winter wheat and conventionally managed (CM) winter wheat following various crops was completed in 1997. Results indicate soil loss from the BLT fields was not significantly different from that of the CM fields with various crops preceding winter wheat. For the BLT fields, soil loss was as closely related to soil disturbance (number of tillage operations) as to the amount of surface residue. When residue and crop cover did not differ with the number of tillage operations, an increased number of tillage operations after burning loosened the soil and resulted in greater soil loss. No adverse effects on soil loss or soil quality from using the BLT with one or two-pass seeding of winter wheat following winter wheat were found in this study. The results have implications for harvesting wheat stubble as a source of biomass, or as an alternative technique for initiating conversion from a conventional tillage to a no-till seeding system, without high initial investment in new seeding equipment.

1. Introduction

Burn/low-till (BLT) for growing winter wheat following winter wheat has been practiced since the mid-1980's by some grain producers in the annual cropping areas of the Northwestern Wheat and Range Region (NWRR) (Austin, 1981) of the Pacific Northwest. Crop residues are burned after harvest. Winter wheat is then seeded with conventional drills after injecting fertilizer, or is direct seeded with a one-pass fertilize-seed operation. The burning eliminates seedbed tillage operations that are normally required to reduce residues. No-tillage management systems require specialized machinery for seeding into heavy residues. BLT enables producers to use existing machinery to plant winter wheat with a minimum of soil disturbance. This practice, however, often leaves less surface cover than Alternative Conservation Systems (ACS) established to meet requirements of the 1985 and 1990 Food Security Acts (FSA).

There is documentation that burning grass and forest residue reduces disease and insect infestations (Daubenmire, 1968; Iwanami, 1973). However, the effect of burning cereal residues on disease and weed pests appears to be variable (Hardison, 1976). Since high temperatures are not uniform over the soil surface during a burn, there is incomplete destruction of weed seeds and organisms (Rasmussen et al., 1986). With tillage systems, repeated burning followed by tillage decreases soil organic matter, microbial activity, and produces undesirable changes in soil physical properties (Unger et al., 1973; Dormaar et al., 1979; Biederbeck et al., 1980; Rasmussen et al., 1980). The effects of residue burning followed by one or two-pass fertilize-seed management on erosion and soil quality had not been studied prior to this project.

Soil quality has been defined as 'the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health' (Doran and Parkin, 1994). Soil quality encompasses not only crop productivity and environmental protection, but also food safety, and animal and human health. Soil functions as a major producer of food, an environmental filter to clean air and water,

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and recycler of nutrients. Soil quality is the end effect of soil degrading and beneficial processes acting on the soil and is not controlled or determined by any single process, for example, by soil erosion. Proper soil management that conserves and enhances soil quality will not only improve crop productivity, but environmental quality as well. Enhancement of soil quality may assist in reducing wind and water erosion by providing better aggregation and aggregates more resistant to breakdown (Karlen et al., 1994; Wienhold et al., 2004). Changes in soil quality parameters as management changes are imposed may indicate the potential beneficial or degrading effects of a given management practice. Soil quality is assessed by evaluating physical, chemical, and biological parameters (Doran, 1980; Parr et al., 1992). Conventional tillage practices decrease the organic matter content (Anderson and Coleman, 1985; Frye and Blevins, 1989; Lindstrom et al., 1994), and potentially mineralizable carbon and nitrogen (Wood and Edwards, 1992). In low organic matter soils, increasing the percentage of surface organic matter content through reduced tillage can have positive effects on the soil physical condition (Arshad et al., 1990; Angers et al., 1993b). Increased aggregation can lead to improved soil structure and decreased erosion potential (Lindstrom et al., 1994). Monitoring soil quality changes due to management differences allows the opportunity to evaluate the effects of tillage and residue management on agricultural lands.

Soil microorganisms are largely responsible for processes, such as nutrient cycling, nitrogen fixation, and aggregate formation. These microorganisms are intimately involved in the healthy functioning of the soil, and are sensitive to changes in their environment. Microorganisms are excellent early indicators of changes in soil quality. To monitor the soil community several assays can be used. Microbial biomass is an estimate of microorganisms in the soil. The soil microbial biomass accounts for only 1–3% of soil organic C, but it is that portion through which organic residues pass to form organic matter (Jenkinson, 1988). Often a positive correlation between microbial biomass and organic matter exists (Janzen et al., 1992; Angers et al., 1993a; Houot and Chaussod, 1995; Jordan et al., 1995). Furthermore, microbial biomass was found to change before detectable changes in total C occurred (Powlson and Brookes, 1987; Jordan et al., 1995). The dehydrogenase assay is used to estimate overall microbial activity in the soil. β-Glucosidase, a key enzyme in energy transformations, breaks down long carbon chains and has been correlated with organic C content in surface soils (Angers et al., 1993a). Microbial respiration is indicative of microbial community and the amount of carbon in the soil easily available to soil microorganisms. Fatty acid methyl ester (FAME) analysis provides a fingerprint of the biological community. Fatty acid profile analyses of various soils exhibit unique characteristic profiles and can be used to differentiate soils of dissimilar soil types, management, or locations (Ibekwe and Kennedy, 1999).

This 3-year study, initiated in the fall of 1994, was conducted by the Agricultural Research Service (ARS) in cooperation with the Natural Resources Conservation Service (NRCS) and Washington State University (WSU) Cooperative Extension. The study was part of an NRCS field trial of BLT in Walla Walla, Columbia, and Whitman counties in Washington. Producers who elected to enroll in the field trial could use BLT, but were committed to cooperate in the research study if their fields were selected. The study objectives were to compare the effects on soil erosion and soil quality of the BLT management system for winter wheat following winter wheat with those of conventional tillage-based management systems with winter wheat following various crops or summer fallow (CM) that met NRCS Alternative Conservation Systems (ACS) requirements.

2. Methods

2.1. Runoff plots

Treatments were established in September 1994 and 1995 on three fields in Columbia County, and in September 1994, 1995, and 1996 at the Palouse Conservation Field Station (PCFS) near Pullman in Whitman County, Washington. The purpose was to compare soil loss from BLT and CM winter wheat after winter wheat. The plots in Columbia County were laid out in a side-by-side comparison. Before an entire field was burned in September, an area 15.2 m × 45.7 m was disked once. The field was burned leaving the disked area unburned. The entire field was then cultivated once with a heavy-shank fertilizer injector. The field was seeded across the slope with conventional double disk drills in early October. On each of the three fields two bordered runoff plots were installed, one on the tilled area and the other on the adjacent BLT area. A set of more closely monitored runoff plots with the same treatments was established at the PCFS. In addition to the winter wheat after winter wheat treatments, in 1995–1996 and 1996–1997, an adjacent area on the same slope at the PCFS was seeded to winter wheat following summer fallow as part of a crop canopy study. The summer fallow was chiseled in the fall after harvest, cultivated the following spring, rod weeded occasionally during the summer, and seeded in the fall. While not part of the BLT study, these treatments provided useful information as to potential soil loss rates under a more aggressive tillage system. Runoff and soil loss for both locations were determined by collecting water and sediment in tanks that were sampled and emptied after each runoff event (McCool et al., 1995). Percent surface cover and random roughness estimates were made after the plots were established in the fall (after seeding winter wheat) and again in early spring before substantial growth. Residue and canopy covers were estimated by the evenly spaced 15.2 m 100-point line-transect method, and random roughness by comparison with photos (McCool et al., 1996). All plots in Columbia County were 1.8 m wide and 22.3 m long on slopes from 15% to 26% steepness. Plots at the PCFS were 3.6 m wide and 22.3 m long on slopes of 22–24% steepness. The plots in Columbia County were not replicated whereas there were two replications of each treatment at the PCFS. Data from the runoff plots are presented in Table 1 and will be discussed later.

Select biological, chemical and physical properties were monitored on soils of the runoff plots. Three replicate samples for soil quality analysis were collected from the Columbia County and two replicates from each of the PCFS runoff plots at 0–5, 5–10, and 10–20 cm depths. Biological analyses consisted of enzyme activity, microbial biomass and respiration, and fatty acid methyl ester extractions to explore the soil community structure differences between the treatments.

2.2. Field study

In 1994 and 1995, the BLT field trial was restricted to those parts of Walla Walla, Columbia, and Whitman counties with greater than 457 mm annual precipitation. In the fall of 1996, the BLT field trial was extended to include areas of those counties where long-term winter wheat yields averaged more than 4030 kg ha^{-1}. Fields were identified to verify that the treatments on the runoff plots were representative of practices in the region, and to provide data from a broader geographic area than represented by the runoff plots. Conventionally managed and seeded (CM) fields near BLT fields were selected for comparison of the practices. The CM fields were selected based on their similarity of soils, aspect, and topography as well as on their proximity with respect to the BLT fields, and included a variety of crops and conditions prior to

Table 1
Averages of runoff and soil loss from BLT and CM treatments of the runoff plots in Columbia County and at the PCFS for the 1994–1995, 1995–1996 and 1996–1997 erosion seasons[a]

	Runoff (mm)		Soil loss (kg ha^{-1})	
	BLT	CM	BLT	CM
1994–95				
PCFS Rep 1	2.3	0.5	9.2	0.8
PCFS Rep 2	2.0	1.3	17.6	3.5
Columbia County Rep 1	0.0	0.0	0.0	0.0
Columbia County Rep 2	2.5	0.3	64.2	4.1
Columbia County Rep 3	1.3	0.8	15.5	4.9
Average	1.6	0.6	21.3	2.7
1995–1996				
PCFS Rep 1	4.8	3.8	0	90
PCFS Rep 2	1.5	7.4	134	157
Columbia County Rep 1	data not included because of rodents burrowing under borders			
Columbia County Rep 2	9.7	5.3	358	22
Columbia County Rep 3	0.0	0.5	0	0
Average	4.0	4.3	123	67
1996–1997				
PCFS Rep 1	4.8	11.4	0	0
PCFS Rep 2	9.1	11.9	0	0
	Columbia county—no plot sites were available			
Average	7.0	11.7	0	0

[a] No significant differences in average runoff or soil loss were found between BLT and CM treatments within any given sampling year; BLT, burn/low-till winter wheat following winter wheat; CM, conventionally managed winter wheat following winter wheat; PCFS, Palouse Conservation Field Station.

Table 3
Percent of conventionally managed (CM) winter wheat fields that were previously in small grain (winter wheat, spring wheat, and barley) and canola, annual legumes (pea, lentil, and garbanzo beans) and summer fallow (McCool et al., 2001)

	Small grains, canola (%)	Annual legumes (%)	Summer fallow (%)
1994–1995	40	45	15
1995–1996	30	55	15
1996–1997	11	78	11
Average	27	59	14
Typical mix of crops prior to winter wheat for the area	35	50	15

seeding. Residue cover was not considered in CM field selection. On each BLT or CM field, we sought a uniform up and downhill strip or area that was not affected by upslope tillage marks or runoff from an adjacent area. If no such area was located, the field was not selected. It was not possible to find a comparison CM field for every BLT field, although in some cases we had two comparison fields for one BLT field. Those BLT fields with no comparison CM field were retained in the study in order to provide a larger population of BLT fields for statistical analysis. Data from the field study are presented in Tables 2–4 and will be discussed later.

No field observations were made in the fall of 1994, but in the falls of both 1995 and 1996, all fields were evaluated for surface cover, crop canopy cover, and random roughness. In the spring of 1995–1997, the fields selected in the previous falls were evaluated for soil loss, surface cover, canopy cover, and random roughness. Soil loss in a 15.2 m width was measured at the bottom of the slope (BOS) above any deposition or concentrated flow using the voided rill method (a cross-sectional area of rills in a given width of hill slope converted to soil loss in t ha^{-1} using surface bulk density). Residue and canopy covers were estimated by the evenly spaced 100-point line-transect method, and random roughness by comparison with photos (McCool et al., 1996). Record sheets were sent to all growers participating in the field trial. When returned, these sheets provided detailed information on number and type of tillage operations. These assembled data sets enabled comparison of erosion estimates, topographic characteristics, surface cover, canopy cover, random roughness, and tillage operations. Detailed field data can be found in Appendix A of McCool et al. (2001).

All treatment means were tested for significant differences using a standard one tailed '*t*' test at an alpha level of 0.05. The null hypothesis was H_0: $\mu_1 = \mu_2$, i.e., all compared means were assumed to be from the same parent population. It should be emphasized that acceptance of the null hypothesis does not mean the two means under consideration are necessarily the same; it merely indicates there is not enough evidence to state they are from different populations. While rejection of the null hypothesis means there is at least a 95% chance the means are "significantly" different (given our selected alpha level of 0.05), this implies there is still as much as a 5% chance they are the same.

In the fall of 1996, below-ground portions of the stems were collected from one field in each of three precipitation zones receiving mean annual precipitation of 305–356, 406–457, and 508–610 mm, respectively. Four replicate samples were collected from the bottom, middle, and top slope positions of each field. Two of the fields were in conventional tillage-based management, but were not part of the erosion study and one was in long-term BLT with one-pass seeding and was part of the soil quality study.

Fields for soil quality analysis were identified in Walla Walla County and sampled in the spring of 1996 and 1997 and the fall of 1996. Two fields in long-term BLT management were identified as well as two adjacent CM fields for comparison. One field had been in continuous winter wheat BLT one-pass fertilize-seed management since 1985. The comparison CM field

Table 2
Estimated length steepness factor (LS), number of tillage operations, random roughness, surface cover, and bottom-of-slope soil loss from the BLT and comparison CM fields for the 1994–95, 1995-96 and 1996-97 erosion seasons[a]

Season	Management	Number of fields	LS	Number of tillage operations	Random roughness (cm)	Surface cover (%)	Soil loss (t ha^{-1})
1994–1995	BLT	20	3.05a	1.9a	1.48a	11a	5.3a
	CM	20	2.92a	3.4b	1.59a	25b	4.6a
1995–1996	BLT	24	2.50a	1.8a	0.95a	9a	18.5a
	CM	27	2.48a	2.9b	0.80a	15b	18.2a
1996–1997	BLT	26	2.28a	1.7a	0.94a	8a	19.6a
	CM	27	2.30a	3.0b	0.96a	16b	19.7a

[a] Different letter indicates significance at $p = 0.05$ within a column and a year; BLT, burn/low-till winter wheat following winter wheat; CM, conventionally managed winter wheat following various crops and summer fallow.

Table 4
The number of fields, length steepness factor (LS), random roughness, surface cover, and the average bottom-of-slope soil loss, for one through three tillage operations on the BLT fields in 1994–1995 and 1995–1996, and for one and two tillage operations on the BLT fields in 1996–1997[a]

Year	Tillage operations	Number of fields	LS	Random roughness (cm)	Surface cover (%)	Soil loss (t ha^{-1})
1994–1995	1	15	4.41a	1.03a	10a	5.2a
	2	16	2.82b	1.44a	9a	4.8a
	3	6	2.93b	1.35a	10a	17.0b
	Total/average	37	3.48	1.26	10	6.9
1995–1996	1	16	3.04a	0.84a	8ab	34.4a
	2	11	2.18b	1.12a	6a	15.2a
	3	7	2.75ab	1.03a	12b	15.6a
	Total/average	34	2.70	0.97	8	24.3
1996–1997	1	20	2.52a	0.90a	9a	13.4a
	2	50	2.41a	1.45b	6a	17.7a
	Total/average	70	2.44	1.29	7	16.4

[a] Different letter indicates significance at $p = 0.05$ within a column and within a year.

had been in a garbanzo bean/winter wheat/spring grain rotation since 1990. At the second paired field set, one field had been in continuous winter wheat BLT with one-pass fertilize-seed management since 1984 and the comparison field in the CM system in a winter wheat/pea rotation since 1986. Because of rotational sequence or very low slope, these fields were not a part of the paired-field erosion study. Soil quality data obtained from fields included microbial biomass (Anderson and Domsch, 1985), dehydrogenase activity, β-Glucosidase activity (Tabatabai, 1994), microbial respiration (Zibliske, 1994), organic carbon (OC) (Walkley and Black, 1934), water-stable aggregates (Kempe and Rosenau, 1986), and FAME (Ibekwe and Kennedy, 1999). β-Glucosidase activity and water-stable aggregates data were not collected for the PCFS plots. Biological data were analyzed using the proc GLM procedure except for FAME, which was analyzed using the covariance matrix of principal component analysis (SAS, 1999).

3. Results

3.1. Season and location variation

Erosion was highly variable across the region during the 1994–1995 season. Some areas, particularly west and southwest of Spokane, WA, received rain while the soil was bare and thawing and suffered extremely high erosion rates, even on chiseled stubble. Areas where BLT was tested (i.e., Columbia, Walla Walla, and Whitman counties) experienced less severe erosion.

There were extreme weather conditions during the 1995–1996 erosion season. Precipitation was 150% of normal over much of the region and flooding occurred in some streams in Walla Walla, Columbia, and Whitman counties. In November, areas where the BLT experiments were located received high intensity rains on saturated soils causing severe erosion. In late January and early February, a week of heavy snowfall followed by a week of intense cold preceded a rapid increase in temperature and rainfall on soil that was bare and thawing. This sequence caused flooding and considerable erosion.

Above normal precipitation occurred throughout the entire region during the fall of 1996. There were greater than normal snow accumulations during December, and warm weather with rain occurred while the snow was on the ground, causing much runoff, but little erosion. Many of the erosive events occurred in February and March 1997 on frozen or thawing soils. These conditions were widespread throughout the BLT experimental areas.

3.2. Runoff plots

3.2.1. 1994–1995

Very little runoff and soil loss occurred on the runoff plots in the 1994–1995 season at the PCFS or in Columbia County. Neither runoff nor erosion from the burn/low-till (BLT) plots were statistically different from the conventionally managed (CM) plots, and the amounts were extremely small (Table 1).

3.2.2. 1995–1996

Runoff and soil loss from the runoff plots during the 1995–1996 season were similar to 1994–1995 results. Neither runoff nor erosion on the BLT plots were statistically different from the CM plots from all locations (Table 1).

There was some concern about the low magnitude of these runoff and soil loss values both in 1994–1995 and 1995–1996. However, the relative erosion resistance of both BLT and CM winter wheat after winter wheat can be better understood by considering 1995–1996 data from an adjacent set of winter wheat after summer fallow plots at the PCFS, established to study the effects of crop cover. The study area, on the same hillslope as the BLT study and with same slope length and steepness, summer fallowed with minimal surface cover and seeded up and down the slope, suffered over two hundred mm of runoff and more than 147,950 kg ha^{-1} (147.95 t ha^{-1}) soil loss. This indicates the low runoff and soil loss from both the BLT and CM treatments were not caused by lack of storm events, but were the result of the runoff and erosion resistance of both the BLT and CM winter wheat following winter wheat treatments.

3.2.3. 1996–1997

In the fall of 1996, cooperators in Columbia County experienced severe cheat grass (*Bromus tectorum* L.) infestations on the fields where runoff plots had been established. This is not an uncommon problem with continuous winter wheat production and burning does not control the winter annual grasses that infest fields in continuous wheat production. Because many fields were already burned at the time the cooperators decided to leave the field trial, runoff plots were not established in Columbia County.

Very little runoff and no soil loss occurred on the runoff plots at the PCFS (Table 1). The runoff resulted from a combination of snow on the ground and thawing temperatures with rain. No sediment was measured in the runoff water. In comparison, an adjacent study (second year of previously mentioned crop cover study) on the same soil, aspect, and with similar canopy cover that was fallowed the previous year, suffered over 35,870 kg ha^{-1} (35.87 t ha^{-1}) soil loss.

3.3. Comparison fields

3.3.1. 1994–1995

The field study verified that the treatments imposed on the runoff plots in 1994–1995 were similar to practices of growers in the region. Crop canopy was very low at the end of winter on growers' fields as well as on the runoff plots because of lack of precipitation in the early fall. The average surface cover on the runoff plots was 13% for the BLT and 38% for the CM treatments. The average surface cover on the study fields was 11% for the 20 BLT and 25% for the 20 CM treatments. There were more tillage operations on the CM fields compared with the BLT fields (Table 2). However, there was no statistical difference in BOS soil loss between the treatments.

The mix of crop treatments prior to winter wheat for the CM fields was examined to determine if it was typical of the higher precipitation zone of southeastern Washington. Arranged in order of increasing susceptibility to soil erosion when winter wheat is seeded, prior crop treatments were grouped into (1) small grains and canola, (2) legumes (peas, lentils or garbanzo beans), and (3) summer fallow. A typical mix of crops prior to winter wheat is estimated to be small grains and canola 35%, annual legumes 50%, and summer fallow 15%. The percent of these prior crops in the CM fields in 1994–1995 was 40%, 45%, and 15%, respectively (Table 3).

3.3.2. 1995–1996

The field study again verified that the surface cover on the runoff plots was within the range of typical percent surface cover after planting, but was at the higher end of that range. Average surface cover on the runoff plots was 16% for the BLT treatments and 28% for the CM treatments. Average surface cover on the study fields was 9% for the 24 BLT and 15% for the 27 CM treatments. Crop canopy cover averaged 5% for the BLT and 7% for the CM fields. There was more tillage and a greater amount of surface cover on the CM fields as compared with the BLT fields (Table 2). The BOS soil loss was higher than in 1994–1995, and was not statistically different for both treatments. The data on prior crop treatments on the CM fields indicate 30% of the fields were in small grains and canola, 55% were in annual legumes, and 15% were in summer fallow (Table 3).

3.3.3. 1996–1997

Surface cover on the runoff plots was within the range of that measured in the field study. Average surface cover on the runoff plots was 10% for the BLT treatment and 15% for the CM treatment. Comparable values for the 26 BLT and 27 CM fields were 8% and 16%, respectively. Similar to the 1994–1995 season, crop canopy was very low at the end of winter on growers' fields as well as on the runoff plots because of low precipitation in the early fall. There was more tillage and a greater amount of surface cover on the CM as compared with BLT fields (Table 2). The BOS soil loss was not statistically different for both treatments. The data on prior crop treatments on the CM fields indicate only 11% were in small grains and canola, 78% were in annual legumes, and 11% were in summer fallow (Table 3).

3.3.4. All years combined

There was no difference in the LS between the BLT and CM in all years (Table 2), indicating that the CM fields selected had similar slope length and steepness to the BLT fields. There were more tillage operations, but also more surface cover on CM than BLT in all 3 years of the study. Based on average values, there were no differences in BOS soil loss between BLT and CM for all years of the study. The mix of crops prior to winter wheat on the CM fields varied from year to year (Table 3), and from the typical mix that has been used in the higher precipitation area of southeastern Washington. On the average, during the 3-year study, comparing the crops prior to winter wheat on the CM fields with typical crops prior to winter wheat in the study area, there were fewer small grains and canola (27% vs. 35%), more annual legumes (59% vs. 50%), and near average summer fallow (14% vs. 15%). Soil loss data from the 3-year field study show 48% of the BLT fields and 54% of the CM fields had less than 11.2 t ha^{-1} BOS soil loss. With an average BOS soil loss of 15.9 and 14.3 t ha^{-1} for the BLT and CM fields, respectively, the data distribution was highly skewed.

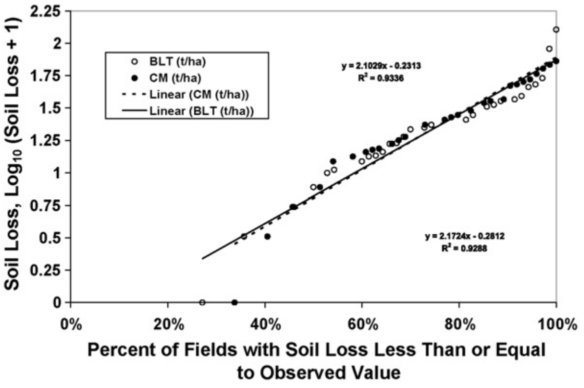

Fig. 1. Soil loss data summary from all comparison fields during winter seasons of the 3-year (1994–1995 through 1996–1997) BLT study. Transformed soil loss = $\log_{10}$((soil loss in t/ha) + 1).

Data were then log transformed for additional statistical analysis. Linear regression of the transformed data resulted in a slope of 2.1029 and an intercept of −0.2313 for the BLT data and a slope of 2.172 and an intercept of −0.2812 for the CM data (Fig. 1). The data were fit using the relationship: $Y = a + bX$, where Y equals the log(soil loss + 1), a the Y intercept, b the slope of the fitted line, and X is the percent of fields with BOS soil loss less than or equal to Y. Coefficients of determination were 0.93 for both BLT and CM. A t-test ($p = 0.05$) of the log-transformed data indicated that the slope and intercept for each management practice are not significantly different.

The CM fields had a wide range of surface cover. Because of yearly variation and influence of other factors, such as topography, cropping history, random roughness, and green cover, it was not possible to fit a reliable relationship between surface cover and BOS soil loss. However, a plotting of the BOS soil loss vs. surface cover indicates that on no field with residue of 30% or greater was BOS soil loss more than 11.2 t ha^{-1} (Fig. 2). Below 20% surface cover, soil loss varied greatly. Sixty-one percent of the 72 CM fields had less than 20% surface cover and mean BOS soil loss of

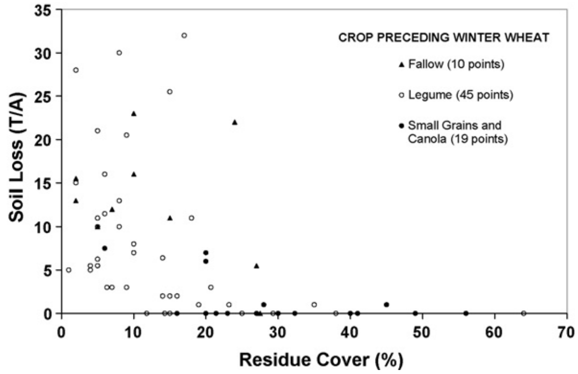

Fig. 2. Soil loss vs. percent surface cover for the CM fields in the comparison field portion of the 3-year (1994–1995 through 1996–1997) BLT study.

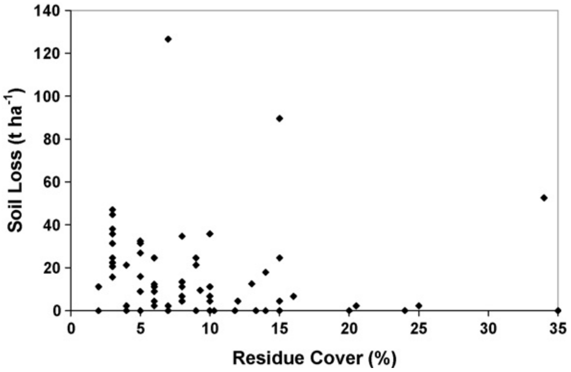

Fig. 3. Soil loss vs. percent surface cover for the BLT fields in the comparison field portion of the 3-year (1994–1995 through 1996–1997) BLT study.

22.0 t ha^{-1}. Thirty-four percent of the 72 CM fields had less than 10% surface cover and mean BOS soil loss of 26.4 t ha^{-1}.

The BLT fields had a smaller range of surface cover compared with the CM fields, but the same factors that influenced the range on the CM fields also prevented fitting a reliable relationship between soil loss and surface cover. Ninety-three percent of the BLT fields had less than 20% surface cover and mean BOS soil loss of 16.4 t ha^{-1} (Fig. 3). Seventy percent of the BLT fields had less than 10% surface cover and mean BOS soil loss of 17.5 t ha^{-1}. Soil loss for the BLT fields was less related to amount of surface cover than to the amount of soil disturbance by tillage, as will be discussed later.

3.4. *All BLT fields*

3.4.1. *1994–1995*

Estimated BOS soil loss was higher (6.9 t ha^{-1} vs. 5.4 t ha^{-1}) for the entire population of BLT fields as compared with those with comparison CM fields. Soil loss estimates were not correlated with surface cover, the number of tillage operations, the length-steepness factor (LS), or random roughness on the BLT fields. Of the BLT fields evaluated, 41% (15) had one tillage operation, 43% (16) had two, and 16% (6) had three tillage operations. There were significant differences in LS and random roughness, but no difference in surface cover with the number of tillage operations (Table 4). The average BOS soil loss for a one-pass seeding was 5.2 t ha^{-1} and for fields with two tillage operations was 4.7 t ha^{-1}. However, when three tillage operations were performed, the average BOS soil loss was significantly higher, 17.0 t ha^{-1}.

3.4.2. *1995–1996*

The BOS soil loss was higher (24.2 t ha^{-1} vs. 18.6 t ha^{-1}) for the entire population of BLT fields as compared with those with comparison CM fields. Estimated soil loss was not correlated with the number of tillage operations, the length-steepness factor, random roughness, or surface cover. The average BOS soil loss for a one-pass seeding was 34.3 t ha^{-1}, for fields with two tillage operations BOS soil loss was estimated at 15.2 t ha^{-1}, and when three tillage operations were performed, the average BOS soil loss was 15.7 t ha^{-1} (Table 4). These results of the number of tillage operations on both soil erosion and residue cover represent a trend that contrasts with the previous year's results. Nothing in the field data explains these differences. Average surface cover, though not statistically different, was 8% and 12% for the one- and three-tillage operation fields, respectively, and slightly lower (6%) for the two-tillage operation fields.

3.4.3. *1996–1997*

The BOS soil loss was lower (16.4 t ha^{-1} vs. 19.7 t ha^{-1}) for the entire population of BLT fields as compared with those with comparison CM fields. There were no differences in LS and surface cover with the number of tillage operations, but a larger random roughness for two tillage operations (Table 4). The average BOS soil loss for one-pass seeding on the BLT fields was 13.4 t ha^{-1}; for fields with two tillage operations, BOS soil loss was estimated at 17.7 t ha^{-1}. The small difference was not statistically significant.

3.5. *Soil quality/soil biology*

3.5.1. *Runoff plots*

There was little change in soil quality parameters between the BLT and CM treatments at the PCFS or in the plots in Columbia County over the sampling years (Table 5). The data were variable, and a longer study period would be needed to determine if significant treatment differences arose. There were no differences between the BLT and CM treatments in microbial biomass, microbial respiration, and dehydrogenase activity. These results indicated that either the two treatments were similar or they were in a transitional period and the soil ecology had not reached equilibrium.

3.5.2. *Long-term fields*

The long-term BLT fields with one-pass seeding and comparison CM fields were analyzed for soil quality parameters (Table 6). The BLT fields had been in continuous winter wheat cropping for over 10 years and burned every fall prior to seeding. One CM field was in a winter wheat–pea rotation using a fall moldboard plow after wheat and a chisel plow after pea harvest. The other CM field was in a 3-year rotation where winter wheat followed a legume, either peas or garbanzo beans, followed by spring barley. A chisel plow was used as the primary tillage operation after winter wheat. For soil quality measurements to be consistent, we sampled only in those sites in which wheat was growing.

Microbial biomass in the top 5 cm of BLT fields with one-pass seeding was equal to or greater than the CM fields. The difference was only statistically significant in May 1996 (Table 6). Dehydrogenase activity also tended to be greater in the BLT fields with one-pass seeding, but was only statistically greater than that in the CM fields in October 1996. β-Glucosidase activity was highly variable and did not show treatment differences. Microbial respiration was higher in the top 5 cm of BLT soils in May 1996, but was not different between the two treatments at other

Table 5
Soil microbial biomass, dehydrogenase activity, microbial respiration, and organic carbon measured in the top 5 cm of soil from BLT and CM of the runoff plots in Columbia County and at the PCFS in September 1994, February and May 1995[a]

Location	Treatment	Microbial biomass (μg CO_2–C cm^{-3})	Dehydrogenase activity (μg triphenyl formazan cm^{-3} h^{-1})	Microbial respiration (μg C as CO_2 cm^{-3})	Organic carbon (kg C m^{-3})
PCFS	BLT	90.3 + 67.5	1.81 + 0.43	5.38 + 2.66	25.5 + 2.18
PCFS	CM	96.1 + 98.9	1.57 + 0.36	5.27 + 3.08	26.6 + 2.84
Columbia County	BLT	43.6 + 16.9	1.60 + 0.59	3.78 + 1.80	16.9 + 4.03
Columbia County	CM	56.9 + 14.8	2.02 + 0.24	5.76 + 1.30	17.4 + 1.77

[a] Data were analyzed using the proc GLM procedure (SAS, 1999). No significant differences were found among treatments at any sampling date.

Table 6

Soil microbial biomass, dehydrogenase activity, β-Glucosidase activity, microbial respiration, organic matter, and water-stable aggregates measured in the top 5 cm of soil from BLT and CM field studies[a]

Sampling date	Treatment	Microbial biomass (μg CO_2 C cm^{-3})	Dehydrog-enase activity (μg TPF cm^{-3} h^{-1})	β-Glucosidase activity (μg *p*-nitro-phenol cm^{-3} h^{-1})	Microbial respiration (μg C as CO_2 cm^{-3})	Organic carbon (kg C m^{-3})	Water-stable aggregates (%)
May 1996	BLT	65.6a	2.68a	93.5a	5.07a	21.2a	48.6a
	CM	52.3b	1.54a	86.4a	2.90b	16.4b	22.2b
October 1996	BLT	63.5a	9.11a	114.8a	2.35a	21.2a	nd
	CM	65.7a	3.75b	128.3a	2.98a	14.8b	nd
March 1997	BLT	227.3a	4.77a	42.6a	3.36a	21.7a	50.4b
	CM	189.3a	4.02a	56.1a	3.15a	14.1b	57.6a

nd, Not determined.

[a] Data were analyzed using the proc GLM procedure (SAS, 1999). Values followed by the same letter are not statistically different from each other within each location and sampling time.

sampling dates. The higher dehydrogenase and microbial respiration in the BLT treatments indicate that the BLT soil is more biologically active and that a portion of the carbon added from residue is in an available form. Organic carbon was significantly greater in the top 5 cm of BLT soil compared with the CM soil for all sampling dates, even after 0.1% was calculated from that left after burning a mass of residue and subtracted to account for the possible contribution of ash to organic carbon levels in BLT soil. The difference in OC between BLT and CM soils is most likely due to reduced soil disturbance achieved with one-pass seeding. Aggregate stability was greater in the top 5 cm in the BLT fields with one-pass seeding in 1996, while in 1997, aggregate stability was greater in the top 5 cm of CM fields.

Fatty acid methyl ester profiles showed the greatest differences between BLT and CM soil communities (0–5 cm), in May 1997 (Fig. 4). This result agrees with the other soil quality data that indicated differences between the two treatments in the surface layer of soil, but not over the entire plow depth (0–20 cm, data not shown). It is possible that more time under BLT management is needed before differences in all depths can be detected; however, another possibility is that BLT and CM are different only in the distribution of organic carbon, microbial activity, and biological communities. Our results indicate that the two management practices resulted in changes in the soil biology, most likely due to the unique soil environments created by each practice. In our short-term studies, soil quality parameters did not or could not distinguish between them.

Comparisons of FAME profiles indicate the treatments have resulted in distinct microbial communities. The soil communities are different, but the data do not indicate whether one practice is agronomically better or worse than the other in productivity or environmental function. Other parameters (microbial biomass, dehydrogenase activity, microbial respiration, OC) indicate the two treatments are comparable in terms of maintaining soil quality. Although not always significant, BLT soils compared with CM soils tended to have greater dehydrogenase activity, microbial respiration, and microbial biomass, indicating that the OC in the top 5 cm of BLT soils is more active biologically, and is not inactive ash. Higher OC content that is biologically active is favorable for nutrient cycling and overall soil health. In other studies, soil quality parameters have declined in soils from fields that were burned and tilled for many years, such as in the long-term field burning experiments at the Columbia Basin Agricultural Research Center (Rasmussen et al., 1989).

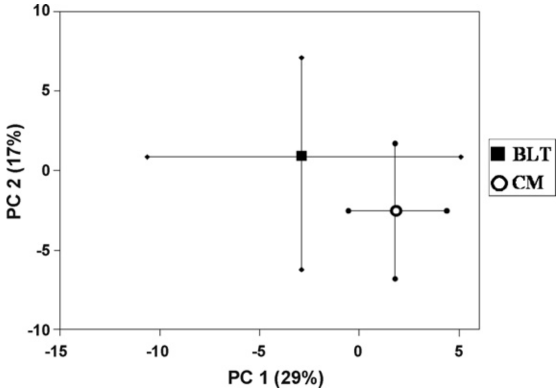

Fig. 4. Principal component score plot of fatty acid methyl ester profiles in March 1997 of the top 5 cm of long-term BLT and CM soils in Columbia County, WA. PC 1, Principal component one scores; PC 2, principal component two scores; percentage of variance explained by that principal component is in parentheses. Symbols indicate means and lines indicate standard error of the mean for each treatment.

Table 7

Below-ground stem weights in three precipitation zones[a]

Precipitation zone (mm)	305–356	406–457	508–610
Weight (kg ha^{-1})	375a	372a	376a

[a] Values followed by the same letter are not statistically different from each other.

3.6. *Other below-ground effects*

3.6.1. *Below-ground stems*

Below-ground stem weight measured in the fall of 1996 was the same from all fields sampled. Three fields in different precipitation zones were sampled at bottom, middle, and top slope positions. There were no differences between the BLT and CM treatments and no difference among the precipitation zones sampled (Table 7). This material, generally located in the upper 5 cm of the soil profile under dryland conditions, can have a major effect on soil erosion. For a 4710 kg ha^{-1} wheat yield and removal of all surface residues, the consideration of this biomass under no-till conditions resulted in predicted erosion less than 75% of the amount predicted without accounting for this biomass (Yoder et al., 1997). For a 4710 kg ha^{-1} wheat yield and removal of all surface residues, when the soil is undisturbed the total below-ground stem biomass is estimated to reduce erosion to about 70% of that when the soil is highly disturbed and the below-ground stems are no longer anchored to surrounding soil.

4. Conclusion

A 3-year runoff plot and field study in the annual cropping regions of Whitman, Walla Walla, and Columbia counties of southeastern Washington State was completed in 1997. The study compared erosion and soil quality resulting from burn/low-till

(BLT) seeded winter wheat following winter wheat with conventionally managed (CM) winter wheat following various crops.

Results from the runoff plot study indicate that soil losses from the BLT and CM winter wheat following winter wheat were equal and were very low (less than 0.34 t ha^{-1}) in any of the 3 years. The high erosion resistance of both treatments is illustrated by comparison with adjacent winter wheat following summer fallow plots having similar vegetative cover where erosion was 35.9 t ha^{-1} or more.

Results from the field study indicate soil loss on the BLT fields was not significantly different from that on the CM fields with various crops preceding winter wheat. For the BLT fields, soil loss was as closely related to soil disturbance (tillage operations) as to surface residue. When residue and crop cover did not differ with the number of tillage operations, an increased number of tillage operations after burning loosened the soil and resulted in greater soil loss. The CM fields had significantly more tillage operations and surface cover, yet statistically the same soil loss as BLT. When surface cover was 30% or greater on these CM fields, soil loss was drastically reduced as compared with lower cover values. Prior crop history on the CM fields indicated there were fewer small grain fields, more legume fields, and a normal number of summer fallow fields as compared with typical long-term conditions for the study area.

Soil microbial parameters (microbial biomass, dehydrogenase activity, microbial respiration, OC) indicate that the BLT and CM treatments are comparable in maintaining short-term soil quality. Fields with a long history of BLT one-pass seeding showed greater organic carbon in the top 5 cm as compared with CM. This indicates that minimizing soil disturbance, even in conjunction with surface-residue removal, can have positive effects on soil quality. Comparisons of FAME profiles indicate that the treatments have resulted in distinct soil communities. The data do not indicate whether one practice is agronomically better or worse than the other in productivity or environmental function.

Below-ground stem material is of sufficient magnitude to influence erosion rates when surface residue is removed and soil disturbance is kept to a minimum, such as BLT with one-pass seeding. At the time of the study, this biomass was not included in the databases for RUSLE and other erosion models.

Use of the BLT practice allows producers to develop no-till management experience and expertise without the purchase of specialized seeding equipment. Producers can then gradually shift into reduced and no-till seeding systems, without residue burning, that will result in less soil erosion and improved water quality.

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