Comparison of Runoff and Soil Erosion from No-till and Inversion Tillage Production Systems

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Abstract

Conservation tillage systems that prevent soil erosion and maintain or increase soil carbon offer long-term benefits for producers in the inland Pacific Northwest (PNW) of the United States. Our objective was to compare conventional tillage and no-till for runoff and soil erosion. Two neighboring drainages in the 13-inch precipitation zone of northeastern Oregon were instrumented to record rainfall, runoff, and erosion over a 4-year period (2001-2004). One drainage was cropped to a winter wheat-fallow rotation and received inversion tillage. The second drainage was cropped in a 4-year no-till rotation: winter wheat-chemical fallow-winter wheat-chickpea. We recorded 13 runoff events from the inversion tillage drainage and 3 from the no-till drainage. Runoff totaled 0.20 inch and erosion 0.19 tons/acre from inversion tillage, versus 0.03 inch and 0.00 tons/acre from no-till. Small, 11-ft^2 runoff collectors placed on the hill slopes measured large amounts of water and soil moving down slope under inversion tillage. The no-till cropping system was very effective in reducing soil and water movement.

Keywords: conservation assessment, crop rotation, direct seeding, erosion, no-till, Pacific Northwest, runoff, small grain production

Introduction

More than 2.2 million acres are planted to winter wheat following fallow each year in the interior Pacific Northwest (PNW) of the United States (Smiley 1992). Soil erosion in this system has been recognized as early as 1909 (McGregor and Greer 1982), with average rates ranging from 1.3 to 22.3 tons/acre/year (Nagle and Ritchie 2004, Zuzel et al. 1982). In most areas of the region this exceeds the USDA soil loss tolerance limits of 1.0 to 5.0 tons/acre/year established for sustained economic productivity (Renard et al. 1997).

No-till leaves the soil undisturbed from harvest to planting. This practice also leaves crop residues on the surface after planting, which promotes infiltration of rain falling during winter months when crop cover is minimal (McCool et al. 1995). Water runoff and soil erosion can be reduced by 40 to 80% by leaving 0.5 to 0.9 tons/acre of crop residue on the surface compared to bare soil (McCool et al. 1995). In a study in northeastern Oregon, Zuzel and Pikul (1993) similarly reported that percent straw cover and soil loss were inversely correlated (r = 0.99).
No-till research in the dryland region of the PNW has been limited to small plot experiments, and the runoff occurred only in conjunction with frozen soil (Khalid and Chen 2003). We found no other reports in the literature in which no-till and its soil conservation effects were investigated at the field scale using drainages or small watersheds in the PNW.

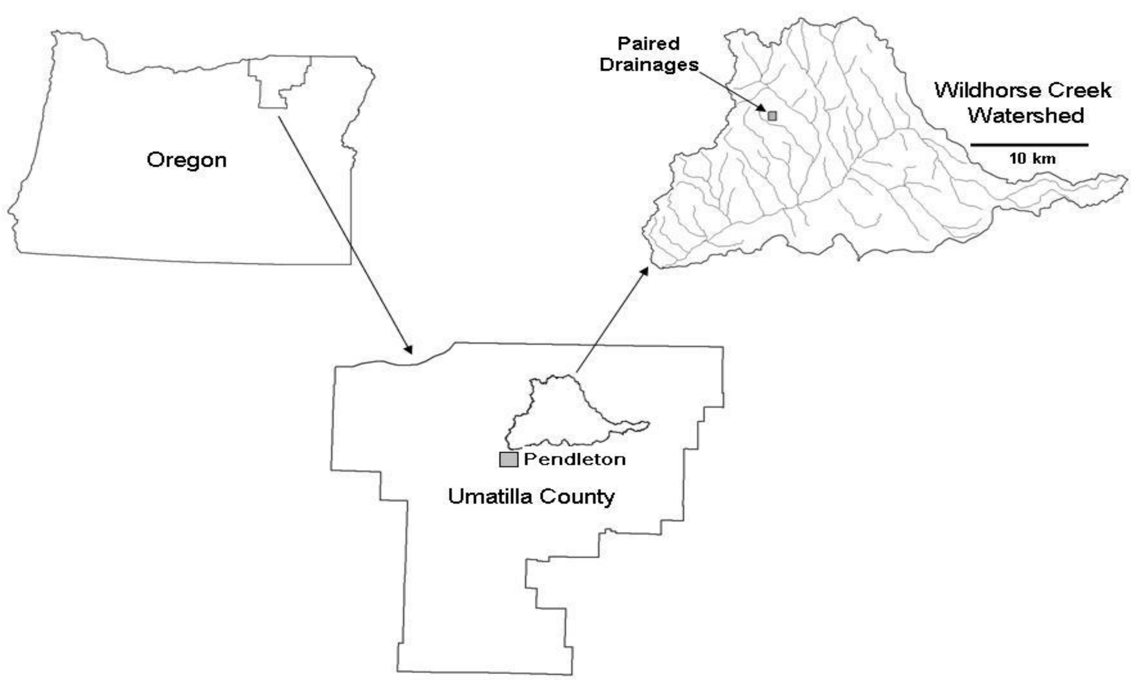
The objectives of this study were to compare runoff and soil erosion from conventional winter wheat-fallow with intensive tillage versus a 4-year cropping system with no tillage. The results presented here emphasize water movement and soil erosion in two drainages typical of the steep rolling terrain found within the inland PNW.

Methods

Site Description

The research began in October 2000 and was conducted for 4 years within two small neighboring ephemeral drainages in the Wildhorse Creek watershed (45°49'0.43"N, 118°38'35.46"W) in northeastern Oregon (Fig. 1). We installed instruments to record runoff and erosion. The soils were well drained Walla Walla silt loams (coarse-silty, mixed, superactive, mesic Typic Haploxerolls). Ground cover, comprised of current year growth and previous year residue, was measured in 2002, 2003, and 2004 using a digital adaptation of the cross-hair frame method developed by Floyd and Anderson (1982).

Figure 1. Location of paired drainage research sites within Wildhorse Creek watershed in northeastern Oregon.



Cultural Practices and Field Plots

One drainage was divided into four plots (Fig. 2) to accommodate all phases of a 4-year rotation (winter wheat-chemical fallow-winter wheat-chickpea) each year (Table 1). The second drainage was not divided, but farmed using conventional inversion tillage in a 2-year, winter wheat-fallow rotation. Fertilizer was applied at time of seeding using a Conserva Pak drill in the no-till drainage, and in May preceding the fall planting of wheat in the inversion tillage drainage.

Figure 2. Plot layout and topography of paired drainages, Wildhorse Creek watershed, northeastern Oregon.

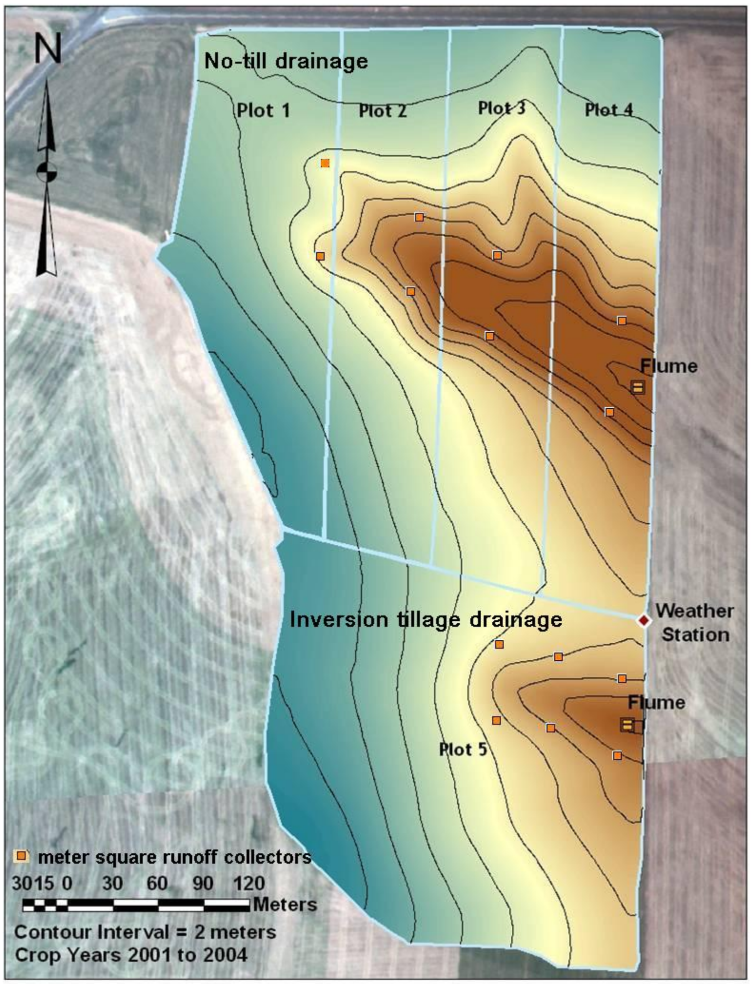


Table 1. Rotation assigned to no-till and inversion tillage drainages for crop years 2001 through 2004, Wildhorse Creek watershed, northeastern Oregon.

	No-till				Inversion-till
Crop-year	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
2001	Ch[†]	CF	SW	WW	F
2002	WW	WW	CF	Ch	WW
2003	CF	Ch	WW	WW	F
2004	WW	WW	Ch	CF	WW

[†]Ch = chickpeas; CF = chemical fallow; F = fallow (inversion tillage); SW = spring wheat; WW = winter wheat.

Monitoring and Sampling Procedures

A meteorological station located on the ridge between the drainages recorded precipitation, air temperature, soil temperature at 1-inch and 2-inch depths, wind speed and direction, solar radiation, and relative humidity (Oviatt and Wilkins 2002).

Runoff was measured at the bottom of each drainage with 9-inch Parshall flumes (Fig. 2). Flow stage was recorded using ultrasonic distance sensors, and flow rate was calculated using a standard rating curve (Oratech Controls Inc. 2001). Runoff samples were collected using flow activated, commercial storm water samplers using a liquid level switch at a stage of 0.5 inch or greater. Samples of 0.1 gal were collected every 40 minutes, for up to 8 hours of continuous runoff. Samples were analyzed for suspended sediment concentrations (Glysson and Grays 2002).

In addition to measuring runoff and erosion at the drainage bottoms, during crop years 2003 and 2004 runoff and suspended sediments were collected in plastic containers connected to 11-ft^2 steel frames. Six to eight frames were placed on back-slope positions in each drainage. The containers were emptied periodically to determine total water and suspended sediment. Collection times from these hill-slope runoff collectors did not correspond to runoff events recorded at the drainage scale, but rather were after multiple events.
Each of the plots was harvested using a Case IH 1470 rotary combine equipped with a 25-ft header. Grain weights were determined using certified truck scales at time of delivery to the local elevator.

Experimental Design and Statistical Procedures

This study was designed as a field scale, 8-year, side-by-side, unreplicated comparison of two tillage types in adjoining headwater drainages. The experimental units are the drainages. The results reported here are from the first complete 4-year rotation. One-way Analysis of Variance (ANOVA) was used to compute a standard error of the mean in each treatment and to test for variance differences between treatments for runoff and soil erosion (SAS Inst. 1990). Difference in treatment means ($P < 0.05$) were then analyzed using an appropriate "t" test. Annual data were analyzed for runoff and soil loss from 11-ft^2 plots for 2003 and 2004 (n = 2). Individual event data were used for analysis of runoff and soil loss at the drainage scale. Crop yield data from 2001 were not reported because this was the year the treatments were first set up.

Results and Discussion

An examination of monthly precipitation for January through February in 2001 and December through May in 2002 shows that the erosion seasons during these 2 years were drier than normal, accounting for the lack of runoff during this period (see precipitation in appendix, this issue). Conditions were wetter than normal during 2003. Although it was cooler and wetter than normal during the winter of 2004, this did not lead to highly erosive rain-on-frozen-soil events. Large soil losses in this region typically result from either rain on frozen soil, with or without snow cover, or rain on snow-covered, unfrozen soil. These types of events are expected to occur from one to five times each year (Zuzel et al. 1986). Tilled, unprotected soil may also move down slope in the absence of rainfall when the top inch or two of soil thaws and becomes a viscous, flowing slurry (Zuzel and Pikul 1987). Conditions of deep frozen soil did not occur at any time within 2001-2004. As expected, residue cover was significantly greater in the no-till (67%) than in the inversion tillage plots (5%).

Dry autumns in 2002, 2003, and 2004 resulted in late seeding of the no-till winter wheat compared to seeding under conventional tillage. Wheat yields in both tillage systems were depressed as a result of the dry 2001 and 2002 winters and springs. Lower than normal spring precipitation also contributed to very low chickpea production in those years.

Drainage-scale Runoff and Soil Erosion

There were 13 runoff and soil erosion events that reached the flumes during the 4 years of study (Table 2). During four of the events, runoff and erosion were observed in the inversion tillage drainage but not measured due to equipment failure. This means the annual soil loss values reported for the inversion tillage drainage are lower than what actually occurred.

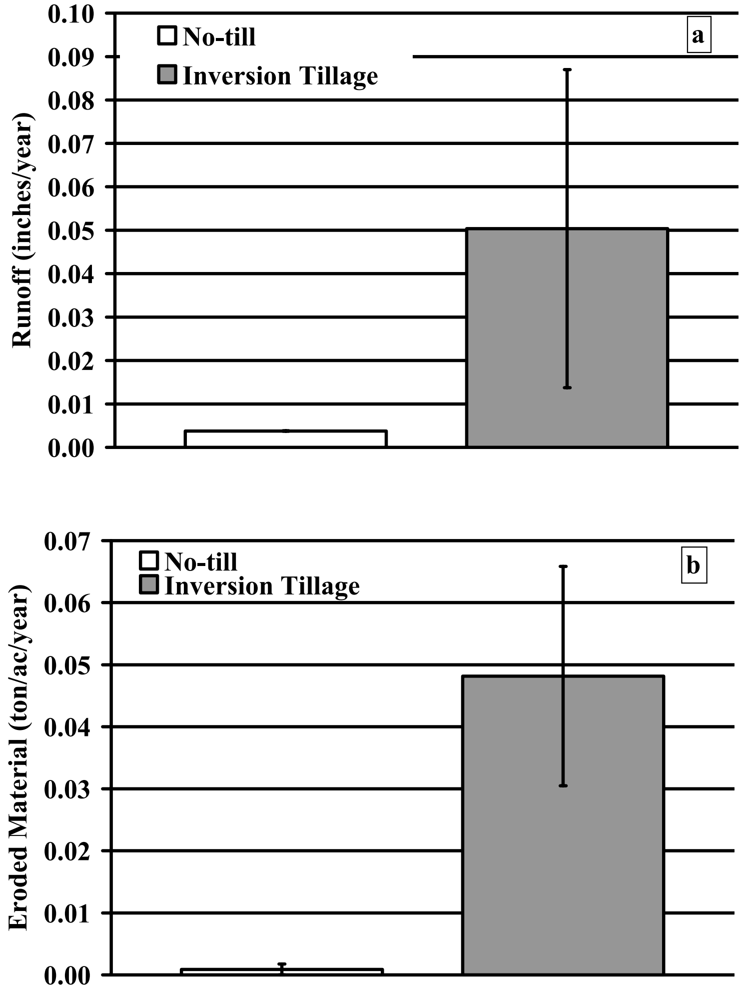
Four-year runoff and soil erosion values at the drainage scale were significantly less in the no-till system (Fig. 3). In 2003, the inversion tillage drainage had been fall burned and moldboard plowed, leaving a bare but rough surface that helped trap water and sediment. In the no-till drainage, the crop rotation nearest the flume was winter-wheat following chickpeas. In 2004, the inversion tillage drainage was cultivated once, fertilized, and rod-weeded twice before fall seeding. The plot nearest the flume in the no-till drainage was fallow in 2004.

Table 2. Runoff and erosion events at bottom of inversion tillage and no-till drainages during 2001-2004, Wildhorse Creek watershed, northeastern Oregon.

	Precipitation				Event	Measurements at drainage bottom			
			Intensity			Inversion tillage		No-till	
	Total	Duration	Maximum	Mean	Type*	Runoff	Erosion	Runoff	Erosion
	inches	*hours*	*in/hour*	*in/hour*		*inches*	*tons/acre*	*inches*	*tons/acre*
26 Jan 03	0.61	21:43	0.24	0.08	NFS	0.012	0.004	0.000	0.000
29 Jan 03	0.57	13:46	0.17	0.07	NFS	0.016	0.009	0.004	<0.01
30 Jan 03	0.57	21:10	0.31	0.09	NFS	0.020	0.031	0.008	<0.01
31 Jan 03	0.67	16:04	0.46	0.11	NFS	†	0.013	0.008	<0.01
23 Jan 04	1.05	31:15	0.14	0.05	RS	†	†	0.000	0.000
26 Jan 04	0.09	49:54	0.04	0.02	RS	0.012	0.00	0.000	0.000
28 Jan 04	0.77	39:24	0.45	0.09	RS	0.024	0.018	0.000	0.000
6 Feb 04	0.41	21:15	0.20	0.07	NFS	0.012	0.004	<0.1	0.000
16 Feb 04	0.45	39:41	0.17	0.07	NFS	0.024	0.062	0.000	0.000
17 Feb 04	0.30	15:08	0.22	0.07	NFS	0.012	0.022	0.000	0.000
24 Feb 04	0.36	9:54	0.69	0.17	NFS	0.012	0.022	0.000	0.000
15 Apr 04	0.98	8:29	0.56	0.18	NFS	0.012	†	0.000	0.000
8 Jun 04	0.93	15:32	0.60	0.19	NFS	0.051	†	0.000	0.000

*Event types: NFS = rain on non-frozen soil, RS = rain on snow (discontinuous patches of frozen soil).
† Event observed but no data collected.

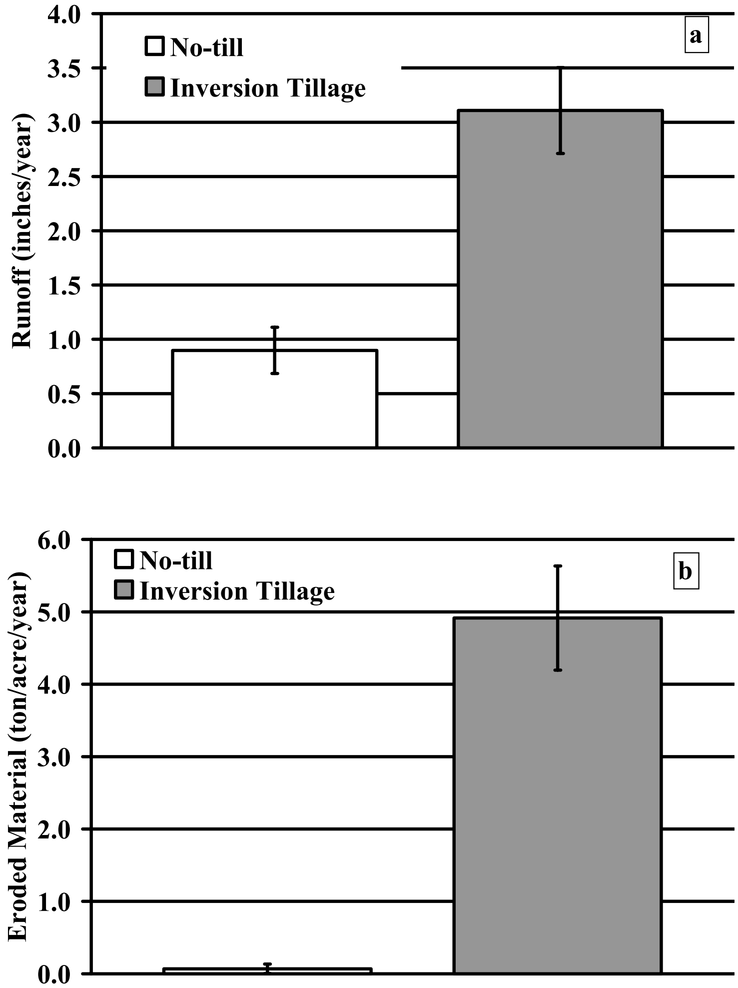
Figure 3. Average yearly runoff (a) and erosion (b) for flumes at the bottoms of drainages managed with no-till or inversion tillage during crop years 2001 through 2004, Wildhorse Creek watershed, northeastern Oregon. Error bars, where visible, show standard error of the mean (n = 4).



Runoff and Soil Erosion in 11-ft^2 Collector Plots

In plots with the 11-ft^2 collectors, the inversion tillage system produced 3.5 times more runoff and 52 times more eroded material than the no-till production system ($P \leq 0.05$, Fig. 4). This can be attributed to a complete lack of cover after the residue was burned and the soil plowed in the fall of 2002. Inversion tillage with residue burning is a common practice in the PNW region to control weeds, especially downy brome (*Bromus tectorum*).

Figure 4. Average yearly runoff (a) and erosion (b) measured by 11-ft^2 collectors on hill slopes of the drainages managed with no-till or inversion tillage during crop years 2003 and 2004, Wildhorse Creek watershed, northeastern Oregon. Error bars show standard error of the mean (n = 2).



In a concurrent study, runoff and soil erosion were monitored at three drainages within 6 miles of this research site through the same set of weather events. Each had a long history (100 years) of winter wheat-summer fallow managed with inversion tillage resulting in severe soil erosion before the research began. All three were no-till systems during crop years 2001-2004, and no runoff or erosion was measured or observed. This supports the conclusion that no-till greatly reduces runoff and erosion.

As noted previously, weather conditions typically associated with large erosion events did not occur during this study period. Three events occurred with rainfall on snow-covered soil frozen in patches, but the total accumulated soil loss during these three events ranked below the fourth largest event recorded during 2001-2004. The three largest erosion events were rain on unfrozen soils at moderate rainfall intensity and accumulation.

Comparing Response of Plots with 11-ft^2 Collectors vs. Entire Drainage

Substantially more runoff per unit area was recorded from 11-ft^2 collectors than from flumes at the bottom of either drainage. The average runoff leaving the inversion tillage drainage in 2003-2004 was 0.10 inch, approximately 1 percent of the 10.30-inch erosion-season precipitation. In contrast, hill slope water movement measured in the 11-ft^2 collectors was 3.11 inches, or 30 percent of precipitation. The difference between hill slope and drainage runoff leaves 3 inches of water that apparently infiltrated into the lower slope and drainage bottom before reaching the flume. This represents a substantial redistribution of water. With less localized runoff, the no-till system maintains a more uniform distribution of precipitation across the landscape, resulting in more stored water on hill slopes.

At the field scale, the dominant erosion process in the PNW is concentration of runoff and formation of rills (Zuzel et al. 1982). We observed a classic example of this process in the inversion tillage drainage in 2004. Less soil was measured leaving the bottom of the inversion tillage drainage in 2003 after rough plowing than in 2004 after the winter wheat was planted. This was because the rough surface following moldboard plowing restricted soil and water movement to the nearest drainage bottom. In 2004, after rod-weeding, planting and weathering reduced surface roughness and rills developed on the sides of the drainage, which in turn coalesced into a concentrated channel down the drainage bottom. In contrast, results from the 11-ft^2 plots indicated more soil movement downhill after rough plowing than after the winter wheat was planted. This indicates that, in the inversion tillage system, both rough and smooth surface conditions allow substantial amounts of soil to move downhill, but under smoother conditions more soil is delivered out of the drainage bottom. We never observed rills in the no-till system.

Our soil erosion data can be compared to values reported in recent soil erosion research conducted within the Wildhorse watershed, which encompasses the drainages where our study was located. In other research, the authors recorded erosion values of 0.33 tons/acre/year and 0.64 tons/acre/year in winter wheat-summer fallow inversion tillage systems where residue was plowed under or burned on 2-6 percent slopes (J. D. Williams, personal communication). Nagle and Ritchie (2004) conducted a landscape-scale evaluation of soil erosion in the Wildhorse watershed, using ^{137}Cs and other nucleotides resulting from radioactive fallout. They reported a rate of 2.3 tons/acre/year from a winter wheat-summer fallow field on a 5 percent slope. This value represents an integration of large and small soil erosion events that have occurred since atmospheric testing of nuclear weapons ended in 1963, whereas the values we report are from a relatively mild meteorological period.

Crop Yields

Mean yield of winter wheat ranged from 46 bu/acre to 81 bu/acre (Table 3) in accordance with yearly rainfall, which was 10.16 inches in 2002, 13.82 inches in 2003, and 17.32 inches in 2004. Mean yields of winter wheat by cropping system were 71 bu/acre following tilled summer fallow versus 65 bu/acre following chemical fallow and 47 bu/acre following chickpea under no-till. In this experiment the no-till winter wheat crops were seeded each year between 15 and 20 October whereas the crop in the inversion tillage could be seeded in early October. We do not have enough data to perform meaningful statistics on these crop yields. We also caution that the no-till rotation and farming techniques are relatively new to the region and may not have been optimal.

Table 3. Winter wheat yields, Wildhorse Creek watershed, northeastern Oregon, 2002-2004.

Cropping System	2002	2003	2004	Mean Yield
	---------------------bu/acre-----------------			
Inversion Tillage				
Summer Fallow-Winter Wheat	65	(fallow)	78	71
No-Till				
Chemical Fallow-Winter Wheat	58	52	87	65
Chickpea-Winter Wheat	17	45	78	47
Mean Yield	46	48	81	

Summary and Conclusions

A field scale, side-by-side comparison of runoff and erosion was undertaken for a conventional inversion tillage system and a no-till system using two small drainages in northeastern Oregon. Significantly less runoff and soil erosion occurred within the no-till drainage. This was not only true at the drainage scale, but also at a localized 11-ft^2 scale on mid slopes. Under certain conditions, winter wheat yield from the no-till fallow system was similar to that of the tilled fallow system, but we did not generate enough data to draw conclusions on yield or economics. Nevertheless, this study demonstrates that adoption of no-till production systems in the semiarid wheat producing region of interior Oregon and Washington will provide substantial soil and water conservation benefits. In addition, this study brings to light the substantial amount of water and soil that moves down slope in inversion tillage systems even without the development of rills or loss of soil from the drainage. Although the total amount of soil lost from these drainages during the 4-year period of study may seem small compared to published tolerance values, the continual shift of soil toward drainage bottoms represents a persistent and permanent loss of productive capacity at a rate far exceeding soil replacement rates.

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