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ROTARY SUBSOILING TO REDUCE EROSION AND IMPROVE INFILTRATION IN NEWLY PLANTED WINTER WHEAT AFTER SUMMER FALLOW

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Abstract

Water erosion and runoff can be severe due to poor infiltration through frozen soil in the dryland wheat (*Triticum aestivum* L.) production region of the inland Pacific Northwest (PNW), USA. For more than 70 years, farmers and researchers have used various methods of subsoiling to reduce runoff and erosion and to improve infiltration and soil water storage. The practice and equipment have evolved from chiseling continuous open channels across hillslopes to the rotary subsoiler that pits the soil. Farmers often subsoil wheat stubble after harvest, but do not employ this practice on newly-planted winter wheat fields. These fields are especially vulnerable to erosion because of meager residue cover after a year of fallow. A 6-year field study was conducted in eastern Washington to determine the effect of rotary subsoiling in newly-planted winter wheat on over-winter water storage, erosion, infiltration, and grain yield. There were two treatments, rotary subsoiling and control. The rotary subsoiler created one 16-inch-deep pit with 0.98-gallon capacity every 7.5 ft^2. Natural precipitation did not cause rill erosion in either treatment because of mild winters during the study period. Net change in water storage was significantly ($P < 0.05$) improved with rotary subsoiling compared to the control in 2 of 6 years. Grain yield was not affected by treatments in any year or when averaged over years. In 2003, we simulated rainfall for approximately 3 hr at a rate of 0.72 inch/hr on both subsoiled and control plots to determine runoff and erosion responses on frozen soils. Rotary subsoiling reduced runoff ($P < 0.01$) by 38 percent. Rotary subsoiling also significantly reduced erosion ($P < 0.01$) during the 20- to 45-min period after runoff had begun. The total quantity of eroded soils were 0.58 and 1.52 ton/acre for the subsoiled and control treatments, respectively, with inter-rill the dominant erosion process. The average infiltration rate for the control treatment (0.13 inches/hr) was half of the rate for the subsoiled treatment (0.26 inches/hr), at the end of the 3-hr simulation. Rotary subsoiling of newly-planted winter wheat can increase soil water stored over-winter and reduce runoff and soil loss on frozen soils, but the benefit of this practice for increasing grain yield has not been proven.

Key words: frozen soil, runoff, Pacific Northwest, water infiltration

Introduction

The winter wheat–summer fallow system of farming, where one crop is produced every 2 years, has historically proven to be the most reliable and generally most profitable method for growing wheat in the 6- to 14-inch precipitation zone in the inland PNW. However, tillage during fallow to control weeds and inject fertilizer, and preparation of the seedbed is often intensive, (i.e., eight or more tillage operations), and often leaves soil prone to wind and water erosion. When winter wheat is planted into fallow in late summer residue cover is often lacking and, depending on weather conditions and date of planting, winter wheat seedlings contribute as little as 3 percent cover by the first of November and the onset of water erosion events.

Infiltration rates for unfrozen silt loam soils in the region are relatively high. Zuzel and Pikul (1987) reported a 0.59-inch/hr infiltration rate in Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll), a representative soil for much of this region where 95 percent of storms have precipitation rates less than 0.18 inch/hr (Williams et al. 1998). Soil freezes regularly to a depth of 4 inches, and occasionally to 16 inches (Papendick and McCool, 1994). The most severe erosion generally occurs when snowmelt or rain occur on thawed soil overlying a subsurface frozen layer (Zuzel et al. 1982, Zuzel 1986). Erosion occurs predominately as rills (McCool et al. 1982) with smaller contributions by sheet erosion, and soil suspension movement below frozen soil surfaces and above plow pans. Zuzel and Pikul (1987) and Pikul and Zuzel (1993) demonstrated that infiltration into frozen silt loam soil can approach zero, depending on the depth of freezing and soil water status (Willis et al. 1961). Combined, these events and conditions lead regularly to losses of 2.2 to 8.9 ton(s) of soil/acre/year, and occasionally up to 89.2 tons of soil/acre/year, in the approximately 2.22 million acres planted to winter wheat following summer fallow in this region (USDA 1978, Smiley 1992, McCool et al. 1993).

Most farmers pursue the goal of limiting runoff and associated erosion from frozen soils. Unfortunately, even management practices that combine residue retention, contour tillage and planting, and terraces often do not prevent erosion (Saxton et al, 1981). To reduce erosion, farmers have used various methods of chiseling or subsoiling since the 1930's (Spain and McCune 1956). Subsoiling, also known as ripping in France and chiseling in the United States and Canada, is the creation of deep channels, without inversion, using knife-like shanks that are pulled through the soil to create continuous grooves 30- to 24 inches deep and spaced 24- to 59-inches apart. The desired result is the capture of snowmelt or rain and improved infiltration through frozen soil and/or tillage pan to enhance soil conservation, soil water storage, and wheat grain yield. For these reasons, many farmers chisel recently harvested wheat stubble (i.e., start of the fallow cycle) to increase over-winter capture of water for winter wheat planted the following year.

A number of subsoiling techniques have been evaluated in recent years that aim to capture rain and snow melt in newly planted winter wheat fields when plants are still in the seedling stage of development. Pikul et al. (1992) chiseled continuous grooves in the soil to a depth of 8 inches, adjusting the spacing between shanks to capture runoff from a range of storms and soil conditions. When depth of freezing is greater than depth of chisel or shank, the effectiveness of subsoiling is reduced or lost (Pikul et al. 1992, Pikul et al. 1996).

Schillinger and Wilkins (1997) used shanks in a 2-year experiment to create continuous 10- to 25-inch-deep channels spaced 12 or 20 ft apart. One winter was relatively dry, the second relatively wet. Erosion was reduced in the subsoiled vs. control plots during both years. They also recorded increased soil water content to a depth of 6 ft, 3 ft down-slope from the tillage channels. In both years, wheat grain yield was reduced in the rows most disturbed by the chisel shank, but was increased in adjacent rows. On a whole-plot basis, there were no differences in grain yield between subsoiled and control treatments in either year. Similarly, Pikul and Aase (1999, 2003) used a paratill to break up a tillage pan in a sandy loam soil, and chiseled narrow channels to a depth of 12 inches. Infiltration and soil strength were improved up to 2.5 years later, after deep chiseling, but root-zone soil water and grain yield showed no response to the treatment. Tillage following deep chiseling reduced infiltration and erosion-control benefits. Pikul and Aase (2003) found that subsoiling a sandy loam soil with paratill to a depth of 12 inches improved infiltration, but water drained to below the rooting depth of wheat. Movement of water below the root zone, loss of nutrients, and possible groundwater contamination are concerns on shallow soils (Pikul and Aase 1999).

Farmers have shown little interest in chiseling continuous channels on the contour in newly planted wheat fields because 1) too many wheat plants are destroyed, negating any increase in grain yield potential even though more water may be stored in the soil; and 2) the likelihood of continuous channels concentrating flow. Continuous channels should be perfectly on the elevation contour to prevent concentrating flows and erosive force at low points (Saxton et al. 1981). Additionally, channels chiseled into dry soil often immediately refill with dry soil (Saxton et al. 1981, Pikul et al. 1996). To avoid this problem, Wilkins et al. (1991) and Wilkins and Zuzel (1994) chiseled winter wheat fields after the soil had frozen using a shank with attached rotary pitter to create infiltration channels with pits. The purpose of the pits was to disrupt the continuity of the groove. The implement did not consistently penetrate the frozen soil. Ponded infiltration rates in plots treated with the implement were greater than rates from control plots. Despite the appearance of some wheat disease, yields were not depressed (Wilkins and Zuzel 1994).

The purpose of rotary subsoiling is to create pits that cause minimum damage to wheat seedlings, eliminate concentrated flow with continuous channels, and reduce power requirements associated with pulling shanks through the soil. Our objectives were to determine if rotary subsoiling 1) reduced runoff and erosion, 2) increased soil water stored over-winter, and 3) affected winter wheat grain yield.

Materials and Methods

Field layout

Six on-farm experiments were conducted near Harrington, Ritzville, Wilbur, and Lind in Lincoln and Adams counties in east-central Washington, from crop years 1997 through 2003 (Fig. 1). The study was not conducted in 2000-2001 because of early snow. Soils at all sites were deep and well-drained silt loams, formed in loess, with slopes ranging from 10 to 40 percent (Table 1) (Stockman 1981, Lenfesty 1967). Winter precipitation generally does not fill the soil profile. Experiment sites were identified by the farmer cooperators as historically prone to water erosion. Individual plot size ranged from 39 to 85 ft wide and 151 to 190 ft long, depending on the available slope area. Experimental design during all years was a randomized complete block with six replications of two treatments: rotary subsoiling and control.

A 2-year rotation of winter wheat summer fallow was practiced at all sites during all years of the study. Tillage during fallow generally consisted of chiseling stubble in the fall, primary spring tillage with either a tandem disk or two passes with a field cultivator plus attached harrow, a separate operation to inject aqua NH_3-N with shanks, and two to four rodweedings (a rotating 1-inch^2 rod) to control weeds and break capillary continuity in the soil to retard the upward movement of liquid water in summer fallow during dry summer months.

Winter wheat was planted from early-to-mid September with a John Deere HZ™ deep-furrow drill on 16-inch row spacing until crop year 2000, after which a John Deere hoe drill with 10-inch row spacing was used.

Uniform stands of winter wheat were achieved each year of the study. Plots were rotary subsoiled each fall following wheat emergence and sufficient rainfall so that the pits did not collapse and fill with dry soil.

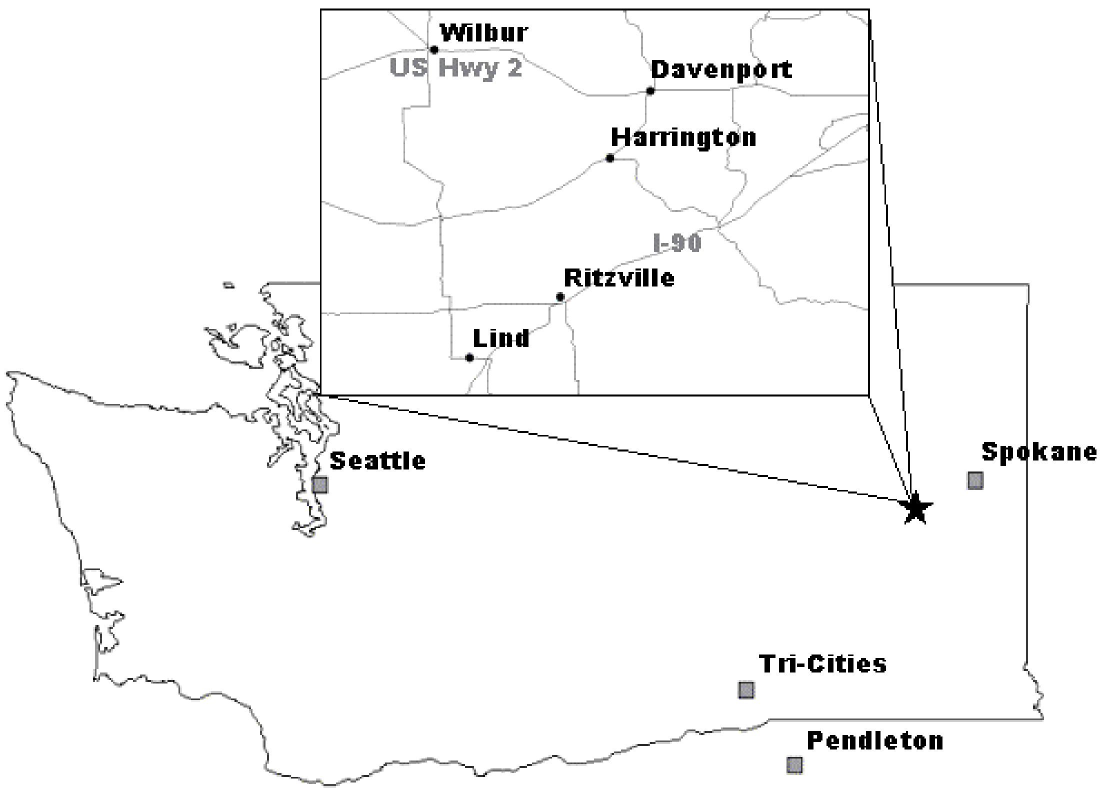


Figure 1. Rotary subsoil research plots were established near the towns of Wilbur, Harrington, Ritzville, and Lind, Washington during 6 years.

Table 1. Location, soil type, precipitation, frost-free days, and mean annual air temperature during 6 years of rotary subsoiler field experiment sites in eastern Washington.

Crop year	Location	Soil type[1]	Annual precipitation (inches)	Frost-free season (days)	Mean annual temperature (°F)
1997	Wilbur	Bagdad silt loam (coarse-silty, mixed, superactive, mesic Calcic Argixerolls)	12.5	110 – 150	49
1998	Ritzville	Ritzville silt loam (coarse-silty, mixed, mesic Calcidic Haploxeroll)	11.2	120 – 160	49
1999	Lind	Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids)	9.6	140 – 170	50
2000	Harrington	Bagdad silt loam and Endicott silt loam (coarse-silty, mixed, mesic Haplic Durixerolls)	13.0	110 – 150	49
2001	No study, early snow				
2002	Harrington	Bagdad silt loam Endicott silt loam	13.0	110 – 150	49
2003	Harrington	Bagdad silt loam Endicott silt loam	13.0	110 – 150	49

[1] Lenfesty (1967), Stockman (1981).

The “shark’s tooth” rotary subsoiler (Fig. 2) created 1 16-inch-deep by 2-inch-wide pit every 8 ft^2 (5,781 pits/acre), each pit with 1-gal capacity. The rotary subsoiler was pulled along the contour of the slope by a crawler tractor and was lifted out of the soil when crossing control plots.

Figure 2. Rotary subsoiler in transport position.

Soil water, erosion, and grain yield measurement

Soil volumetric water content in the 12- to 71-inch depth was measured in 6-inch increments by neutron thermalization (Hignett and Evett 2002). Volumetric soil water content in the 0- to 12-inch depth was determined from two 6-inch core samples using gravimetric procedures (Top and Ferre 2002). Three access tubes were installed in each plot, i.e., 36 access tubes. Neutron probe access tubes were placed 12 inches down-slope from a pit created by the rotary subsoiler. Access tubes were placed in the same general lateral locations in the control treatment. Rill erosion was measured (McCool et al. 1976) in all plots during every year. Winter wheat grain yield was measured by harvesting the grain from plants in a swath through each plot with a commercial combine with 30-ft-wide cutting platform and auguring grain into a weigh wagon.

Simulated rainfall and ponded infiltration

The research site was located 7 mi southeast of Harrington (47° 23'45"N, 118° 11'00"W) at an elevation of 2,200 ft. We simulated rainfall in February 2003 on plots that had received approximately half of the expected annual precipitation, on rotary subsoiled and control plots with 18 percent slope with an east, southeast aspect, at a rate of 0.71 inch/hr. Precipitation collected from a metal-roofed building was used for rainfall simulation. Rainfall was simulated using the Pacific Northwest Rainfall Simulator (Williams et al. 1998), onto areas 6.6 ft wide by 32.8 ft long (215 ft^2). The temperature of the water used for rainfall and the air temperature inside the simulator covers were recorded to assure consistent ambient conditions across treatments. Simulation continued for 120 minutes after runoff began. There were four replications in the simulated rainfall measurements of plot runoff and erosion. Four simulator modules rained on four plots simultaneously, two on control plots and two on subsoiled plots. Simulators used on the control treatment during the first set of four plots were used to rain onto subsoiled treatment during the second set. Time to ponding, time to runoff, and runoff in 5-minute intervals for 120 minutes were recorded. Time to fill 1-quart bottles with runoff was recorded and the bottles were weighed, dried at 221°F for 24 hr, then reweighed to determine runoff rate and eroded mass. Infiltration was calculated as infiltration = precipitation – runoff. Residue cover was measured using a modified point frame method (Floyd and Anderson 1982).

Average pit capacity and infiltration rate were determined on day two of rainfall simulations. Thirteen rotary subsoiler pits were randomly chosen and ponded infiltration was measured as follows: a pit was quickly filled with water to near overflow, and the volume of water used and initial time recorded; when the water level dropped approximately one inch, the pit was refilled, and the water volume and time recorded again; the refill procedure was conducted twice. Ponded infiltration rate was calculated for all three refills. The time between the refills averaged 3 minutes. The results from the thirteen pits were averaged to obtain an estimate of pit volume and infiltration rates at 3, 6, and 9 minutes after onset of ponding.

Data analysis

Analysis of variance was conducted for 1) net gain in soil water content in the 6-ft soil profile from the time experiments were established in November or December until mid-March, and 2) winter wheat grain yield. Treatments were considered significantly different if $P < 0.05$. Data analysis for runoff and infiltration from simulated rainfall was performed using the Mixed Models statement in SAS (1998). Least squares means separation tests were conducted on the response variable if the type-three mixed effects were significant ($P \leq 0.10$).

Results and Discussion

Natural erosion, soil water storage, and wheat grain yield

Winters were generally mild throughout the study period and no measurable rill erosion occurred in any year in either rotary subsoiled or control plots. However, sediment was observed to have partially filled some of the pits at Wilbur in 1997 and at Ritzville in 1998.

Net gain in over-winter soil water was significantly greater in rotary subsoiled plots compared to the control at Lind in 1999 and at Harrington in 2000 (Table 2). This finding suggests that some runoff did occur in control plots, probably when the soil surface was frozen although no rill erosion was observed. Averaged over the 6-year study period, net over-winter soil water gain with rotary subsoiling was not different than for the control (Table 2). Winter wheat grain yield varied widely among sites and years, but there were no differences in grain yield between treatments in any year or when analyzed over years (Table 2).

Table 2. Over-winter net gain in soil water and winter wheat grain yield during 6 years as affected by rotary subsoiling newly planted winter wheat fields. Crop rotation is winter wheat–summer fallow.

		------------Net gain in soil water ------------			------------------Grain yield -------------------		
		Rotary subsoiled	**Control**	**Sig.**[1]	**Rotary subsoiled**	**Control**	**Sig.**[1]
Crop Year	**Location**	----------------------inches---------------------			---------------------bu/acre --------------------		
1997	Wilbur	7.68	7.56	ns	74	74	ns
1998[2]	Ritzville	0.71	0.59	ns	55	58	ns
1999	Lind	1.57	1.02	**	22	25	ns
2000	Harrington	4.72	3.78	*	98	97	ns
2002[3]	Harrington	3.46	2.95	ns	57	56	ns
2003	Harrington	4.96	5.55	ns	44	46	ns
6-year avg.	All locations	3.86	3.58	ns	58	59	ns

[1]ns = no significant differences at $P < 0.05$. *, ** Significant differences at the 0.05 and 0.01 levels, respectively.
[2]Plots were established in December after considerable precipitation had already occurred, thus the low values for net gain in soil water in 1998.
[3]The experiment could not be conducted in the 2001 crop year due to early snow cover.

Simulated rainfall

Ground cover in rainfall simulation plots was approximately 80 percent in both treatments and consisted of old wheat stubble and young wheat seedlings (Table 3). Surface soil was lightly frozen to a depth of 2 inches, and had gravimetric soil water content of ≈ 30 percent. The total simulation time for each plot was 3 hr, during which 2.13 inches of rainfall was applied. Total simulated rainfall was approximately twice the long-term average accumulated precipitation for the month of February for the site (WRCC 2004) and represents a 24-hr storm expected once every 75 years. Average temperature of simulated rainfall was 33°F. Air temperature inside the rainfall simulator covers ranged from 23°F in the morning to 59°F at the end of simulation in the afternoon, when small pockets of frozen soil could still be found.

Table 3. Percent ground cover provided by wheat stubble and winter wheat seedlings in control and rotary-subsoiled treatments at the time of rainfall simulation at Harrington in 2003.

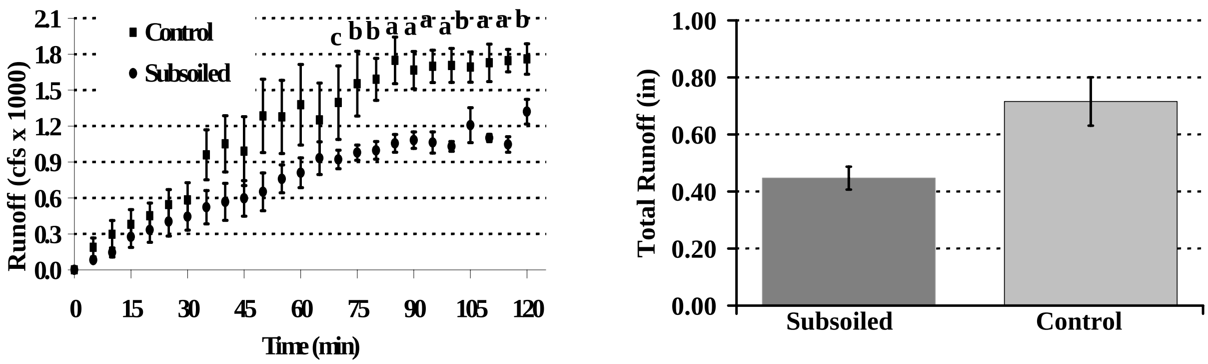
	Control	**Subsoiled**
Wheat stubble	**48.5 (5.2)** [1]	**53.1 (4.9)**
Wheat seedlings	**36.4 (7.9)**	**26.9 (5.8)**
Total cover	**84.9 (3.1)**	**80.0 (3.6)**
Bare soil	**15.1 (3.1)**	**20.0 (3.6)**

[1]Values in parenthesis are standard error.

Runoff and infiltration

Time to ponding in both treatments occurred within 10 minutes and average time to runoff was 50 minutes after onset of rainfall simulation. There were no significant differences between treatments for either time to ponding or time to runoff. The rotary-subsoiled treatment produced runoff at significantly ($P < 0.01$) lower rates than control treatment, after 70 minutes of simulation (Fig. 3a). The total runoff was 38 percent lower in the rotary-subsoiled treatment than the control treatment (Fig. 3b). At the end of simulation, infiltration rate approached steady state of 0.13 inch/hr in the control treatment, just half of the 0.25 inch/hr in the subsoiled treatment.

The average capacity of the pits was 0.98 ± 0.11 gallons (mean ± standard error), equivalent to a rainfall of 0.21 ± 0.02 inches falling onto the contributing area of the pit and running into it. In addition to detaining runoff, the pits create infiltration galleries. The average ponded infiltration rate for subsoiled pits was 0.72 ± 0.02 inches/hr after three minutes, 0.59 ± 0.10 inches/hr between three and six minutes, and 0.28 ± 0.06 inches/hr between six and nine minutes. The decline in infiltration rate over time represents an approach to steady state saturated infiltration. From the time the pits were established in November until infiltration rates were measured, the plots received 6.69 inches of precipitation (NOAA 2003). Thus, the pits were exposed to substantial slaking and sedimentation; processes that reduce infiltration effectiveness of channels created by chiseling (Wilkins et al. 1996, Schillinger and Wilkins 1997).



a b

Figure 3. Runoff averages and standard errors (n = 4) from the first 2 hours of simulated rainfall on rotary-subsoiled and control treatments at Harrington: **a)** Runoff rates in cubic feet per second (cfs) from plots at 5-minute intervals following initiation of flow. Letters above incremental data points indicate significance of difference between treatments; **a:** $P \leq 0.01$, **b:** $P \leq 0.05$, and **c:** $P \leq 0.10$; **b)** total runoff from 1.8 inches of simulated rainfall.

Water infiltration into frozen soil depends on soil texture and structure, tillage practices, quantity of residue on or mixed into soil, soil water content at the time of freezing, and the depth of freezing. Infiltration rate increases with increased rainfall intensity or under ponded conditions (Lusby and Lichty 1983). In soils chiseled after freezing, Pikul et al. (1996) recorded a ponded infiltration rate of about 0.83 inches/hr in soil frozen to a depth of 0.43 inches. This rate is nearly three times greater than measured (0.28 inches/hr) in soil frozen to a depth of 1.97-inches in our simulated rainfall study, after the soil had thawed in a random sample of pits. This finding suggests that continuous channels are more effective for reducing runoff than independent pits. However, when the depth of frozen soil extended down to 13.78 inches, infiltration rate for a continuous-channel treatment decreased to 0.04 inches/hr on 7.5 ft^2 plots (Pikul et al. 1996).

Subsoiling and erosion

Throughout the simulation event eroded soil mass was greater for the control plots than subsoiled plots. The eroded mass was significantly ($P < 0.01$) greater for the control treatment than for the subsoiled treatment from 20 to 45 minutes after runoff had begun (Fig. 4a). The greater variability in the control versus subsoiled treatments was caused by an exceptionally high erosion rate from one control plot. Despite the shallow depth of freezing, patches of frozen soil remained at the end of the simulations in both treatments. There were no obvious observed or measured differences in the plots used for both treatments other than the pits created by rotary subsoiling. We speculate that the pits detained enough sediment and created sufficiently more soil surface area so that the capacity to carry soil in the runoff was uniformly reduced.

Total eroded soil mass was 1.5 ton/acre from the control treatment compared to 0.58 ton/acre from the rotary-subsoiled (Fig. 4b). Working with continuous channels created by chiseling, Schillinger and Wilkins (1997) reported annual erosion of 1.1 ton/acre from the control treatment compared to no soil loss from the chiseled treatment, during a

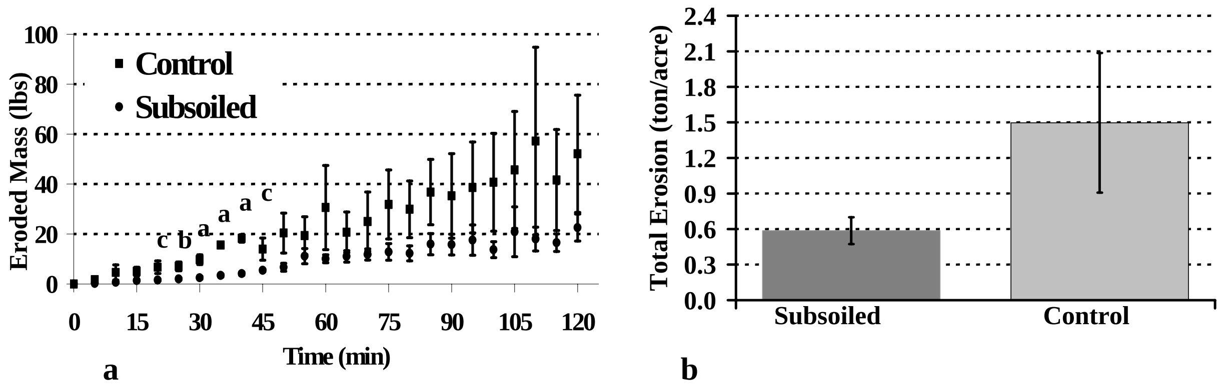


Figure 4. Eroded mass averages and standard errors (n = 4) from simulated rainfall plots: **a)** pounds (lbs) from plots at 5-minute intervals following initiation of flow. Letters above incremental data points indicate significance of difference between treatments; **a: P** $\leq$ 0.01, **b: P** $\leq$ 0.05, and **c: P** $\leq$ 0.10; **b)** total eroded mass in tons per acre from 1.8 inches of simulated rainfall.

relatively dry winter. However, during a wet winter with four major precipitation events, soil loss was 7.0 ton/acre and 1.2 ton/acre in the control and subsoiled treatments, respectively.

Soil erosion resulted from interrill processes, predominately sheet wash, although micro-rills were beginning to form by the end of the simulations. Micro-rills formed where water had ponded in furrows or pits, and the water began escaping through cracks in the soil surface that had formed as a result of drying and freezing. Raindrop splash alone caused little erosion because of the small drop size ($D_{90} \leq 0.01$ inch) produced by the rainfall simulator (Bubenzer et al., 1985).

In our study, where rainfall was simulated at a rate equivalent to the total precipitation expected to fall in a 24-hr period once every 75 years (2.13 inches), the rotary-subsoiled treatment had 40 percent less erosion than the control treatment. This reduction in soil loss from rotary subsoiling is greater than the 13 percent reduction reported by Schillinger and Wilkins (1997) in the third rainstorm of 1.85 inches precipitation, which was preceded by two storms with an accumulated total precipitation of 6.29 inches. A direct comparison of results in the two studies is difficult, because of plot size, rainfall intensity, and erosion processes (i.e., inter-rill vs. rill).

Conclusion

Rotary subsoiling increased net over-winter soil water gain in 2 of 6 years. No measurable rill erosion occurred in either treatment in any year. There were no differences in winter wheat grain yield between the rotary subsoiling and control treatments in any year or when analyzed over the 6 years. Rotary subsoiling reduced runoff and soil loss during rainfall simulation onto frozen soil. Reduction in the eroded soil mass for the subsoiled treatment was statistically significant during the 20- to 45-minute period after runoff had begun.

Rotary subsoiling reduced runoff by 38 percent and improved infiltration compared to the control. The infiltration rate for the subsoiled treatment (0.26 inch/hr) was twice that for the control (0.13 inch /hr). Total quantity of eroded soils were 0.58 and 1.52 ton/acre for the rotary-subsoiled and control treatments, respectively. Rotary subsoiling will benefit over-winter soil water storage in some years and has potential to reduce runoff and soil loss during intense and short-duration rainstorms on residue-deficient farmland when soil is frozen or partially frozen. We conclude that rotary subsoiling is a low-cost practice that will benefit soil water storage in some years and will decrease potential soil loss on residue-deficient hill slopes during wet winters in the Pacific Northwest.

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