Contour ripping: A tillage strategy to improve water infiltration into frozen soil

J.L. Pikul, Jr., D.E. Wilkins, J.K. Aase, and J.F. Zuzel

ABSTRACT: Practices that combine stubble management for snow catch and contour-ripping for snowmelt infiltration have potential to increase water infiltration and soil water storage. Our objective was to investigate soil ripping to improve water infiltration into frozen soil. Infiltration studies on frozen soil were conducted at sites near Pendleton, Oregon (silt loam soil), and Culbertson, Montana (sandy loam soil). Ripping was performed with a single chisel or parabolic subsoiling shank at 6- to 8-m intervals on the contour to a depth of 0.2 to 0.3 m. Final infiltration rate on the sandy loam averaged 11 mm h^{-1} on the rip treatment and 1 mm h^{-1} on the no-rip treatment even when the soil was frozen deeper than 0.6 m. On the silt loam soils, when the average depth of frozen soil was 0.14 m, average final infiltration rate was 28 mm h^{-1} on the rip treatment and 2 mm h^{-1} on the no-rip treatment. There were no treatment differences on the silt loam when the soil was frozen 0.35 m. Soil condition at the time of ripping determined the effectiveness of tillage to improve water infiltration; there was little benefit from ripping a dry pulverized soil because loose soil flowed into the rip and obliterated the rip path. Desirable macropore structure on loose soil was achieved by deferring ripping until the soil was frozen. Infiltration measurements show that soil ripping has potential to increase water infiltration and consequently decrease water runoff, and if used in conjunction with stubble management to maximize snow trapping, may increase overwinter soil water storage.

Soil freezing and thawing affect large agricultural areas, as well as range and forest land. Within the United States, Formanek et al. (1990) estimated that nearly 1.2 million km^2 (0.46 million mi^2) of crop land, 1.3 million km^2 (0.5 million mi^2) of forest land and 1.8 million km^2 (0.69 million mi^2) of grazing land are impacted by freezing and thawing. From an agricultural perspective, defining interactions of freeze-thaw on movement of water and chemicals is of high importance. Miller (1980) described difficulties inherent to investigations related to soil freezing and thawing, and stated that "In nature, these processes [freezing induced water redistribution] go forward rather slowly within and below a frozen crust that may have the strength of concrete. They occur during a season of inclement weather. It is not surprising that knowledge of these processes is less than it should be nor that much of what we do know is derived from laboratory tests and experiments."

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Water infiltration into frozen soil is primarily determined by soil water content at the time of freezing (Kane 1980). The freezing process induces water flux from unfrozen soil to the freezing front (Pikul et al. 1989). As the surface cools, a fraction of the water in the soil pores freezes. Ice particles remain separated from the soil by a thin water film; the thickness of the film depends on temperature, pore size distribution, and solutes in the pore water. Freezing of water effectually dries the soil in the region of ice formation thereby decreasing the matric potential. Water flows towards the region of low matric potential. An increasingly tortuous water flow path develops as pore space fills with ice and water films decrease in thickness. In the inland Pacific Northwest, which has a winter precipitation pattern, soils often freeze at a high water content resulting in a nearly impermeable condition. Air-filled macropores provide important preferential water flow paths through frozen soil and increase water infiltration (Gray et al. 1990; Zuzel and Pikul 1987).

The importance of freeze-thaw on agricultural lands as related to runoff and erosion hazards is recognized and considerable research has been conducted to identify problems and possible solutions. However, implementing solutions at the field scale can be difficult. Typically, soil

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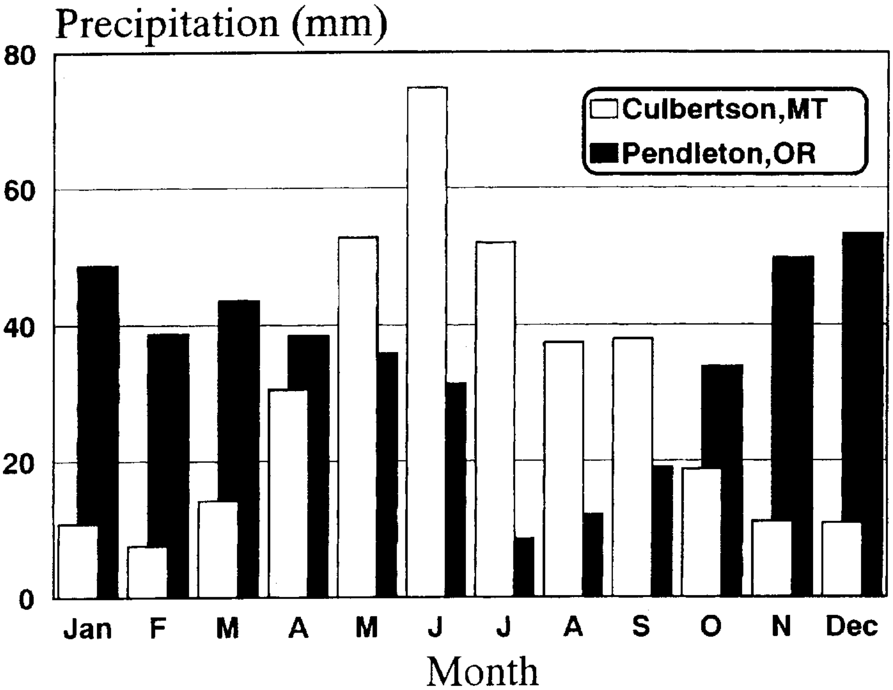

Figure 1. Average monthly precipitation at infiltration sites near Pendleton, Oregon (61-year average), and Culbertson, Montana (27-year average)

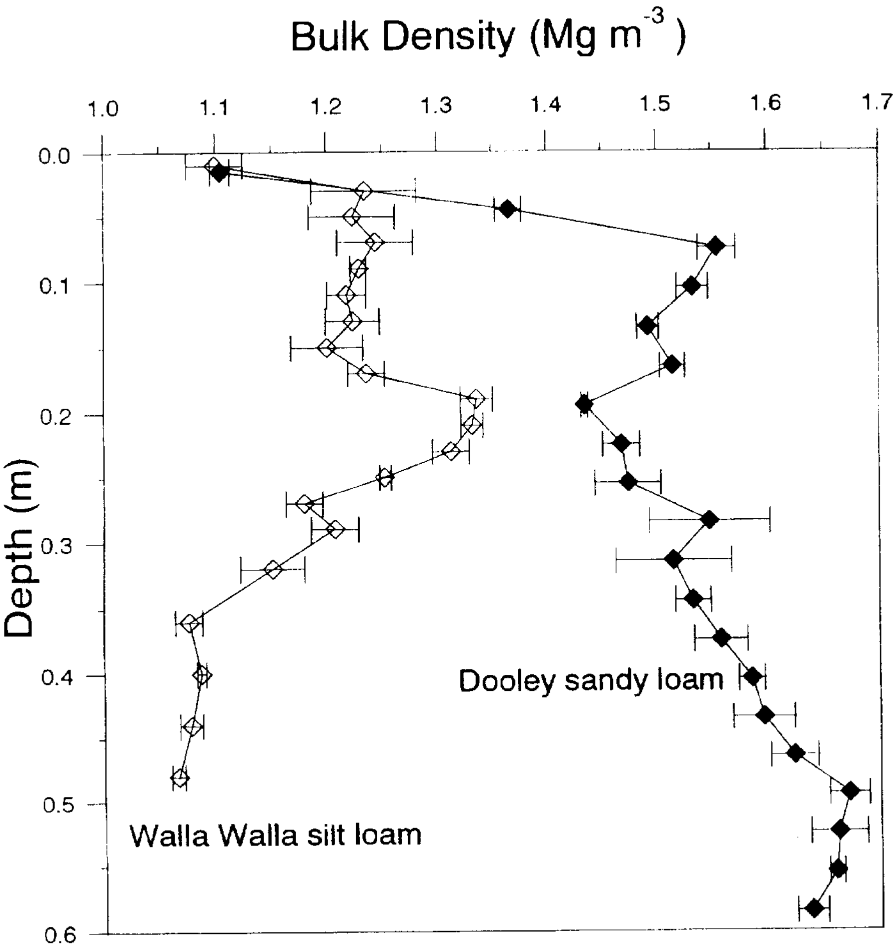

Figure 2. Soil bulk density for Walla Walla silt loam in Oregon and Dooley sandy loam in Montana; brackets show one standard deviation

erosion control efforts have been through tillage and residue management systems that maintain adequate surface roughness and suitable amounts of crop residue on the surface. Allmaras et al. (1979) have shown that erosion control in eastern Oregon often requires combinations of tillage, residue management, contouring, or terracing. Growers must plan on having sufficient residue cover following fall planting. Percent surface cover is determined by the Natural Resources Conservation Service (NRCS) to meet acceptable soil loss tolerances, but even the best management practices may fail to reduce water runoff and erosion when the soil is frozen or partially frozen (Saxton et al. 1981).

Frequent freezing and thawing of soil together with winter rainfall or snowmelt can create severe soil erosion problems. For example, in the summer fallow-winter wheat (*Triticum aestivum* L.) production areas of the inland Pacific Northwest, water erosion problems often develop during the winter following fall planting. Mechanical summer fallowing, such as rodweeding, to control weeds and to limit soil water evaporation, typically leaves the surface soil in a pulverized state with meager amounts of surface residue. Wheat plant development during the fall growing period rarely provides sufficient surface cover to prevent dispersion of the soil surface by raindrop impact. Late fall and early winter rainfall causes crusting of the soil surface which reduces water infiltration. These fields enter the winter months susceptible to soil erosion. Frozen soil further reduces soil permeability, increases the risk of water runoff, and decreases the potential to store soil water. Soil losses caused by water erosion can be especially high during heavy rainfall or snow melt when a thawed soil layer overlies a frozen layer (Zuzel et al. 1982).

On rangelands, various mechanical treatments such as ripping, pitting, and contour furrowing have been used to create surface storage and increase water infiltration opportunity. For example, in eastern Montana contour furrowing of sloping land with low infiltration capacity improved precipitation-use efficiency (Wight and Siddoway 1972). Where snowfall is significant, contour furrowing of range land increased snow water accumulation by 60% and soil water recharge by 161% compared to natural range (Neff and Wight).

On cropland, the objectives of tillage are to incorporate residues or amendments, control weeds, and prepare the soil for seeding. Tillage to specifically prepare

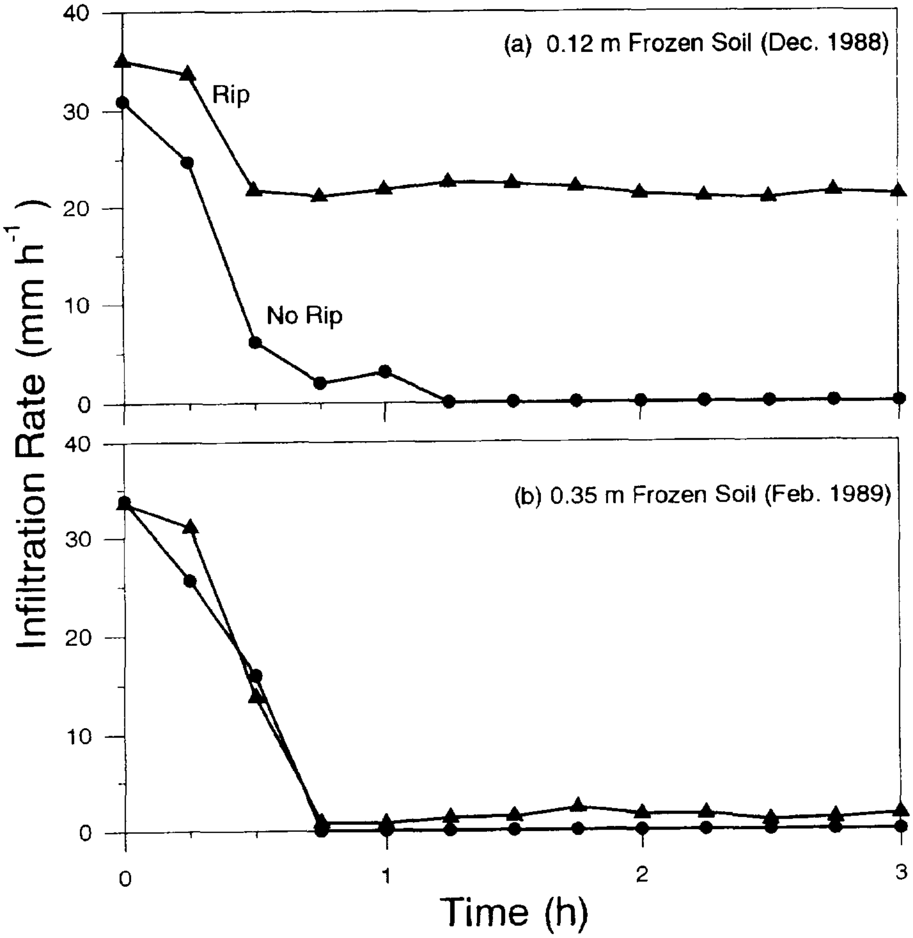

Figure 3. Water infiltration on rip and no-rip treatments at site 1 on Walla Walla silt loam when the soil was frozen 0.12 m in December 1988 (a) and 0.35 m in February 1989 (b)

fields for spring runoff is generally not a consideration. Experiments designed to test the effect of tillage on overwinter soil water storage are often executed using whole-field tillage implements such as disk or chisel plows. Interpretation of the effectiveness of tillage on water infiltration is difficult because whole-field tillage destroys vertical crop residue essential for snow trapping and increases evaporative soil water loss. On the Canadian Prairies, where snowfall accounts for approximately 30% of the annual precipitation, Maulé and Chanasyk (1990) reported that snowmelt recharge, measured from fall to post-melt in the spring, was 36% greater in fields that were chiseled in the fall compared to fields that were not chiseled. Lal and Steppuhn (1980) reviewed literature on the effect of fall tillage on soil water storage and found that on the Canadian Prairies, tillage did not increase overwinter soil water storage.

Management practices that combine the use of stubble management for snow catch and contour-ripping for water infiltration have potential to reduce runoff and increase soil water storage. In southern Saskatchewan, Canada, Gray et al. (1990) reported greater spring wheat yields on plots that had been managed for snow catch and water infiltration than on undisturbed stubble checks. In the inland Pacific Northwest where freezing and thawing accounts for a significant portion of the soil erosion problems, Saxton et al. (1981) used slot-mulching, also termed vertical mulching (Spain and McCune 1956), to reduce water runoff from frozen soil. Saxton et al. (1981) found that water runoff was ten times greater on no-till check plots compared to the slot mulch plots. Pikul et al. (1992) have shown that soil ripping can intercept and infiltrate meltwater through frozen soil and that spacing of soil rips can be estimated from historic precipitation patterns and permeability of unfrozen subsoil. Methods that increase snowmelt infiltration when the soil is frozen need to be considered as part of the management plan in regions where soil water limits plant growth and where soil erosion may be a problem. Our hypothesis is that tillage-induced macroporosity provides important preferential water flow paths through slowly permeable frozen soil. This hypothesis needs to be tested for a variety of soils and weather conditions. Our objective was to investigate soil ripping as a tillage practice to improve water infiltration into frozen soil.

Materials and methods

Experimental sites. Water infiltration studies on frozen soil were conducted at three sites near Pendleton, Oregon, and at a fourth site near Culbertson, Montana, on slopes that ranged from nearly level to 38%. Pendleton has a Mediterranean climate; annual precipitation (61-year average) is 413 mm (16.27 in) (65% during October through March). Culbertson has a continental climate; annual precipitation (27-year average) is 359 mm (14.14 in) (20% during October through March). Average precipitation for Pendleton, Oregon, and Culbertson, Montana, are shown in Figure 1.

Oregon. Site 1 was on a Walla Walla silt loam (Typic Haploxeroll) with no appreciable slope. This field has been in a summer fallow-winter wheat rotation where primary tillage was with a moldboard plow in the spring of the fallow year. Secondary tillage was done with a spring tooth harrow and rodweeder during the summer. Winter wheat was seeded in September 1987. Wheat was mowed to a height of about 0.10 m (4 in) in June 1988 to create uniform surface cover. Cut wheat was raked and removed from the field. Regrowth was killed with glyphosphate. A single 0.05-m (2.0 in) wide straight shank chisel was used to rip the soil 0.20 m (8 in) deep on 6-m (19.7 ft) intervals before soil freeze-up. Soil water content at the time of ripping was $0.14 m^3 m^{-3}$. Treatments were rip or no rip.

A Palouse rainfall simulator (Bubenzer et al. 1985) was used to apply water at a rate of 31 mm h^{-1} to 1 m^2 (1.2 in h^{-1} to 10.76 ft^2) infiltration frames. Infiltration frames were constructed of heavy gage sheet metal and driven into the soil to a depth of 0.25 m (9.8 in) before soil freeze-up. Infiltration frames were installed at randomly selected locations on rip and no rip areas. Inside edges of the infiltration frames were sealed with bentonite clay to prevent water leakage along the metal-soil interface. For the rip treatment, infiltration frames were centered over the fracture zone. Soil was removed from the rip adjacent to the outside of the infiltration frame, then backfilled and packed to eliminate lateral flow of water.

Water application rates were measured by collecting the runoff from a 1 m^2 cali-

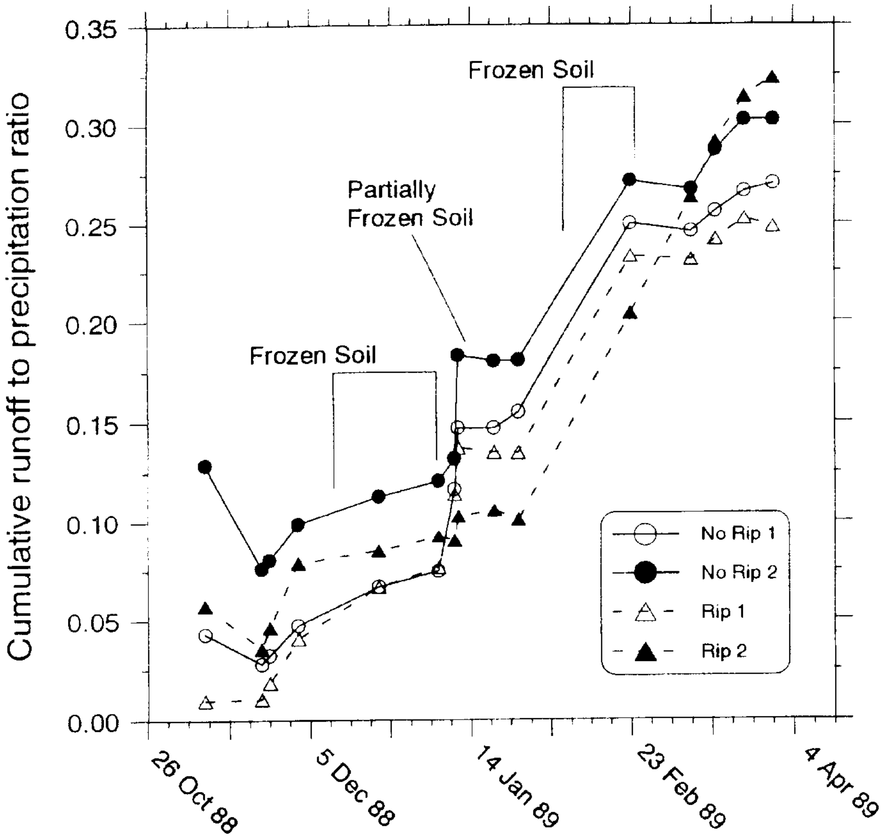

Figure 4. Ratio of cumulative runoff to cumulative precipitation at site 2 on Athena silt loam
(Note: Vertical lines indicate times when the soil was frozen at least 0.05 m deep. Each tick mark corresponds to 5 days.)

bration pan placed over the infiltration frame at the beginning and end of each test. Water was applied for 3 hours. Water temperature for all infiltration tests was close to 0°C to imitate the temperature of runoff from snowmelt. Infiltration rate was calculated as the difference between application rate and runoff rate. This simulator has two rainfall heads, which provided simultaneous infiltration measurements on the rip and no-rip treatments. Infiltration measurements with the simulator were not replicated because of the difficulty of moving the simulator following the frozen soil tests. Infiltration was measured in December 1988 and February 1989. The soil was frozen to a depth of 0.12 m (4.7 in) at the time of the December tests and 0.35-m (13.8 in) for the February tests. After the December tests the soil completely thawed and refroze prior to the February tests. Infiltration frames used for the December tests were not reused for the February tests. Soil bulk density on the no-rip treatment was measured in 0.02-m (0.79 in) increments to a depth of 0.5 m (19.69 in) with a tube sampler having an inside diameter of 20.4 mm (0.8 in) (Allmaras et al. 1988). Twelve cores, each cut into 20-mm (0.79 in) segments, were taken to estimate bulk density. Soil samples for gravimetric soil water content were taken from outside of the infiltration frame.

Site 2 was on an Athena silt loam (fine-silty, mixed, mesic Pachic Haploxeroll) on a 33 to 38% slope. This field has been managed in a wheat-fallow rotation and is highly erodible. Primary tillage was with a moldboard plow in the spring of 1988. Secondary tillage was with a field cultivator and rodweeder during the summer. Winter wheat was seeded October 13, 1988, into a dry seedbed. After seeding, the field was ripped at contour intervals of about 8 m (26.25 ft) to a depth of 0.30 m (11.81 in) using a special single-shank tillage tool designed to rip the soil and create a series of pock marks along the rip-path (Wilkins et al. 1991). Ripping failed to create a well defined macropore channel that was open to the surface because dry soil flowed into the rip. Treatments were rip and no rip. Water runoff during the winter of 1988-1989 was measured using duplicate bordered runoff plots on the rip and no rip treatments. Each runoff plot was 3.33 m^2 (35.84 ft^2). Corrugated sheet metal borders were driven about 0.15 m (5.9 in) deep into the soil. On the rip treatment, borders were installed so that the rip was located in the lower (down slope) portion of the runoff plot near to the collector. This provided a 2.7 m (8.86 ft) catchment up slope from the rip. The intent of this positioning was to test the capability of the rip to intercept runoff. Runoff was measured from November 8, 1988, to March 30, 1989. Soil temperature was measured at a depth of 0.05 m (1.97 in) and was used to determine when the soil was frozen.

Site 3 was on a Palouse silt loam (fine silty, mixed, mesic Pachic Ultic Haploxeroll) on a 18% slope. This field has been classified highly erodible by the Natural Resources Conservation Service. Primary tillage was with a moldboard plow in the spring of the year. Secondary tillage was done with a spring tooth harrow and rodweeder during the summer. Winter wheat was seeded September 1990. The field was ripped at contour intervals of about 8 m (26.25 ft) and to a depth of 0.30 m (11.81 in) on December 31, 1990, when the soil was frozen 0.10-m (4 in) deep. Ripping was done using a special single-shank tillage tool designed to rip the soil and create a series of pock marks along the rip path (Wilkins et al. 1991). Ripping when the soil was frozen resulted in a well defined ripping trough that remained opened to the surface which is in contrast to the ripping performed on Site 2 when the soil was loose and dry.

Borders for the infiltration plots were installed when the soil was frozen by first cutting through the frozen soil with a carbide-tipped chainsaw perpendicular to the direction of the rip. On the no-rip treatment, cuts were made perpendicular to the seed row (furrow). Steel plates were driven into the cuts 0.3 m (11.81 in) deep to define a 1-m (3.28 ft) length of ripped soil on the rip treatment and 1-m length of furrow on the no-rip treatment. Inside edges of the plates were sealed with bentonite clay to prevent water leakage along the metal-soil interface. Soil was compacted on the outside of the plate to eliminate lateral flow of water. The effective area for infiltration was defined by the steel plates and the soil berm and was approximately 0.27 m^2 (2.9 ft^2) on the rip treatment and 0.13 m^2 (1.4 ft^2) on the no-rip treatment. Infiltration frames were installed at three randomly selected locations on the rip treatment and two randomly selected locations on the no-rip treatment.

Ponded infiltration tests were made on January 3, 1991, when the soil was frozen 0.16-m (6.3 in) deep. A ponded infiltration test imitates runoff events where water would naturally accumulate in the

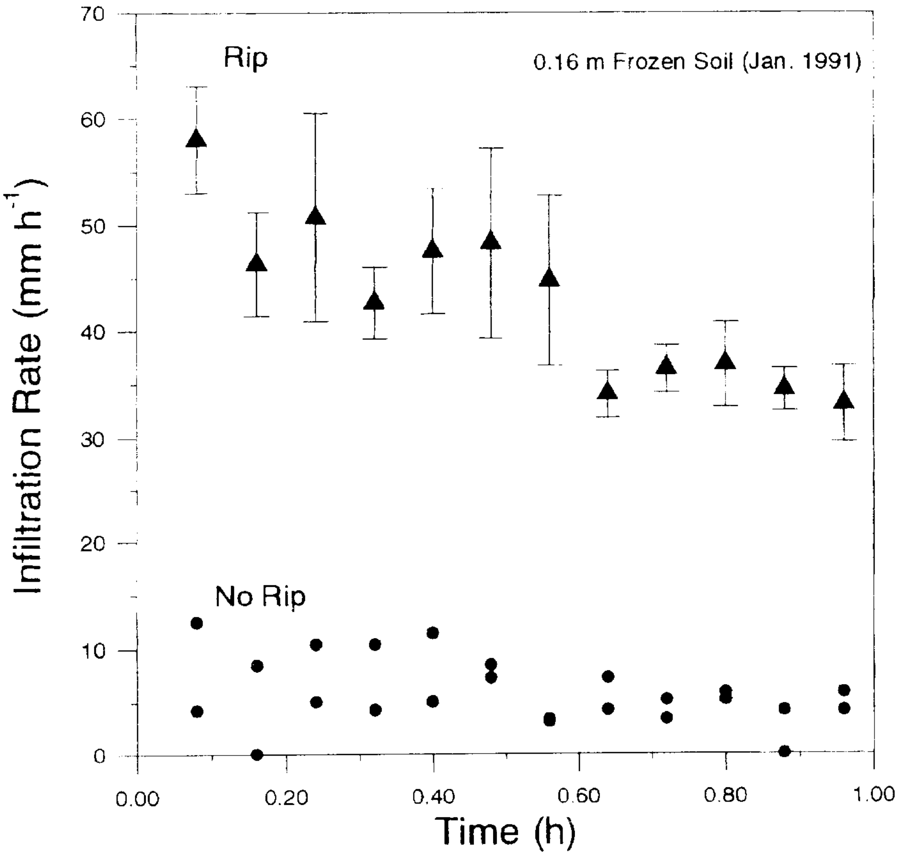

Figure 5. Water infiltration on rip and no-rip treatments at site 3 on Palouse silt loam when the soil was frozen to 0.16m
(Note: Brackets show one standard deviation for the rip treatment and duplicate data points are shown for the no-rip treatment.)

rip or the furrow of the seed row. Water temperature for all infiltration tests was close to 0°C to imitate the temperature of runoff from snowmelt. At the start of the infiltration test, an estimate of surface storage was made by rapidly filling the rip or furrow with water.

Montana. Site 4 was located near Culbertson, Montana, on a Dooley sandy loam (fine-loamy, mixed Typic Argiboroll) with about a 5% slope. Prior to 1975, the experimental area was in grass. Between 1975 and 1991 the land was cropped in a wheat-fallow rotation. On both the rip and no-rip treatments, spring wheat has been grown annually since 1991. Seedbeds were prepared with 0.45 m (17.7 in) wide medium-crown sweeps. In 1992 wheat was harvested using a conventional combine header. Stubble height was about 0.20 m (8 in). In 1993 wheat was harvested with a stripper header which left stubble almost as tall as the 0.6-m (23.6 in) uncut crop. Plots were 79-m (259.2 ft) long and 23-m (75.5 ft) wide with the long axis parallel to the slope. In October 1992 and 1993 a single 0.05-m (1.92 in) wide parabolic sub-soiling shank was used to rip the soil 0.30 m (11.81 in) deep on 6-m (19.7 ft) contour intervals. Statistical design was completely randomized with three replications of rip and no-rip treatments.

Infiltration frames were 1.16 m (3.8 ft) long by 0.61 m (2 ft) wide by 0.3 m (11.81 in) deep and were installed on each replication of each treatment prior to soil freezing in 1992 and 1993. Edges were sealed using techniques previously described. Ponded water infiltration tests were made in January 1993 when the soil was frozen to a depth that exceeded 1 m (3.28 ft) and in February 1994 when the soil was frozen 0.6 m (2.0 ft) deep. Water temperature for all infiltration tests was close to 0°C to imitate the temperature of runoff from snowmelt. At the start of the infiltration test, an estimate of surface storage was made by rapidly filling the rip or furrow with water.

Soil bulk density on the no-rip treatment was measured in 0.03-m (1.2 in) increments to a depth of 0.6 m (2 ft) using the tube sampler previously described. Three cores were taken from each replication of the no-rip treatment. Soil samples for gravimetric soil water content were taken outside the infiltration frame.

Results and discussion

Timing of precipitation can be an important factor affecting water intake into frozen soil. Generally, a soil frozen in a wet state will have less infiltration capacity than the same soil frozen at a lower water content. Average precipitation for Pendleton, Oregon, and Culbertson, Montana, are shown in Figure 1. Rains in October and November at Pendleton may be a liability for infiltration later in the winter because the soil surface freezes in a wet state. In contrast, there are few autumnal rains in eastern Montana and with annual cropping practices, the soil generally freezes in a drier state than that of eastern Oregon. For the infiltration measurements conducted in Oregon (site 1, 2, and 3) precipitation was 23 mm (0.91 in) below normal for measurements made on December 28, 1988; normal for measurements made on February 2, 1989; and 51 mm (2 in) below normal for measurements made on January 3, 1991. For the infiltration measurements conducted in Montana (site 4), precipitation was 26 mm (1.02 in) below normal for measurements made on January 20, 1993, and 29 mm (1.14 in) below normal for measurements made on February 16, 1994.

Water infiltration rates vary between soil types and wide differences in infiltration can occur within a given soil type because of different antecedent soil water contents or management that has created unique tillage pans. Soil bulk density for the Walla Walla silt loam and Dooley sandy loam are shown in Figure 2. The Walla Walla soil is a loess and has a very uniform texture (55% silt) in the top 0.5 m (19.7 in). A distinct increase in bulk density at about 0.2 m (7.9 in) roughly corresponds to the depth of moldboard plowing. Soil ripping did not penetrate the tillage pan. The Dooley sandy loam is glacial till. In the top 0.3 m (11.81 in), sand content decreases from about 65% at 0.05 m (1.97 in) to about 55% at the 0.3-m depth, while clay content increases from about 12% to 20%. The distinct increase in bulk density starting at about 0.05 m (Figure 2) roughly corresponds to the depth of sweep tillage. This pan was fractured by ripping with the parabolic subsoiling shank.

Infiltration. *Oregon.* In the inland Pacific Northwest there are frequent freezing and thawing cycles each year (Zuzel et al. 1986). However, the depth of freezing is typically shallow and rarely exceeds 0.4 m (15.75 in) under a bare surface. In the ab-

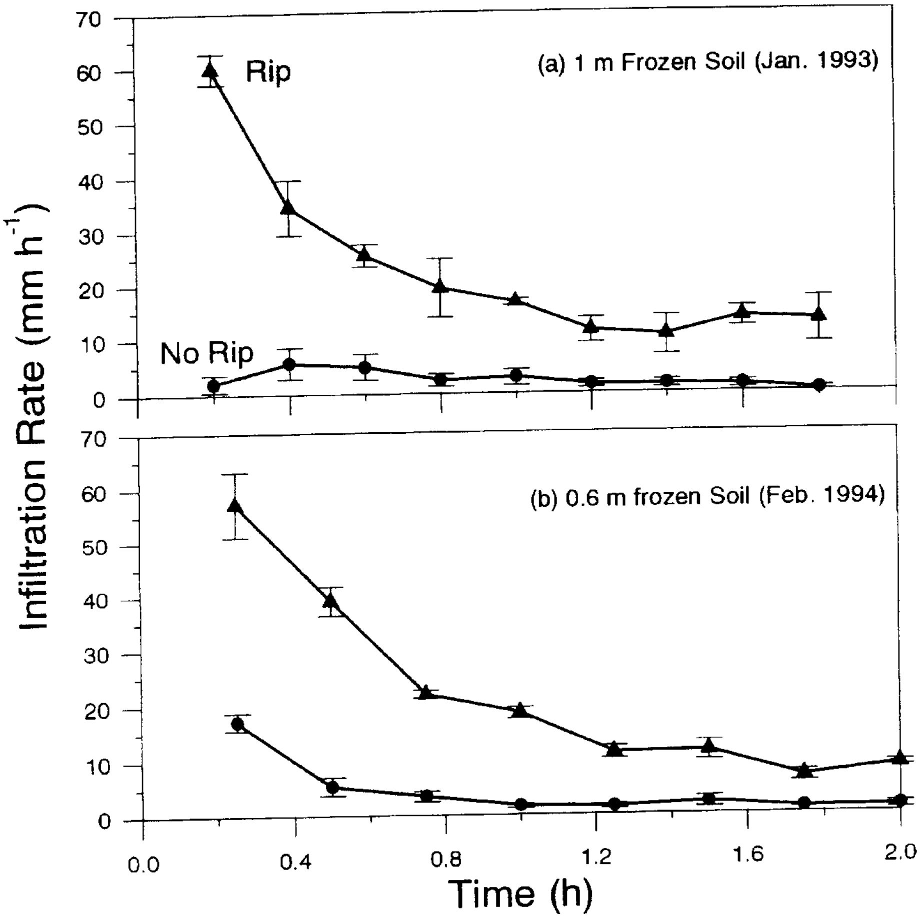

Figure 6. Water infiltration on rip and no-rip treatments at site 4 on Dooley sandy loam when the soil was frozen deeper than 1 m (a) and 0.6 m (b)
(Note: Brackets show one standard deviation.)

sence of snow cover, freezing depth can be 35% less under standing stubble than under a bare surface (Pikul et al. 1986). Depths of frozen soil at the time of the infiltration measurements (Table 1) are typical of the expected freezing depths in eastern Oregon.

Site 1. This field was ripped when the soil was consolidated but unfrozen. Large clods and fractures and incorporated straw in the ripping trough provided a system of surface-connected macropore channels that remained open throughout the winter. For the December 1988 infiltration tests, the depth of frozen soil was less than the depth of tillage and surface connected macropores provided important preferential water flow paths. Final infiltration rate on the rip treatment was 21 mm h^{-1} (0.83 in h^{-1}) compared to 0 mm h^{-1} on the no-rip treatment (Figure 3a). The Walla Walla soil when frozen at a water content of 0.6 m^3 m^{-3} and not ripped (Table 1) was impermeable. High water content in the surface 0.05 m (1.97 in) was a consequence of water accumulation due to the freezing process.

Depth of freezing may limit the effectiveness of ripping as a means to increase water infiltration on the Walla Walla soil. There was no difference in water infiltration when the depth of freezing was greater than the depth of ripping (Figure 3b). Depth of ripping was 0.20 m (7.87 in). Water content of the frozen soil directly under the rip was 0.26 m^3 m^{-3}. When the Walla Walla silt loam soil was

Table 1. Selected soil and infiltration parameters for the infiltration tests conducted in Oregon and Montana

Infiltration test	Soil volumetric water content on day of test: 0 to 0.05m	Soil volumetric water content on day of test: Bottom of rip	Snow water equivalent on day of test mm	Surface storage on day of test* mm	Temperature of water used for infiltration test °C	Final infiltration rate† mm/h
Site 1						
0.12 m frozen soil (Dec. 1988)						
Rip		0.27	0		0.8	21
No-Rip	0.6		0		0.8	0
0.35 m frozen soil (Feb 1989)						
Rip		0.26	0			1
No-Rip	0.64		0			0
Site 3						
0.16 m frozen soil (Jan 1991)						
Rip		0.25	0	40 (55)‡	0.1	35±6
No-Rip	0.44		0	7 (0)	0	4 (4)
Site 4						
1+m frozen soil (Jan 1993)						
Rip		0.26	28	49±4	0	12±6
No-Rip	0.31		28	11±2	0.3	1±1
0.6 m frozen soil (Feb. 1994)						
Rip		0.24	69	56±4	2.5	9±2
No-Rip	0.24		69	5±2	3.0	1±1

* Water storage capacity of ripped trough or non-ripped surface
† Final infiltration rate following 3 h of water application on the Walla Walla soil, 1 h of water application on the Palouse soil, and 2 h water application on the Dooley soil.
‡ Duplicate runs are indicated in parenthesis, otherwise ±1 standard deviation.

frozen, even at a relatively low water content, infiltration was reduced (Table 1). At Site 1, ripping did not fracture the tillage pan which is located at about 0.20 m (Figure 2). Pikul and Allmaras (1986) have shown that the unfrozen saturated hydraulic conductivity of the tillage pan was nearly ten-fold less than the underlying soil. The combination of frozen soil and inherently low unfrozen saturated hydraulic conductivity of the tillage pan may explain why infiltration was reduced when this soil was frozen, even at a relatively low water content.

Site 2. The sequences of tillage during the summer preceding wheat seeding created a pulverized, dry soil that was vulnerable to soil erosion. Because of the dry fall conditions, wheat was seeded into a dry seed bed. Ripping failed to create well defined macropore channels opening to the surface because dry soil flowed into the rip and obliterated the path of the ripping tool. Scanty amounts of crop residue provided little surface protection from an intense 35 mm (1.38) rain storm during the end of October and before soil freeze-up. Down-slope soil movement from this one event silted-in most of the depression areas that were created by ripping.

Runoff measurements from November 9, 1988, to March 30, 1989, failed to show consistent differences between rip and no rip treatments (Figure 4). During a period of intermittent freezing and thawing from January 6, 1989, to January 11, 1989, the ratio of runoff to precipitation increased 70% on the no rip treatment and 42% on the rip treatment. During this short time interval runoff was reduced from the rip treatment. For the season, the ratio of cumulative runoff to cumulative precipitation was 33% on both the rip and the no rip treatments. These data show that there was little beneficial effect of ripping on water infiltration when surface connected macropore channels were silted-in.

Site 3. This site was similar to Site 2 having a sequence of tillage during fallow which left the surface pulverized. Because of the loose soil conditions at seeding time, ripping was deferred until the soil froze approximately 0.10 m (4 in) deep. When frozen, this soil maintained tillage structure which was evidenced by large well defined fractures in the tillage trough opening to the surface. Infiltration measurements when the soil was frozen to a depth that was less than the depth of tillage showed trends that were similar to the measurements made at Site 1. Final infiltration rate on the rip treatment was about 14 mm h^{-1} (0.55 in hr^{-1}) greater than that measured at Site 1. Water content of the top 0.05 m (1.97 in) was 0.44 m^3 m^{-3} (Table 1). This soil froze at a water content that was less than that of Site 1, and final infiltration on the rip treatment was nearly 10 times greater than on the no-rip treatment (Figure 5).

Montana. There is considerable variability in winter weather across Montana. One broad classification to characterize freeze-thaw frequency has been to map the frequency of Chinooks (Capri et al. 1981). Culbertson, Montana, is located in an area of low Chinook frequency. Typically, there is one freeze-thaw cycle where the soil can freeze as early as the first part of November and remain frozen through March. In both 1993 and 1994 the soil froze deeper than 0.6m (23.62 in) (Table 1).

Infiltration was measured during two winters. In January 1993 and February 1994, soil water content at the surface was less than that of the Oregon test sites, but at the depth of tillage, soil water content for the Montana test site was similar to that of the Oregon test sites (Table 1). During the 1993-1994 winter, tall wheat stubble trapped snow and accumulated 69 mm (2.72 in) snow water equivalent (Table 1). By comparison, adjacent fields that had 0.2 m (7.87 in) stubble accumulated only about 20 mm (0.78 in) snow water equivalent.

Similar to the Oregon tests, water infiltration was greater on the rip treatment compared to the no-rip treatment (Figure 6). The soil was frozen deeper than 1 m (39.37 in) during the 1993 tests and to 0.6 m (23.62 in) during the 1994 tests (Table 1). In both years the depth of ripping was 0.3 m (11.81 in) and final infiltration rate averaged 1 mm h^{-1} (0.04 in hr^{-1}) on the no-rip treatment and 11 mm h^{-1} (0.43 in hr^{-1}) on the rip treatment.

Infiltration rates into frozen soil have been shown to be closely linked to soil water content at the time of freezing. However, soil water content alone cannot be used to explain why the ripped treatment had greater water infiltration than the non-ripped treatment in 1994, because soil water content at the surface was the same as soil water content at the depth of tillage (Table 1). Thin surface crusts that form as a result of high intensity summer rainstorms cause reduced water infiltration in unfrozen soil (Pikul and Aase 1995). These same crusts when frozen at relatively low water content could be expected to further reduce water infiltration. Our measurements show a difference in water infiltration between ripped and non-ripped soil and the disruption of surface crusts and tillage pans by ripping as well as the creation of preferential flow paths may all contribute to the increased water infiltration on the ripped plots.

Conclusions

Infiltration tests were conducted at four sites with three different ripping tools. Specific tillage tools were not evaluated in this study; however, the objective of ripping was to create large soil fractures that remained open to the surface throughout the winter. Ideal fracture zones could be obtained by ripping a soil that was consolidated and at an intermediate water content; however, weather vagaries often create conditions that are less than ideal. For example, at Site 2, there was little benefit of ripping a dry pulverized soil in anticipation of improving water infiltration later in the winter because loose soil flowed into the rip and obliterated the rip path. Unfortunately, fields such as this present the greatest risk for water runoff and soil erosion during the winter following fall seeding. The field at Site 3 was also mechanically summer fallowed, but desirable macropore structure was achieved by deferring ripping until the soil was frozen. Between fall seeding and soil ripping at freeze-up the field was vulnerable to runoff and erosion, therefore ripping alone should not be considered a substitute for residue management systems that maintain surface cover. At Site 1 and 4 the soil was consolidated at the time of tillage. Ripping created large clods and consequently large fractures, which remained open to the surface throughout the winter. In addition, the surface was protected by residue cover. The annual wheat cropping system at Site 4 provided ideal conditions to combine management of residue for snow catch and surface cover and tillage for increased water infiltration. Tests at Site 4 are continuing to assess the effect of ripping on soil water recharge and grain yield.

Infiltration measurements are important because they show similarities of the effect of ripping on water infiltration at three sites. With the exception of one test, ripping increased water infiltration into frozen soil compared to non-ripped checks. In the inland Pacific Northwest soil losses due to water erosion can be especially high during heavy rainfall or snow melt when a thawed soil layer overlies a frozen layer. Ripping in combination with other conservation practices provides another tool to reduce water runoff and soil erosion. In the northern Great Plains snow is an important water resource and snow trapping with standing wheat stubble is an important part of overall water management. Infiltration measurements show that ripping has the potential to increase overwinter soil water storage when used in conjunction with stubble management methods that maximize snow trapping.

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