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Mow-plow crop residue management influence on soil erosion in north-central Oregon

John D. Williams*, Dale E. Wilkins, Clyde L. Douglas Jr., Ronald W. Rickman

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This implies research on: characterization or modeling of tillage and field traffic effects on the soil environment; the selection, adaption,or development of tillage systems (including reduced cultivation and direct drilling) suitable for specific conditions of soil, climate, topography, irrigation and drainage, crops and crop rotations, intensities of fertilization, degree of mechanization, etc. and the appropriate use of tillage systems to maintain a balance between acceptable crop production, sustainability and minimum environmental impacts. In this context, papers on the characterization or modeling of tillage effects on: soil physical, chemical and biological properties, processes related to surface and subsurface ground-water quality, soil erosion, carbon and nutrient cycling and crop production, are most welcome . Papers on soil deformation processes, soil-working tools and traction devices, energy requirements and economic aspects of tillage are also considered. Attention will also be given to the role of tillage in weed, pest and disease control. Starting from 1998 the journal incorporates *Soil Technology.*

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Abstract

Soil loss from dryland farms on the Columbia Plateau in Oregon and Washington (USA) results primarily from rain falling on frozen, cultivated soil. Soils are most susceptible to erosion when moldboard plowed, summer-fallowed, repeatedly rod-weeded or cultivated, and fall planted to winter-wheat. These tillage practices are used because they help control weed and disease infestations and consistently produce good crops. Unfortunately, they also destroy soil structure and lead to considerable soil loss by water erosion. Conservation-tillage-practices have not been widely accepted because of associated weed and disease problems. A new conservation system using crop residue management, the mow-plow system, has shown promise for weed control. The moldboard plow is the primary tillage tool, but standing crop residue is cut ahead of the plow and distributed onto the adjacent plowed surface. The system requires a single pass of the equipment. We evaluated runoff and erosion responses in two levels of residue application in the mow-plow (L∼23% and H∼36% cover), traditional moldboard plow, and chisel plow winter-wheat/summer-fallow systems near Pendleton, OR, USA. Following extended periods of sub-freezing air and soil temperatures, we simulated rainfall at 9, 13, and 19 mm h^{-1} and collected runoff to evaluate water and soil loss as the soil thawed. Runoff was not significantly different among treatments. For each of the three rainfall intensities, the chisel plow treatment provided the best protection against soil erosion at 0.11, 0.39, and 0.95 Mg ha^{-1} h^{-1}, followed closely by the mow-plow (H) 0.26, 0.55, and 0.90 Mg ha^{-1} h^{-1}. The moldboard plow treatment was the least effective treatment for erosion control (0.57, 1.38, and 3.76 Mg ha^{-1} h^{-1}). The erosion response from the mow-plow (L) treatment was variable and not statistically different from the moldboard plow treatment (0.33, 2.49, and 1.71 Mg ha^{-1} h^{-1}). These results demonstrate the importance of maintaining cover on the soil surface. The mow-plow system, where adequate straw residue is available, is superior to moldboard plow system for soil conservation. Published by Elsevier Science B.V.

Keywords: Conservation tillage; Residue management; Rainfall simulation; Soil erosion; Infiltration; Frozen soil; Freeze-thaw cycles; Winter-wheat/summer-fallow

1. Introduction

Soil erosion in the dryland cropping areas of the Columbia Plateau in Oregon and Washington regu-

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larly occurs during low intensity rains falling onto bare or snow covered frozen soil (Zuzel et al., 1982). Soil loss is greatest from the approximately 1.8 million ha (Smiley, 1992; McCool et al., 1993) planted to winter-wheat (*Triticum aestivum* L.) following summer-fallow. Annual crops, fall or spring seeded, are most common in the high precipitation areas of the region, but have not attained widespread acceptance in the intermediate precipitation zones. Precipitation is not sufficient to produce an annual crop in at least one third of this region. Common throughout the entire range of rainfall, however, is a crop sequence that includes winter-wheat, 60% of it preceded by summer-fallow, wherein the resulting stubble is moldboard plowed before the erosion season (Hammel, 1996; Papendick, 1996). Soil losses from this crop sequence are estimated to have averaged 2.3 Mg ha^{-1} per year between 1939 and 1978 (USDA, 1978).

Farming practices must be designed to conserve soil water to meet crop water requirements in this region where effective precipitation generally ends by early June, especially in the dryer areas. After harvest, fall, winter, and spring precipitation can, if it infiltrates, be stored in the soil profile. During the following summer, fields are fallowed to minimize soil water loss through typically hot, dry summers. Traditionally, primary tillage is with a moldboard plow, either in late fall or early spring following harvest. Subsequent tillage operations are used to control weed establishment and minimize summer evaporative loss of soil water by creating a loose, powdered soil surface nearly devoid of residue. Winter-wheat is seeded from late August to early November. Through the winter erosion season, the recently emerged wheat provides the only protection against sheet and rill erosion.

Rills account for approximately 90% of the eroded material from croplands in this region (Zuzel et al., 1993). Zuzel and Pikul (1993) speculated that less than 25% soil surface cover is ineffective for erosion control, whereas McCool et al. (1987) reported 92% less erosion from surfaces with 1.1 Mg ha^{-1} (50% cover) surface residue relative to bare surfaces. Once rills begin to form, residue incorporated near the soil surface reduces soil erosion by minimizing shear stress on soil particles in the rill bed and walls (Van Liew and Saxton, 1983).

Sheet flow also contributes to the erosion process, before becoming concentrated flow in rills. A number of factors can slow or impede sheet flow. Tillage practices that leave a rough surface produce detention storage to collect and hold water from small impermeable runoff areas and provide open, unfrozen pathways into the soil surface. However, surface roughness is lost following seeding in conventional farming systems. Abundant stubble and root crowns also provide cover and soil structure, reducing raindrop impact energy and providing pathways for infiltration. Unfortunately, residue provides a potential reservoir for disease and reduces the efficiency of seeding equipment. These problems are largely solved by burying the crop residue with the moldboard plow. Either plowing or stubble will reduce overland flow and sheet erosion during the fallow period, but secondary tillage, often up to six additional passes with field cultivators or rod-weeders, leaves the soil surface bare following fall planting.

A minimum of 30% cover is reported to provide reductions of 53% sheet erosion, 78% rill erosion, and 65% mixed sheet and rill erosion, relative to bare soil (Renard et al., 1997). To obtain cover of this level or greater, no-till and chisel plowing are available alternatives to traditional moldboard plowing. These non-inversion tillage methods leave more crop residue at or near the soil, but also leave abundant weed seeds near the soil surface. Therefore, over-abundant residue is often burned to reduce pathogen substrate, weed seeds, and improve seedbed preparation. Occasionally, burning is used in conjunction with moldboard plowing. Either combination of practices results in depleted residue to cover the soil.

A solution to the dilemma of either having surface residue with associated disease and weed infestations or insufficient residue for protection against erosion is the mow-plow residue management system (Wilkins and Williams, 1997). The mow-plow residue management system was developed to help manage heavy crop residues, and eliminate weed and seedbed preparation problems while providing protection against soil erosion. Kladivko (1994) proposed four main categories for residue placement: (1) on or above the soil surface; (2) partially incorporated, with considerable residue still present at the surface; (3) completely incorporated; and (4) completely removed. The chisel plow treatment falls into the category of partially incorporated but with considerable residue remaining at the surface and the moldboard plow treatment fits into the completely incorporated category. The mow-plow system is a hybrid of the categories 1, 3, and 4, wherein residue is removed, weedseeds and root crowns are completely incorporated, and the straw is replaced on the soil surface. Preliminary studies indicate this system does not increase soil-borne disease problems over traditional moldboard tillage and provides effective weed control (Wilkins and Williams, 1997).

Our objective is to determine the relative effect on soil erosion and surface runoff of the mow-plow system compared to moldboard and chisel plowing. Because of the nature of these treatments, we were also able to examine the influence of residue type, e.g., stems, crowns, and roots, on soil erosion. We expected better runoff and erosion control from the chisel plow treatment compared to high and low level residue application using the mow-plow treatments, and the mow-plow treatments to be superior to the moldboard plow treatment. These results would demonstrate the importance of roots and crowns near the soil surface for decreasing runoff and controlling erosion.

2. Materials and methods

2.1. Location

We collected runoff and erosion data from plots located within two field ≈15 km north of Pendleton, OR, at 45°43′30″N, 118°39′30″W, elevation 410 m and 45°47′30″N, 118°38′55″W elevation 525 m. Meteorological records at the Columbia Plateau Conservation Research Center (CPCRC), located within 15 km east of the research sites, show 39-year minimum, maximum, and mean annual temperatures of −34, 46, and 11°C, respectively. Frost-free days range from 135 to 170. Approximately 70% of precipitation occurs between November and April and results from maritime fronts that produce low intensity storms with a median duration of 3 h, 50% lasting 1–7 h. The maximum, recorded 1 h storm intensity is 13 mm h^{-1} and median storm size is 1.5 mm at 0.5 mm h^{-1} (Brown et al., 1983). Annual precipitation and annual accumulated snow depth average 422 and 474 mm, respectively. An analysis of 10 years of data collected at CPCRC shows that 95% of the 1 h precipitation records in this area are ≤9.0 mm h^{-1}. Snow cover is transient and subject to rapid melting by frequent, warm maritime fronts. At each research site, a meteorological station recorded precipitation, wind speed and direction, solar radiation, relative humidity, and air and soil temperature from planting until harvest.

The soil type at both research sites is a Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll — US; Kastanozems — FAO); the 1996 site on a west–northwest aspect with a 23% slope and the 1997 site on a west aspect with a 5% slope. Soil development occurred within a mantle of loess derived from Pleistocene alluvial deposits onto Basalt flows of the Miocene Epoch (Johnson and Makinson, 1988). The previous crop at each site was soft, white winter-wheat (*Triticum aestivium* L.) following summer-fallow.

2.2. Rainfall simulation

Four crop residue treatments received simulated rainfall during the warming phase of five freeze-thaw cycles, two in February, 1996 and three in January, 1997. The freezing periods were sufficiently cold to freeze the soil 150–450 mm deep. Plots were 1.5 m wide×9.1 m long plots, and sized for the Pacific Northwest Rainfall Simulator (Williams et al., 1998). The simulator produced rainfall at 9 mm h^{-1} (low), 13 mm h^{-1} (middle), and 17 mm h^{-1} (high). The sequence of application was: low intensity for 90 min after runoff began, then middle intensity an additional 40 min, and finally a high intensity for 40 min. A change in intensity required a 5 min shut down. Greater than 90% of the storms on the Columbia Plateau are equal to or less than the low rainfall rate, and the middle and the high rate occur for short periods. We recorded time-to-ponding, time-to-runoff, and runoff in 10-min intervals for 180 min. Runoff was collected in 1 l bottles, which were weighed, dried at 105°C, and then reweighed to determine both rate of runoff and soil loss. Runoff weights were converted to depth values. Douglas et al. (1997) analyzed the runoff for nutrient loss. We also recorded soil moisture before rainfall simulation, soil, air, and water temperature during simulation, frozen soil depth before and after simulation, snow depth when appropriate, and percent ground (green and residue) cover.

2.3. Residue placement treatments

Residue placement treatments consisted of: (1) moldboard plow; (2) chisel plow, and two levels of surface residue placement using the mow-plow system; (3) mow-plow (L) and (4) mow-plow (H). We applied 2.11 Mg ha^{-1} straw residue to the mow-plow (L) intending to create 35% cover after secondary tillage (e.g., field cultivation, rod-weeding), fertilizing, and seeding (Wischmeier and Smith, 1978). Thirty-five percent cover meets a conservative, post-seeding minimum necessary to reduce erosion by 50% compared to bare soil (Zuzel and Pikul, 1993). The mow-plow (H) treatment received 6.21 and 4.17 Mg ha^{-1}, equal to measured, above ground straw residue in 1995 and 1996, respectively. The mow-plow system consists of a harvester-header front mounted on a tractor pulling a moldboard plow. The harvester-header cuts and conveys standing wheat stubble onto soil plowed on the previous circuit and the plow inverts and buries the remaining uncut stubble, crowns, and weed seeds. Thus, each circuit of the field moves weed-seed-free wheat straw onto the previous moldboard pass. The amount of crop residue left to be inverted is controlled by adjusting the header height. Subsequent rod-weeding and planting incorporated some of the wheat straw 20–100 mm into the soil surface. For this experiment, the residue was placed on plot surfaces by hand instead of by the harvester-header. Wheat stubble removed from the treatment area was stored off site while tilling the plots with a two-bottom moldboard plow, and the appropriate weight of air-dried residue redistributed onto the plot surfaces.

We seeded Stephens variety soft, white winter-wheat on 29 September 1995 at 0.120 Mg ha^{-1} and on 10 October 1996 at 0.128 Mg ha^{-1} using a Great Plains drill set to a 33 mm depth. Because of plot locations in the cooperator's fields, seeding direction in the first year was on the contour and across contour the second year. Plant development at time of rainfall simulations each year was 3.5 leaf main stem haun stage (Klepper et al., 1982).

2.4. Experimental design and statistical analysis

We simulated rainfall five times over a period of 2 years (n=5) during five thawing events. Each rainfall simulation was onto four treatments (residue placement), simultaneously. Response variables tested for treatment effect were cover, antecedent soil moisture, depth of frozen soil, time to ponding, and time to runoff, all one-time measurements, and rates of runoff and erosion. We calculated runoff and erosion rates for each treatment in each replication by regressing accumulated runoff and accumulated erosion values against time, respectively. Log-transformations of the rate values were necessary to meet assumptions of normality and homogeneity. A randomized block design, using date as the blocking factor, and analysis of variance was used to test for treatment effects. One-time measurements were analyzed using SAS Institute (1996) PROC GLM program. Runoff and erosions rates were analyzed using SAS Institute (1996) PROC MIXED program, where differences in variance were established ($P \leq 0.05$), mean separation tests were conducted using Scheffe's mean separation tests ($\alpha \leq 0.05$) for one-time measurements and least square means and Tukey–Kramer adjusted P values for runoff and erosion rate separation. Treatment differences are discussed based on pair-wise comparisons, using the moldboard plow treatment as the standard for conventional tillage and the chisel plow treatment as the standard for conservation tillage. Additionally, we graphically examine treatment responses under the specific weather conditions at the time of rainfall simulation. Rainfall was applied twice onto snow covered frozen soil, twice onto bare frozen soil, and once onto rapidly thawing soil.

3. Results

Ground cover in the chisel plow and mow-plow (H) treatments was significantly ($P \leq 0.00$) more abundant than in the mow-plow (L) and moldboard plow treatments (Table 1). The amount of residue applied in the mow-plow (L) was insufficient to meet the 35% cover goal, falling short by 12%. There were no treatment differences in antecedent soil moisture (P=0.97), depth of frozen soil (P=0.99), time to ponding (P=0.79), and time to runoff (P=0.47) (Table 1). Runoff rates were not different among treatments for any of the rainfall rates (9 mm h^{-1}, P=0.40; 13 mm h^{-1}, P=0.32; 18 mm h^{-1}, P=0.11) (Table 2). We observed small rills beginning to form during

Table 1
Plot conditions measured at time of rainfall simulation

Treatment	Cover ($Mg\ ha^{-1}$)[a]	Antecedent soil moisture (%)	Frozen soil depth (mm)	Time to ponding (min)	Time to runoff (min)
Chisel plow	0.90 (0.21) a	23 (9) a	146 (60) a	7 (7) a	60 (85) a
Moldboard plow	0.17 (0.07) b	23 (10) a	143 (56) a	5 (3) a	36 (43) a
Mow-plow (L)	0.46 (0.11) b	23 (9) a	145 (58) a	5 (2) a	45 (71) a
Mow-plow (H)	0.77 (0.18) a	23 (10) a	139 (60) a	4 (4) a	51 (59) a

[a] Treatment means with same letter are not different at α=0.01. Parentheses contain standard deviations.

rainfall simulation, and runoff contained sediment from both inter-rill and rill erosion. Erosion rates were not significantly different at the 9 mm h^{-1} rainfall simulations rate (P=0.07) but were at 13 mm h^{-1} (P=0.01) and 18 mm h^{-1} (P=0.00) (Fig. 1). Erosion rates within the treatments increased in the following manner: chisel plow<mow-plow (H)<mow-plow (L)<moldboard plow (Table 3).

4. Discussion

Secondary tillage to control weeds seals the soil surface and controls soil water content, depth of frost, and thus, the initial hydrologic responses of ponding and time to runoff (Hammel et al., 1981). Singh et al. (1996) provided evidence that residue has a greater influence than tillage on soil hydrology. Each of the four treatments in this study received the same secondary tillage. Any differences in hydrologic or erosional responses should, therefore, be attributable to a combination of primary tillage or to position (surface or buried) and type (straw, crowns, or roots) of residue following planting.

Table 2
Treatment runoff rate for at end of each rainfall simulation rate[a]

Treatment	Rainfall simulation ($mm\ h^{-1}$)		
	9	13	18
Runoff ($mm\ h^{-1}$)			
Chisel plow	0.5 (0.3) a	1.0 (0.5) a	1.3 (0.7) a
Moldboard plow	0.6 (0.3) a	1.0 (0.3) a	1.4 (0.4) a
Mow-plow (L)	0.6 (0.2) a	1.2 (0.4) a	1.6 (0.4) a
Mow-plow (H)	0.5 (0.3) a	1.0 (0.6) a	1.2 (0.7) a

[a] Treatment means with same letter are not different at α=0.05. Parentheses contain standard deviations.

Van Liew and Saxton (1983) and McCool et al. (1997) demonstrate the importance of shallowly incorporated and surface residue, respectively, for reducing erosion in winter-wheat/summer-fallow systems in the silt rich soils of the Palouse. Renard et al. (1997) demonstrated that residue distributed within 100 mm of the soil surface is the most effective placement for erosion control. In our research on the Columbia Plateau with similar soils and shallower slopes, the results are much the same. The chisel plow treatment produced the lowest erosion rates at all rainfall intensities, followed by the mow-plow (H) treatment. Both of these treatments were characterized by significantly large amounts of residue on or near the soil surface and both were more effective for reducing erosion than the moldboard plow or mow-plow (L) treatments (Table 1). The pattern of treatment erodibility is apparent at the low rainfall intensity (Fig. 1). With increased rainfall intensity, the erosion rates were proportionally greater in the mow-plow (L) and moldboard plow treatments, demonstrating the effectiveness of abundant residue cover (Table 3). Application of the middle and high rainfall intensities demonstrates treatment responses to storms in the upper range of rainfall intensities recorded in this region and magnifies responses recorded at the low rainfall intensity.

An examination of residue distribution and composition, based on known relationships, demonstrates the differences between the mow-plow, moldboard plow, and chisel plow treatments. At harvest, winter-wheat has an approximate root:shoot weight ratio of 0.3 (roots include roots and crowns) (Belford et al., 1987). Roots will decompose ~57% through the fallow period (Douglas and Rickman, 1992), however, residue decomposition is minimal between late summer or fall seeding and January–February (Douglas and Rickman, 1992). Thus, we would expect the same

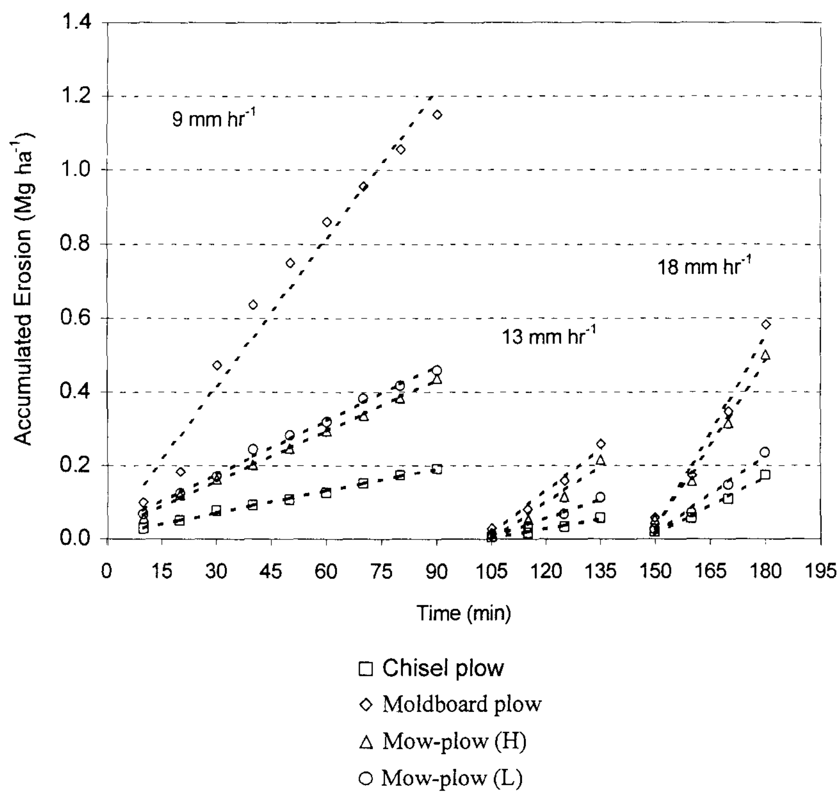

Fig. 1. Average accumulated erosion for each of the four treatments, five plots per treatment, at three rainfall intensities; 9 mm h^{-1} from 0 to 90 min, 13 mm h^{-1} from 105 to 135 min, and 18 mm h^{-1} from 150 to 180 min. Two, 5-min breaks in rainfall were required to change intensities (90–95, 135–140 min). Soil cover for treatments are chisel plow 0.90 (Mg ha^{-1}), moldboard plow 0.17 (Mg ha^{-1}), mow-plow (L) 0.46 (Mg ha^{-1}), and mow-plow (H) 0.77 (Mg ha^{-1}).

root:shoot ratios to have persisted until rainfall was simulated, or, more importantly, through this region's erosion season. Chisel plowing leaves the residue near or on the surface and intact above the rod-weed line (Wilkins and Kraft, 1988). The rod-weed line (50–100 mm) is the depth at which a rod, turning counter to the direction of travel, is pulled through the soil for weed control. Alternatively, moldboard plowing inverts and distributes roots and crowns throughout (~200 mm) or near the bottom of the plow layer, depending on the implement (Wilkins, 1996), and thus leaving one-half as much residue in the 0–100 mm depth. The difference in residue type, stems versus roots and crowns, and distribution of the residue near the soil surface amounts to approximately 2 Mg ha^{-1} (Douglas and Rickman, 1992). However, there is no apparent advantage of keeping the roots and crowns near the surface. More important is the maintenance of high residue levels of any type near the surface.

Table 3
Erosion rate averages from five rainfall simulations at three rates[a]

Treatment	Rainfall simulation (mm h^{-1})		
	9	13	18
Erosion (Mg ha^{-1} h^{-1})			
Chisel plow	0.1 (0.1) a	0.1 (0.1) a	0.2 (0.3) a
Moldboard plow	0.3 (0.5) a	0.5 (0.8) b	0.8 (1.3) b
Mow-plow (L)	0.1 (0.2) a	0.4 (0.6) b	0.6 (0.9) b
Mow-plow (H)	0.2 (0.3) a	0.2 (0.3) ab	0.3 (0.6) a

[a] Treatment means with same letter are not different at α=0.05. Parentheses contain standard deviations.

Three distinct sets of weather conditions occurred during rainfall simulations. Rainfall was simulated twice onto snow covered frozen soil with air temperatures below 0°C, twice onto bare (no snow) soil and

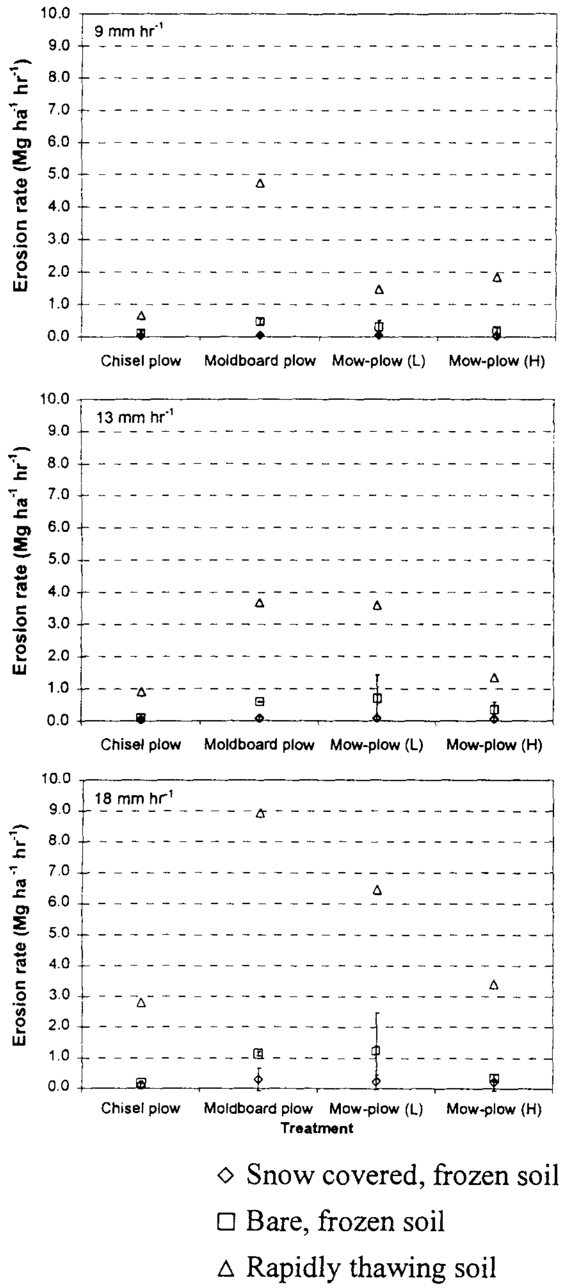

Fig. 2. Erosion rates resulting from three rates of rainfall simulation (mm h^{-1}) onto three different soil temperature and cover conditions. Means and 0.05 S.D. error bars presented for conditions of snow covered, frozen soil and bare, frozen soil (n=2), and the results of a single simulation onto rapidly thawing soil. Soil cover for treatments are chisel plow 0.90 (Mg ha^{-1}), moldboard plow 0.17 (Mg ha^{-1}), mow-plow (L) 0.46 (Mg ha^{-1}), and mow-plow (H) 0.77 (Mg ha^{-1}).

slowly thawing soil and air temperatures from −5 to 5°C, and once onto rapidly thawing bare soil with air temperatures increasing from 0 to 5°C. The relationship between treatments for the pooled data was consistent in all weather conditions (Fig. 2). Treatment differences were most apparent in the rapidly thawing soil with no snow cover and after soil particles were no longer frozen together.

The purpose of mow-plow (L) treatment was to examine erosion control at or near the minimum cover requirements (Renard et al., 1997). In essence, we accomplished that task, although we would have preferred cover values closer to 35%, and in retrospect a value of 30% would have been ideal. The residue in the moldboard plow treatment was as effective as the mow-plow (L), while providing less than half the surface cover.

5. Conclusion

The mow-plow (H) treatment prevented erosion more effectively than the moldboard plow treatment. The mow-plow (L) treatment was not as effective as the mow-plow (H) treatment and was roughly equivalent to the moldboard plow treatment. Under these conditions and tillage practices, residue composed of roots and crowns left by the chisel plow does not provide any more protection against erosion than large amounts of straw residue mixed within 100 mm of the soil surface. The mow-plow system would best be applied in highly erodible areas, with an over abundance of residue, where chisel plowing would be inappropriate because of weed problems. The mow-plow system needs to be evaluated through an entire erosion season and be subjected to multiple freeze-thaw and storm cycles to more fully evaluate its potential.

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