Packing summer fallow in the Pacific Northwest: Seed zone water retention

William F. Schillinger and Floyd E. Bolton

ABSTRACT: Seed zone water loss from summer-fallowed soils appears to accelerate in August and September in the Pacific Northwest (PNW) during the annual shift in the direction of coupled heat and water flows. A 2-year study was conducted to determine whether packing the surface of a stubble mulch and bare soil (moldboard plow) fallow with a roller in mid-August would benefit seed zone water retention at the time of planting in mid-September. Packing increased surface soil bulk density, resulting in increased soil volumetric water content to a depth of 0.1 m. However, at the time of planting 34 days after the packing operation, there were no differences in seed zone water content between packed and non-packed plots. Wheat seedling emergence was not significantly affected by packing. The stubble mulch, in addition to providing protection from wind erosion, was slightly more efficient than the bare soil mulch in conserving seed zone water. In this study there were no benefits of packing summer fallow >1 month before planting wheat. Therefore this practice is not recommended, especially on soils already vulnerable to wind erosion.

Insufficient seed zone water is a major limitation to the establishment of winter wheat (*Triticum aestivum* L.) on summer-fallowed soils in areas of the Pacific Northwest (PNW) receiving < 300 mm (11.8 in) annual precipitation. A wheat-fallow rotation is the dominant cropping system in these low precipitation areas. The primary objective of fallow is to store a portion of the precipitation occurring during the fallow period for use by the succeeding wheat crop. Soil water recharge occurs during the fallow winter when temperature and evaporation are low and precipitation is high. About 70% of total annual precipitation in the PNW occurs between November and April (Leggett et al. 1974).

Low soil water potential at the time of seeding may result in slow seed imbibition and germination, which influences seedling vigor and can effect yield (Noori et al. 1985). In a relatively dry soil, small increases in water content can produce marked increases in wheat germination and emergence rate (Hanks and Thorp 1956). Successful establishment of winter wheat on fallow, in addition to increasing yield potential, has a major influence on decreasing wind erosion in the fall and water erosion during the winter. The increased residue from well established stands also provides protection against both water and wind erosion during the subsequent fallow cycle (Cochran et al. 1970). Residues are especially critical for wind erosion control in very low precipitation [< 250 mm (9.8 in) annual] areas of the PNW where soils are generally coarse textured, poorly aggregated, and do not readily form clods with tillage (Papendick and McCool 1994).

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Creating the soil mulch

Spring tillage is generally performed with a cultivator, sweeps, or moldboard plow during the fallow cycle. The moldboard plow inverts the upper soil profile and buries about 90% of the surface residue. Use of the moldboard plow in wheat-fallow production areas is declining because of the associated risk of wind erosion. Instead, growers commonly use implements such as the V-shaped cultivator and sweeps, which lift, cut, or otherwise loosen the surface soil without inversion. With this system, more than 70% of the residue remains on or near the soil surface to create a stubble mulch. Stubble mulching reduces the risk of wind erosion compared to bare soil tillage.

Primary spring tillage is followed by three or more rodweedings during the late spring and summer to control weeds and form a soil mulch. Rodweeding creates a dry, low bulk density soil mulch that overlays a firm moist layer at the rodweeding depth (Pikul et al. 1985). The soil mulch conserves water during dry periods by slowing or preventing capillary flow to the soil surface where it would be lost by evaporation (Hammel et al. 1981). In addition to restricting the liquid phase flow of water, the finely divided soil aggregates of a surface mulch reduce the flow of heat into the soil (Boersma and Jackson 1977).

Under PNW conditions, the tillage mulch must be established prior to the period of high potential evaporation in the summer to impede seed zone drying from fallow (Schillinger and Bolton 1993). Conversely, in the wheat-fallow areas of the Great Plains, where much of the precipitation occurs during the summer, soil water storage with no-tillage fallow may be greater than (Good and Smika 1978; Smika 1990) or equal to (Black and Power 1965; Tanaka 1985) that of mulched soils.

Water loss through the mulch

During summer, water loss from fallow soil occurs mainly as vapor flow through pores across the dry 0.05-to 0.15-m (2.0 to 6.0 in) thick soil mulch layer (Papendick et al. 1973). To maintain seed zone water, water lost through vapor flow must be replenished by liquid flow from the moist soil below. Rate of seed zone water loss in mulched fallow is relatively low during most of the summer but appears to accelerate in late August and September. This hastening of late summer seed zone water loss is thought to occur as a result of the annual shift in the direction of coupled heat and water flows. The increasingly low night temperatures that occur in late summer rapidly reduce soil surface temperatures while higher temperatures exist at lower depths (Boersma and Jackson 1977). Under these conditions, the vapor concentration gradient towards the soil surface is high and considerable soil water loss may occur (Hillel 1982). When the water loss rate through the mulch is greater than the replenishment rate from the moist soil below, drying in the seed zone occurs. Late season seed zone water loss from fallow forces growers to plant deeper to reach sufficient soil water for wheat germination and seedling emergence or to delay seeding until sufficient rainfall occurs. Both practices can result in late, less vigorous stands, which reduces yield potential and increases erosion hazard.

The processes of simultaneous heat and water transport are complex. Detailed descriptions of thermal and isothermal liquid and vapor transport have been given by Jury and Miller (1974). The soil mulch in summer-fallowed soils is dry enough so that vapor movement is the

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dominant mechanism for water flux (Pikul et al. 1985). Water vapor moves primarily by diffusion and, occasionally, by mass flow. Diffusion (q) can be described by the equation (Marshall and Holmes 1988):

$$q = -Dv\, f a \nabla P$$

where Dv is the diffusivity of water vapor in air, f is the air-filled porosity, a is the tortuosity of the flow path, and ∇P is the vapor pressure gradient. By packing the soil surface, the soil air-filled pore volume (f) is decreased, which causes an increase in the tortuous path length (Hillel 1982). As the tortuosity factor is the inverse of tortuous path length, the a value also decreases. Packing the soil surface will also affect soil thermal properties such as thermal conductivity and volumetric heat capacity. Increased thermal conductivity due to packing will reduce the soil temperature gradient between the soil surface and deeper depth, thus decreasing the vapor pressure gradient (∇P). The beneficial effects of reduced pore volume on reducing water vapor flow may be negated, however, by increased heat flow (Papendick et al. 1973).

The objective of this study was to determine the effects of packing a surface mulch during the annual shift in the direction of coupled heat and water flows in August and September on the following: (1) soil bulk density; (2) seed zone water retention between the time of packing and seeding; and (3) emergence and stand establishment of fall-sown wheat.

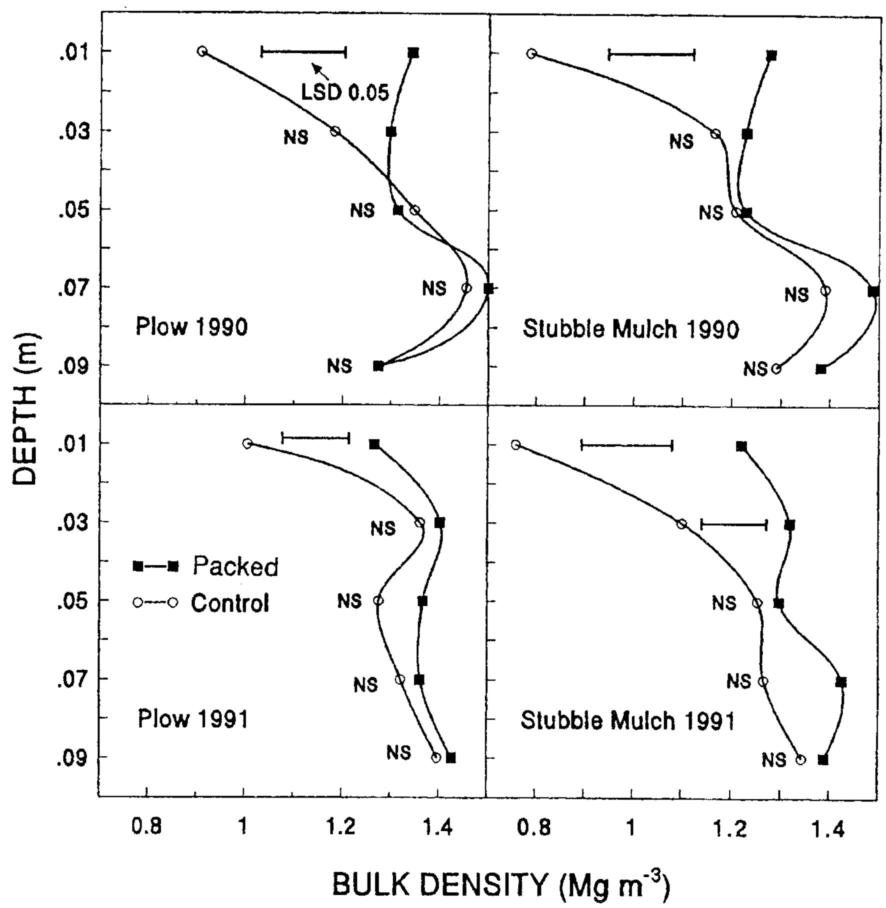

Figure 1. Soil bulk density in the surface 0.1 m of plow and stubble mulch tillage systems as affected by packing; horizontal bars indicate LSD values for each sampling depth

Methods and materials

The 2-year experiment was conducted during August and September of 1990 and 1991 at Oregon State University's Sherman Experiment Station in Moro, Oregon. The soil at the experimental site is a Walla Walla silt loam (coarse loamy, mixed, mesic Typic Haploxeroll). Average annual precipitation during the past 80 years at this location is 290 mm (11.4 in). Precipitation data during the study period were recorded at a standard U.S. Weather Bureau shelter located < 1 km from the experimental site. The terrain at the experimental site had < 2% slopes. Experimental design was a randomized block with four replications. Four treatments were established on undisturbed wheat stubble as follows:

1. Plow Not Packed: Moldboard plow [0.15 m (6.0 in) deep] for initial tillage in March to create a bare soil surface, followed by three shallow [0.05 to 0.1 m (2.0 to 4.0 in)] rodweedings during the late spring and summer.
2. Plow Packed: Identical to treatment 1, except that the soil surface was packed on August 15.
3. Stubble Mulch Not Packed: Sweep plow (0.15 m deep) with shanks spaced 0.3-m (1.0 ft) apart for initial tillage in March to create a stubble mulch where approximately 70% of the residue remained on the soil surface, followed by three shallow (0.05 to 0.1 m) rodweedings during the late spring and summer.
4. Stubble Mulch Packed: Identical to treatment 3, except that the soil surface was packed on August 15.

In both 1990 and 1991, the soil surface of treatments 2 and 4 was packed by making one pass through each 41 m × 2.44 m (134 × 8 ft) plot with a roller attached behind a rodweeder and pulled by a small crawler tractor. The roller was a cylindrical tank filled with water. Total mass was 714 kg (1,574 lbs) and dimensions were, length 1.82 m (6.0 ft) and radius 0.23 m (0.75 ft). An average of 13.9% of the roller surface area was in contact with the soil, exerting a pressure of 0.019 MPa (2.75 lb/in^2). Bulk density and volumetric water content were determined, as described by Gardner (1986), between 15 and 18 August from both packed and non-packed treatments at 0.02-m (0.8 in) increments to a depth of 0.1 m (4.0 in) using an incremental soil sampler developed by Pikul et al. (1979). The incremental soil sampler is specially designed for sampling in loose dry surface soil. A tractor mounted hydraulic soil probe was used to take core samples for bulk density and volumetric water determination at 0.05-m (2.0 in) increments from the 0.1 to 0.3-m (1.0 ft) depth. Two samples from the 0 to 0.3-m profile were obtained from each plot. Soil volumetric water content was again determined from these depth intervals using the same procedure both years between 18 and 21 September. The soil was not disturbed between the time of the packing operation in mid-August and seeding in mid-September.

A soft white common winter wheat (cv. Malcolm) was seeded in 0.4-m (1.3 ft) rows with deep furrow split-packer drills at a rate of 56 kg ha^{-1} on September 21, 1990, and September 22, 1991. Depth of seed placement was ≈0.13 m (5.1 in)

Table 1. Water (cm) in the surface 0.3 m of summer fallow as affected by packing in 1990 and 1991

Tillage method	Water content Not packed Aug. 15	Not packed Sept. 18	ΔH_20 mm	Evaporation mm/day*	Water content Packed Aug. 15	Packed Sept. 18	ΔH_20 mm	Evaporation mm/day	P-Value for ΔH_20
				1990					
Plow	30.1 a†	41.2 ab	+11.1	0.97	34.9 ab	43.3 b	+8.40	1.05	0.001
SM	35.5 a	41.8 b	+6.30	1.11	38.2 a	41.1 b	+2.90	1.21	0.001
				1991					
Plow	37.3 a	33.8 a	3.50	0.11	39.8 a	34.0 a	-5.80	0.18	0.072
SM	37.9 a	35.1 a	-2.80	0.09	40.6 a	34.2 a	-6.40	0.19	0.075

*Evaporation = (Precipitation - Storage) / 34 days
†Within row means followed by the same letter are not significantly different at $P = 0.05$.

below the fallow soil surface both years. An average of 0.08 (3.1 in) and 0.10 m (3.9 in) of soil covered the seed in 1990 and 1991, respectively. Wheat seedling emergence was measured by counting individual plants in 1-m (3.28 ft) row segments 8 to 14 days after planting (DAP). Row segments were randomly selected and marked within each plot prior to wheat seedling emergence. Final stand establishment was determined by counting individual plants > 25 DAP.

An analysis of variance for soil bulk density at each sampling depth, water at each sampling depth, total water in the 0.3-m soil profile, and wheat seedling emergence on each sampling date was conducted. Treatments were considered significantly different if the P-value was < 0.05. Treatment means were compared using Fisher's protected least significant difference (FPLSD).

Results and discussion

Precipitation. Precipitation during the study period was greater than average in 1990 and less than average in 1991. In 1990, 44 mm (1.7 in) of precipitation fell during the study period, almost three times the 80-year mean. Dates and quantity of precipitation received in 1990 were: August 17, 7.1 mm (0.23 in); August 21, 14.5 mm (0.57 in); August 22, 6.7 mm (0.26 in); August 30, 8.6 mm (0.34 in); and September 8, 7.1 mm (0.28 in). In 1991 only trace amounts of precipitation [August 18, 0.2 mm 0.008 in)] occurred during the study period.

Soil bulk density. Packing the soil surface with a roller in August increased soil bulk density in the surface 0.1 m (4.0 in) (Figure 1). The greatest bulk density difference between packed and non-packed treatments occurred at 0 to 0.02-m (0.8 in) and decreased proportionally with soil depth. A higher bulk density layer, apparently due to rodweeding, was measured at 0.07 m (2.8 in) in both plow and stubble mulch systems in 1990, whereas it was difficult to discern in 1991.

Soil water content. Volumetric water contents of packed and non-packed treatments measured on August 15-18 and September 18-21 in 1990 and 1991 are presented in Figure 2 and Figure 3, respectively. Mass water content of the soil among treatments in mid-August was similar during both years but, due to increased bulk density in packed plots, differences in volumetric water content were discernible. In 1990, packing significantly increased volumetric water content to a depth of 0.1 m in the plow system and to 0.06 m (2.4 in) in the stubble mulch system (Figure 2). Because of the 44 mm of precipitation that occurred during the 1990 study period, all treatments held more (0- to 0.3-m) water at the end of the study period than in mid-August (Table 1), thus masking evaporation data.

In 1991, significant increases in mid-August volumetric water content were measured in packed versus non-packed treatments to a depth of 0.08 m (3.1 in) under both tillage systems (Figure 3). Evaporative water loss in the 34-day period after packing was greater in packed than from non-packed plots and, at time of planting in mid-September, there were no differences in soil water content among treatments at the 0- to 0.3-m depth (Table 1). This is opposite to our original thoughts, which were that the

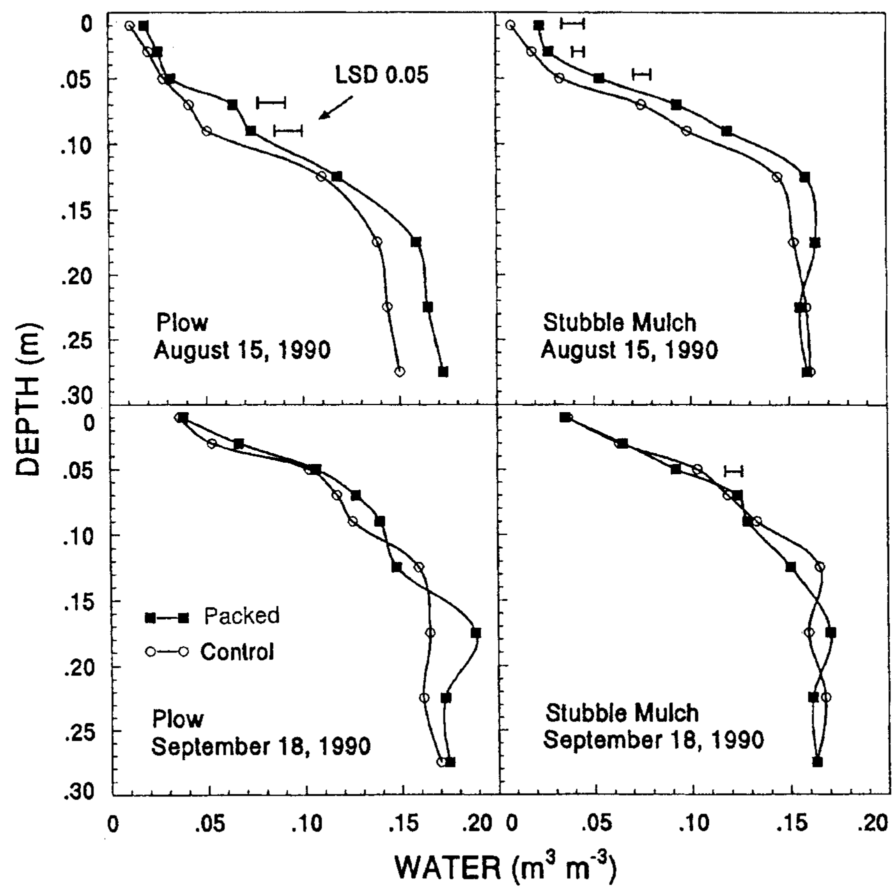

Figure 2. Soil water in the surface 0.3 m of plow and stubble mulch tillage systems as affected by packing in 1990; horizontal bars indicate LSD values for each sampling depth

Table 2. Wheat seedling emergence† (plants per m of row) as affected by packing in 1990 and 1991

DAP	Plow control	Plow packed	SM control	SM packed	*P*-value
			1990		
8	9.2	10.4	7.4	8.8	0.092
9	22.6a	24.3a	19.4b	20.2ab	0.048
12	27.9	29.0	25.4	26.1	0.083
25	27.2	28.6	26.1	25.7	0.121
			1991		
8	7.3	7.1	6.6	6.9	0.112
11	21.1	23.2	18.5	19.0	0.082
14	23.6a	25.9a	19.9b	20.3b	0.041
42	24.2a	25.5a	20.1b	21.0b	0.036

DAP = days after planting
†Within row means followed by the same letter are not significantly different

packing effects of reduced soil porosity, increased tortuosity, and decreased vapor pressure gradient might outweigh those of increased heat flow. Water content in the surface 0.3 m of non-packed plots was slightly greater with stubble mulch tillage than with bare soil tillage at the beginning and end of the study period during both years (Table 1). These data support results from previous fallow management studies in the PNW which have demonstrated the desirability of maintaining residues on the surface for water conservation (Ramig et al. 1983).

Wheat seedling emergence. There was no significant effect of packing on wheat seedling emergence during either year (Table 2). However, wheat seedling emergence and stand establishment were greatest under bare soil tillage (Table 2). Better seed-soil contact, more uniform seedbed conditions, and better grain drill performance are probable explanations of why seedling emergence with moldboard plowing surpassed that of stubble mulch tillage despite slightly less water (Cochran et al. 1982; Papendick and Miller 1977).

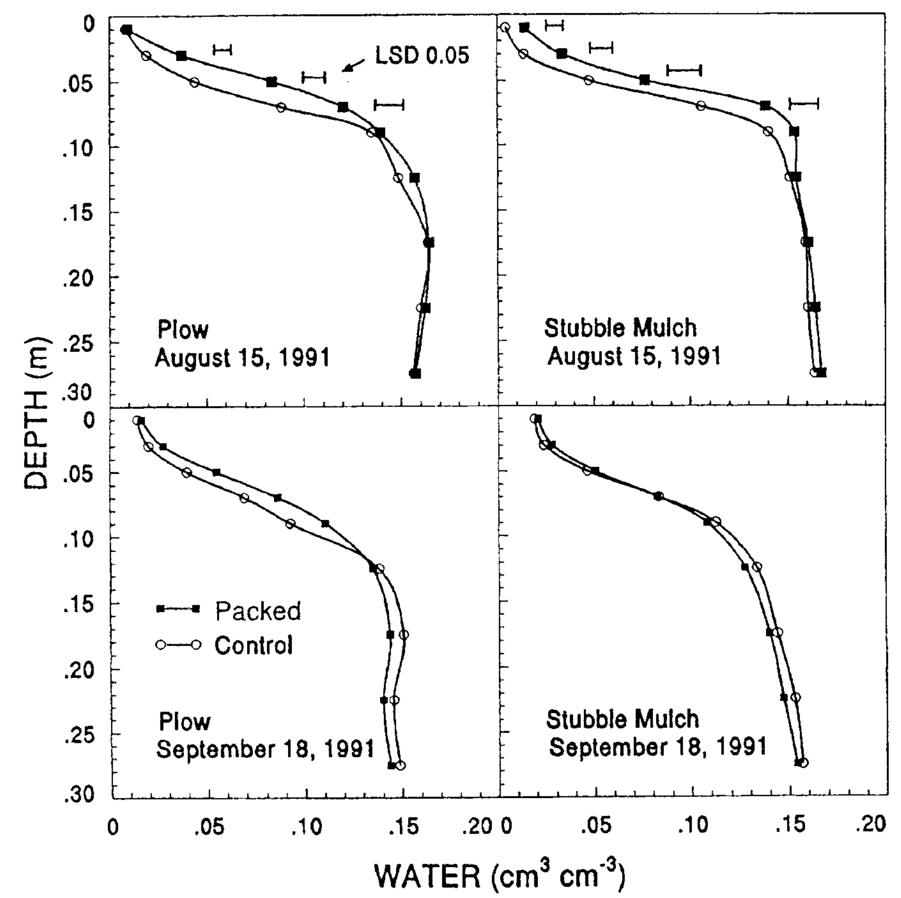

Figure 3. Soil water in the surface 0.3 m of plow and stubble mulch tillage systems as affected by packing in 1991; horizontal bars indicate LSD values for each sampling depth

Summary

This experiment was conducted in a wet and a dry year. In both years, packing summer fallow in mid-August reduced the thickness of the dry mulch layer and increased soil bulk density—resulting in increased soil volumetric water content to a depth as great as 0.1 m (4.0 in). Evaporative soil water loss in the 34-day period after packing was greater in packed than from non-packed plots and, at time of planting in mid-September, there were no significant differences in 0- to 0.3-m (1.0 ft) water content among treatments. The stubble mulch, in addition to protecting the soil from erosion, was slightly more efficient than the bare soil mulch in conserving seed zone water. Wheat seedling emergence was not affected by packing in either year.

Tillage during fallow in the PNW frequently buries excessive amounts of crop residue and reduces soil roughness. Development and adaptation of agronomically feasible and environmentally friendly fallow management methods which cause less soil disturbance and maintain surface crop residue and soil clods are needed. In this study, there were no agronomic benefits to packing a summer fallow mulch 1 month prior to planting winter wheat. Additionally, in our opinion, packing may further pulverize soil that is already prone to wind erosion.

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