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Tillage Mulch Depth Effects during Fallow on Wheat Production and Wind Erosion Control Factors

William F. Schillinger* and Robert I. Papendick

ABSTRACT

Blowing dust from summer fallow is a major soil loss and air quality concern in winter wheat (*Triticum aestivum* L.) production areas of the inland Pacific Northwest (PNW). The objective of our 3-yr on-farm study in a 286-mm precipitation zone in eastern Washington was to determine the effects of tillage mulch depth during fallow on surface soil roughness, residue retention, seed-zone water storage, wheat establishment, and grain yield. Soil is a Ritzville silt loam (coarse-silty, mixed, mesic Calcidic Haploxeroll). Mulch depth combinations were created by primary spring tillage with noninversion implements at 100- or 160-mm depths, and with subsequent rodweedings at 50- or 100-mm depths. Tillage mulch depth during fallow did not affect seedling emergence after two wet fallow cycles, but wheat spike density was consistently greatest in deep-tilled plots. In a dry fallow cycle, when dry soil extended beneath the rodweeder or secondary tillage layer, deep tillage increased stand establishment from 30 to 62 seedlings m^{-2}, grain yield from 4.4 to 5.3 Mg ha^{-1}, and residue production from 5.7 to 8.4 Mg ha^{-1} compared with shallow tillage. Surface soil clods >50-mm diameter, desirable for wind erosion control, increased with tillage mulch depth from 14 to 21 Mg ha^{-1} in 1994, and from 22 to 37 Mg ha^{-1} in 1995. A drawback to deep tillage mulches was the need to reduce tractor speed during planting. Surface residue retention was not affected by tillage mulch depth. Results show that surface clod structure and roughness during fallow can be maintained to protect the soil from erosion, mostly benefiting wheat production potential.

WINTER WHEAT–SUMMER FALLOW ROTATION is practiced on about 1.5 million ha in the low-precipitation (<300 mm annual) dryland areas in the inland PNW (Ramig et al., 1983). The climate of this region is characterized by winter precipitation with warm, dry summers. Successful establishment of winter wheat on fallow from late summer planting depends on carryover moisture from the previous winter and is essential for high yields and protection of soil from both wind and water erosion (Leggett et al., 1974). Additionally, growers plant cultivars with the ability to emerge under conditions of poor seed-zone water, high temperature, and deep planting (Donaldson, 1996). In dry years, winter wheat is planted as deep as 200 mm below the summer fallow soil surface to reach adequate water for germination, and seedlings emerge through as much as 150 mm of soil cover (Schillinger, 1996). In the driest years, deep planting is not attempted. Rather, seed is shallowly "dusted in" to dry soil, or planting is delayed until the arrival of fall rains, or postponed until spring.

The benefits of tillage during fallow on water retention and winter wheat stand establishment have been reported by several workers. Over-summer water loss from the seed-zone depth occurs by evaporation across a dry soil layer generally 80 to 130 mm in thickness (Hammel et al., 1981). Seed-zone water is best conserved by a loose soil mulch of maximum resistance to vapor and liquid water flow, and maximum thermal insulation, overlying a seed zone having good capillary continuity with deeper soil layers (McCall and Hails, 1921; Papendick et al., 1973; Lindstrom et al., 1974). Finely divided soil aggregates within the soil mulch are most effective in retarding water loss during fallow, but tillage to create such a mulch often buries excessive surface residue and may pulverize surface clods.

A soil surface deficient in roughness, clods, and residue may pose a serious wind erosion threat (Fryrear, 1984; Fryrear and Bilbro, 1994), especially with large (65- to 260-ha) fields and the frequent high winds common in the inland PNW. In the semiarid Canadian prairies, measured soil loss from summer fallow during individual windstorms has exceeded 30 Mg ha^{-1} (Larney et al., 1995). In addition to loss of soil, blowing dust from excessively tilled soils is a major air quality concern. The Federal Clean Air Act of 1990 mandates control of dust particulates 10 μm and smaller (PM-10), which may lodge in lung tissue and be a health concern (Saxton, 1995). Surface residue, roughness, and clods are effective in reducing wind erosion from summer-fallowed soils.

Many growers in low-rainfall wheat–fallow areas of the PNW use V-shaped sweeps or similar noninversion implements for primary spring tillage to maximize surface residue and clod retention. Rodweeders are used for secondary tillage during late spring and summer to control weeds and maintain the dry mulch layer. Papendick et al. (1973), operating sweeps and rodweeders at several depths during fallow, found that: (i) increasing the depth of the tillage mulch reduced seed-zone water loss enough to benefit wheat seedling emergence; and (ii) seed-zone water was best retained when rodweeding operations were conducted at the depth of initial tillage, i.e., conducting all tillage operations at the same depth to create an abrupt break between tilled and untilled soil.

More information is needed concerning both the agronomic feasibility and environmental friendliness of conservation tillage practices during fallow in the PNW. This study compared the effects of four fallow tillage mulch depth combinations created by noninversion tillage implements on: surface residue retention, surface and subsurface soil cloddiness, seed-zone water retention, winter wheat seedling emergence, and grain yield components and crop characteristics.

W.F. Schillinger, Dep. of Crop and Soil Sciences, Washington State Univ., 210 W. Broadway, Ritzville, WA 99169; and R.I. Papendick (retired), USDA-ARS Land Management and Water Conservation Research Unit, 215 Johnson Hall, Pullman, WA 99164. This study was funded by the Washington Wheat Commission and the Columbia Plateau Wind Erosion/Air Quality Project. Washington State Univ. Crop and Soil Sciences Dep. Technical Paper no. 9607-03. Received 22 July 1996. *Corresponding author (schillw@wsu.edu).

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Abbreviations: DAP, days after planting; PNW, Pacific Northwest.

Table 1. Field operations conducted during three fallow cycles at Ralston, WA.

Month	1992–1993 fallow cycle	1993–1994 fallow cycle	1994–1995 fallow cycle
August	Subsoil 0.4 m deep, 1-m spacing.	Subsoil 0.4 m deep, 1-m spacing.	Subsoil 0.4 m deep, 1-m spacing.
March	Spray glyphosate herbicide, 0.35 L ha^{-1}. Light disking.	Spray glyphosate herbicide, 0.35 L ha^{-1}. Light disking.	Spray glyphosate herbicide, 0.47 L ha^{-1}. Light disking.
April		Primary tillage with 0.46-m-wide sweeps with attached harrow. Aqua N injection, 67 kg ha^{-1} + S 13 kg ha^{-1}.	
May	Primary tillage with 0.8-m-wide sweeps with attached rotary hoe. Aqua N injection 62 kg ha^{-1} + S 12 kg ha^{-1}.	First rodweeding.	Primary tillage with 0.46-m-wide sweeps with attached harrow. Aqua N injection, 84 kg ha^{-1} + S 17 kg ha^{-1}.
June	First rodweeding.		First rodweeding.
July	Second rodweeding.	Second rodweeding.	
August		Plant 'Moro' winter wheat, 39 kg ha^{-1}	Second rodweeding.
September	Plant 'Eltan' winter wheat, 39 kg ha^{-1}.		Plant 'Lewjain' winter wheat, 34 kg ha^{-1}.

MATERIALS AND METHODS

An on-farm experiment was conducted between August 1992 and July 1996 on the Curtis Hennings farm in Adams County, Washington. Annual precipitation at the site averages 286 mm and the cropping pattern is winter wheat–fallow. The soil is a Ritzville silt loam with 15 g organic matter kg^{-1} in the surface 100-mm layer. Soil depth is >1.8 m and slopes are <2%. Precipitation and minimum–maximum air temperature were recorded daily at the Hennings's farmstead located 1 km from the experiment site.

The experimental design in 1992–1993 and 1993–1994 was a randomized complete block of three tillage mulch depth treatments replicated four times. In 1994–1995, a split-plot design included four tillage mulch depth treatments (main plots) and two tractor speeds for rodweeding (subplots). Main plots were 190 by 22 m and subplots 95 by 22 m. Paired adjacent parcels of land were used so that data could be collected each year from both crop and fallow phases of the experiment.

Soils were subsoiled at the beginning of each fallow cycle to a depth of 0.4 m with shanks spaced 1 m apart (Table 1). In March, plots were sprayed with glyphosate herbicide [*N*-(phosphonomethyl)glycine] to control weeds and then lightly disked to create a thin (≈20-mm) soil mulch. In mid-April in 1994 and mid-May in 1993 and 1995, primary tillage was conducted with V-shaped sweeps at shallow (100-mm) or deep (160-mm) depths (Table 1). Aqua NH$_3$–N was delivered with the V-shaped sweeps at rates ranging from 55 to 65 kg N ha^{-1}. Between June and August, plots were rodweeded two times at either a shallow (50-mm) or deep (100-mm) depth. Three tillage mulch depth combinations were compared in 1993 and 1994. These were: (i) shallow primary tillage at 100 mm and shallow rodweedings at 50 mm (shallow–shallow); (ii) shallow primary tillage at 100 mm and deep rodweedings at 100 mm (shallow–deep), and; (iii) deep primary tillage at 160 mm and deep rodweedings at 100 mm (deep–deep). Tractor speed for rodweeding operations was 2.7 m s^{-1}. In 1995, an additional tillage mulch depth treatment was included: deep primary tillage at 160 mm and shallow rodweedings at 50 mm (deep–shallow), and subplots were slow (1.6 m s^{-1}) and fast (2.7 m s^{-1}) tractor speeds for rodweeding. To reduce variability, all measurements described hereafter were obtained from a 3-m-wide swath made by a specific section of the rodweeder implement.

Table 2. Precipitation occurring during three 13-mo fallow cycles compared to the 20-yr average at Ralston, WA.

Time period	1992–1993	1993–1994	1994–1995	20-yr avg.
	mm			
August–March	203	133	292	209
April	59	20	29	26
May	28	44	21	23
June	15	9	59	17
July	32	6	23	11
August	11	0	10	9
13-mo total	348	212	434	295

Water measurements in the 1.8-m soil profile were made each spring prior to primary tillage and again in late August before planting. Soil volumetric water content in the 0.3- to 1.8-m depth was measured in 0.15-m increments by neutron attenuation. Volumetric water in the 0- to 0.3-m depth was determined from two 0.15-m core samples using gravimetric procedures (Gardner, 1986). Additionally, in late August, volumetric water content in the seed zone was determined in 20-mm increments to a depth of 160 mm in 1993, and to 220 mm in 1994 and 1995, using an incremental soil sampler (Pikul et al., 1979). Soil water measurements were always obtained from three locations in each plot.

Surface soil cloddiness was determined at the end of the fallow cycle in 1994 and 1995 by measuring the diameter of individual soil clods within a 1-m-diam. sampling hoop randomly positioned at three locations in each plot. Wheel tracks were avoided. All clods with diameters >50 mm were sorted into 10-mm size increments and the mass of each size group determined. Surface residue at the end of the fallow cycle in 1994 and 1995 was measured by collecting and weighing all aboveground dry matter within three 1-m-diam. sample hoops randomly placed in each plot.

Subsurface soil cloddiness was measured before planting in 1995 by gently sieving 0.01 m^3 of soil from the 0- to 100-mm mulch layer through stacked 50-, 25-, and 12-mm^2 mesh screens. Mass of clods not passing through each of the three mesh screens was then measured. Subsurface clods measurements were obtained from the same area where surface clods had been removed; thus surface clods >50 mm in diameter were excluded from subsurface samples.

Plots were planted to soft white winter wheat in late August or September (Table 1) with deep furrow split-packer drills. Row spacing was 0.4 m and planting rate varied from 26 to 40 kg ha^{-1}. Seed placement and soil roughness after planting were determined in 1994 and 1995 by measuring: (i) furrow ridge height, i.e., the distance to the ridge from the bottom of the furrow; (ii) depth of soil covering the seed; and (iii) depth of seed placement below the tillage layer created by the rodweeder. Wheat seedling emergence and stand establishment were determined by counting individual plants in 1-m row segments at 24-h intervals beginning 8 d after planting (DAP). Three row segments were selected and marked within each plot prior to emergence of wheat seedlings.

Grain yield and spike density were measured from hand-cut samples obtained from three 1-m row sections in each plot at harvest in July or August. Clean grain yield, kernels spike^{-1}, 1000 kernel wt., and dry matter were determined from these samples.

An analysis of variance was conducted for 1.8-m soil profile

Table 3. Soil water in 1.8-m soil profile in the spring and at the end of three fallow cycles at Ralston, WA. Precipitation occurring from spring sampling to August sampling: 1993, 69 mm; 1994, 67 mm; 1995, 114 mm.

Treatment	1993			1994			1995		
	20 May	31 Aug.	ΔH_2O	15 Apr.	18 Aug.	ΔH_2O	27 Apr.	18 Aug.	ΔH_2O
					mm				
Shallow–shallow	298	264	−34	181	169	−12	314	264	−50
Shallow–deep	299	264	−35	178	174	−4	312	263	−49
Deep–shallow†							310	260	−50
Deep–deep	300	262	−38	176	175	−1	314	262	−52
LSD (0.05)	NS‡	NS		NS	5		NS	NS	

† Deep–shallow treatment included in 1995 only.
‡ NS = not significant.

and seed-zone soil water, surface soil cloddiness, subsurface soil cloddiness, surface residue, seed placement characteristics, wheat emergence on each sampling date, and yield components and crop characteristics. Treatments were considered significantly different if the *P* value was <0.05. Treatment means were separated using Fisher's protected least significant difference.

RESULTS AND DISCUSSION

Precipitation and Soil Water Retention

The 1992–1993 and 1994–1995 fallow cycles were wetter than average, whereas the 1993–1994 fallow cycle was one of the driest on record (Table 2). About 300 mm of stored water was present in the 1.8-m soil profile in the spring of the wet fallow cycles, compared with <200 mm of stored water in the spring of the dry year (Table 3). Despite spring and summer rainfall, oversummer soil water loss occurred every year in all treatments, but was lowest after the dry 1993–1994 winter and greatest following the wet 1994–1995 winter (Tables 2 and 3). These data agree with other findings showing summer rainfall in the PNW rarely adding to stored soil water (Massee and Siddoway, 1970). Total 1.8-m soil profile water retention was not affected by depth of tillage mulch during the wet fallow cycles, but was significantly improved with deep tillage mulching during the dry fallow cycle (Table 3).

Seed-zone conditions for planting winter wheat in 1993 (Fig. 1) and 1995 (Fig. 3) were some of the wettest many growers had ever experienced, whereas the seed zone was extremely dry in 1994 (Fig. 2). Soil water sufficient for wheat seedling emergence is generally found just below the firm layer created by rodweeders, but in dry years soil drying occurs below rodweeding depth (Schillinger, 1996). Tillage mulch depth combinations affected seed-zone water retention differently each year. Deep mulching significantly increased seed-zone water retention in 1993 (Fig. 1) whereas the shallower mulches maintained the highest seed-zone water content in 1995 (Fig. 3). We speculate that the 59 mm of rain received in June 1995 (Table 2), which wet through the shallow mulch layers but not the deep mulch treatments, attributed to these differences. Depth of tillage mulch had no effect on seed-zone water content at the end of fallow in the dry year (Fig. 2).

Planting and Seedling Emergence

Seed was placed ≈120 mm below the summer fallow soil surface in the wet years and ≈180 mm below the soil surface in the dry year. Soil covering the seed and height of furrow ridges increased proportional to depth of tillage mulch (Table 4). Tall furrow ridges create a rougher surface than short ridges and are more effective for wind erosion control (Fryrear, 1984).

Seed was placed deeper beneath the firm layer created by rodweeding in the shallow mulch treatments (Table 4). Tractor speed for planting the deep–deep treatment had to be reduced to 0.9 m s^{-1} to avoid pushing loose soil in front of the packer wheels of the drill, whereas shallow mulch plots were easily planted at twice this speed. This is of important practical consideration, and a disadvantage of deep tillage mulching, as growers want to complete planting operations quickly. Drill

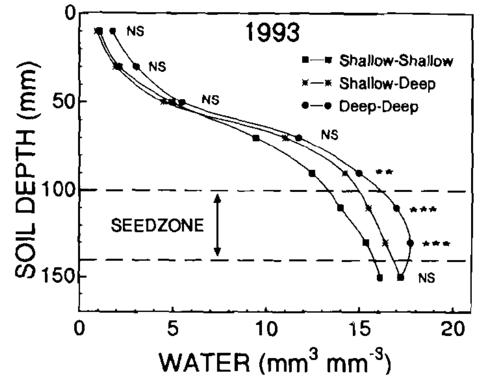

Fig. 1. Seed-zone water content in August 1993 as affected by tillage mulch depth during fallow. **, * Significant differences at the 0.01 and 0.001 probability levels, respectively; NS = not significant.**

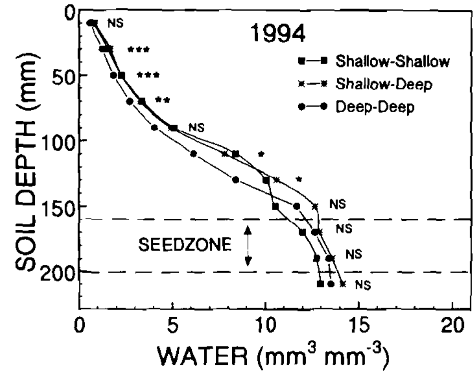

Fig. 2. Seed-zone water content in August 1994 as affected by tillage mulch depth during fallow. *, **, * Significant differences at the 0.05, 0.01, and 0.001 probability levels, respectively; NS = not significant.**

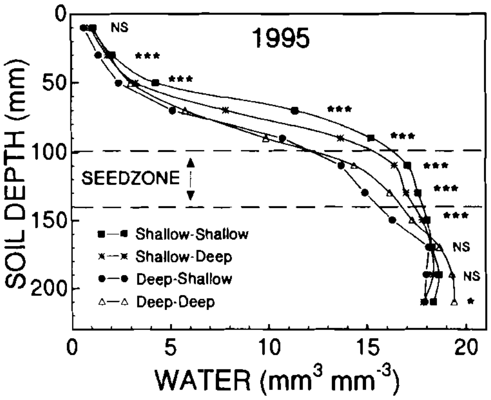

Fig. 3. Seed-zone water content in August 1995 as affected by tillage mulch depth during fallow. *** Significant differences at the 0.001 probability level; NS = not significant.

opener points easily penetrated into wet soil below rodweeding depth in 1993 and 1995 regardless of tillage mulch depth. But in 1994, soil drying extended below rodweeding depth in the shallow–shallow treatment and seed placement was impeded by hard, dry soil that the drill had difficulty penetrating, as evidenced by recoil of springs controlling opener placement in the soil. In contrast, drill openers easily penetrated the loose, friable soil created by deep primary tillage and deep rodweeding.

There were no differences among treatments in wheat seedling emergence on any date or in final stand establishment with the wet planting conditions in 1993 and 1995. Improper drill adjustment caused several openers to plug in the deep–deep treatment in 1995, but measurements were not taken from these locations. Plant stand 20 DAP averaged 89 and 71 seedlings m^{-2} in 1993 and 1995, respectively (data not shown).

With dry 1994 planting conditions, highly significant differences in seedling emergence occurred on all dates. By 10 DAP, there were 5, 15, and 50 seedlings m^{-2} in the shallow–shallow, shallow–deep, and deep–deep treatments, respectively (Fig. 4). By 20 DAP, these differences were 30, 44, and 62 seedlings m^{-2} for the same treatment combinations (Fig. 4). In deep–deep plots, seedling emergence was uniform, whereas there were recurrent 0.2- to 0.5-m gaps between seedlings in the shallow–shallow treatment. Uniform stand establishment is critical for achieving good wheat yields under dryland conditions in the PNW.

Table 4. Winter wheat seed placement characteristics in 1994 and 1995 as affected by tillage mulch depth during fallow.†

Treatment	Furrow ridge height	Soil covering seed	Rod depth to seed
		mm	
	1994		
Shallow–shallow	86 a	99 a	71 a
Shallow–deep	91 ab	109 b	69 ab
Deep–deep	97 b	117 b	63 b
P value	0.04	0.002	0.01
	1995		
Shallow–shallow	89 a	58 a	23
Shallow–deep	91 a	61 a	21
Deep–shallow	94 a	66 ab	15
Deep–deep	102 b	71 b	15
P value	0.01	0.02	0.12

† Within-column means followed by the same letter are not significantly different at the 0.05 probability level.

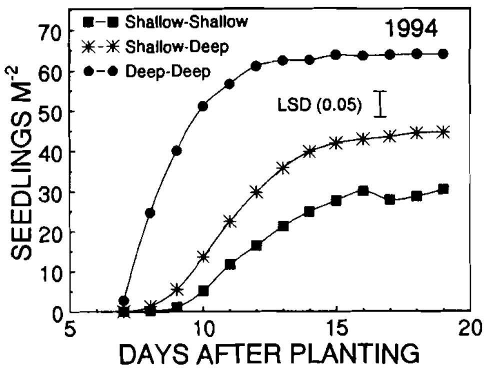

Fig. 4. Wheat seedling emergence in 1994 as affected by tillage mulch depth during fallow.

Yield Components and Crop Characteristics

Wheat spike density at harvest in July 1994 was highest in the deep–deep treatment, but grain yield and other yield components and crop characteristics were not affected (Table 5). Yield components in July 1995 and July 1996 were significantly affected by tillage mulch depth in the preceding fallow cycle. In 1995, the deep–deep treatment had the lightest kernels and fewest kernels per spike but produced more spikes per square meter and grain than the other treatments (Table 5). The deep–deep treatment also attained the most spikes per square meter and highest grain yield in 1996.

In both 1995 and 1996, the deep–deep treatment produced the most residue for wind and water erosion control during the subsequent fallow cycle (Table 5). In contrast, grain and residue yields were lowest for treatments receiving shallow rodweeding.

Surface Clods, Subsurface Clods, and Residue Retention

Mass of surface soil clods >50-mm diameter at the end of fallow ranged from 14 to 21 Mg ha^{-1} in 1994 and 22 to 37 Mg ha^{-1} in 1995 (Fig. 5 and 6b). In both years, surface cloddiness increased proportional to depth of mulching during fallow (Fig. 5b and 6b). Fast tractor speed during rodweeding reduced surface clod mass in all mulch depth combinations compared with slow tractor speed (Fig. 6b). Surface residue at the end of fallow was not affected by tillage mulch depth in 1994 and 1995, or tractor speed in 1995 (Fig. 5a and 6a).

Subsurface (0–100-mm) clod mass ranged from 102 to 177 Mg ha^{-1} (9–15% of total soil mass) and, as with surface clods, increased relative to depth of mulching (Fig. 6c). The majority of subsurface clods were in the 12- to 25- and 25- to 50-mm-diam. range, with relatively few clods >50-mm diameter (Fig. 7). Unlike surface clods, however, increased tractor speed during rodweeding did not consistently reduce subsurface clod mass and size distribution. The greater mass of subsurface clods within the 0- to 100-mm soil mulch with deeper

Table 5. Yield components and crop characteristics of 'Lewjain' winter wheat in 1994, 'Moro' winter wheat in 1995, and 'Lewjain' winter wheat in 1996 as affected by tillage mulch depth during the previous fallow cycle.

	Previous fallow treatment					
Component or characteristic	Shallow–shallow	Shallow–deep	Deep–shallow	Deep–deep†	*P* value	LSD (0.05)
			1994			
Grain yield, Mg ha^{-1}	3.24	3.5		3.64	NS	
Spikes m^{-2}	309	315		326	0.04	8
1000 kernel wt., g	32.7	33.2		34.1	NS	
Kernels spike^{-1}	30.9	33.5		32.7	NS	
Residue dry wt., Mg ha^{-1}	4.34	4.28		4.37	NS	
			1995			
Grain yield, Mg ha^{-1}	4.37	4.93		5.28	0.046	0.32
Spikes m^{-2}	266	309		426	0.001	30
1000 kernel wt., g	33.9	33.2		31.7	0.022	1.5
Kernels spike^{-1}	49.4	48.7		39.4	0.001	4.4
Residue dry wt., Mg ha^{-1}	5.73	6.29		8.39	0.001	1.09
			1996			
Grain yield, Mg ha^{-1}	4.73	5.36	4.65	5.55	0.014	0.63
Spikes m^{-2}	505	573	501	604	0.009	61
1000 kernel wt., g	32.3	30.6	32.7	31.4	0.035	1.5
Kernels spike^{-1}	28.9	30.6	28.4	30.2	NS	
Residue dry wt., Mg ha^{-1}	6.38	7.13	6.31	7.52	0.016	0.87

† Several rows in the deep–deep treatment had inadequate stand in the 1995–1996 crop year because grain drill openers were not properly adjusted for seeding through a thick soil mulch. Wheat seedling emergence, yield components, and crop characteristics were measured from sections of the deep–deep plots where stand establishment was uniform.

tillage probably reduced water conservation effectiveness compared with the more finely divided soil aggregates in the shallower tillage mulch treatments, and may account for some of the inconsistency in seed-zone water retention across years. On the other hand, we theorize that the greater subsurface soil macroporosity created by deep tillage mulching may benefit infiltration during the winter when water erosion is a concern.

SUMMARY AND CONCLUSIONS

In this study, deep tillage mulch combinations during fallow: (i) created the cloddiest surface for wind erosion control, (ii) produced the most desirable seedbed for wheat stand establishment after a dry fallow cycle, and (iii) resulted in the highest residue and grain production in two out of three crop cycles.

Conducting rodweeding operations at fast vs. slow tractor speed reduced surface clod mass in all mulch depth combinations but did not consistently reduce subsurface cloddiness. Surface residue retention was not affected by either tillage depth or rodweeding tractor speed.

Disadvantages of the deep tillage mulches were: (i) increased clod mass within the 0- to 100-mm subsurface soil layer, which possibly reduced water retention efficacy, and (ii) the need to reduce speed when planting with deep-furrow drills.

Results from this study suggest that growers in the PNW will benefit from deep tillage mulching when winter precipitation is less then average because the drying front can extend below rodweeding depth by late August. Under these conditions, deep primary tillage may

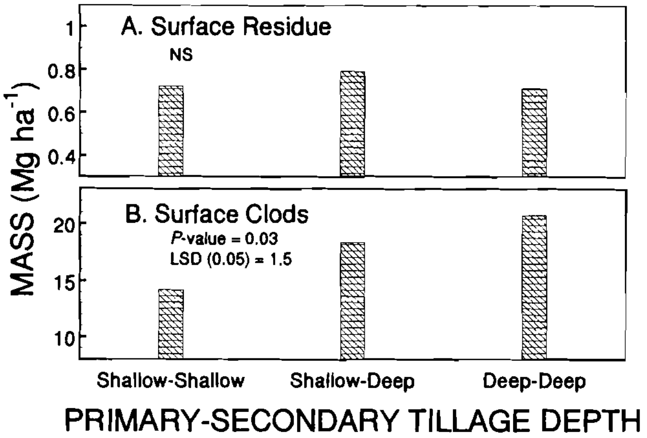

Fig. 5. Surface residue and surface clods >50-mm diameter of fallow in August 1994 as affected by tillage mulch depth.

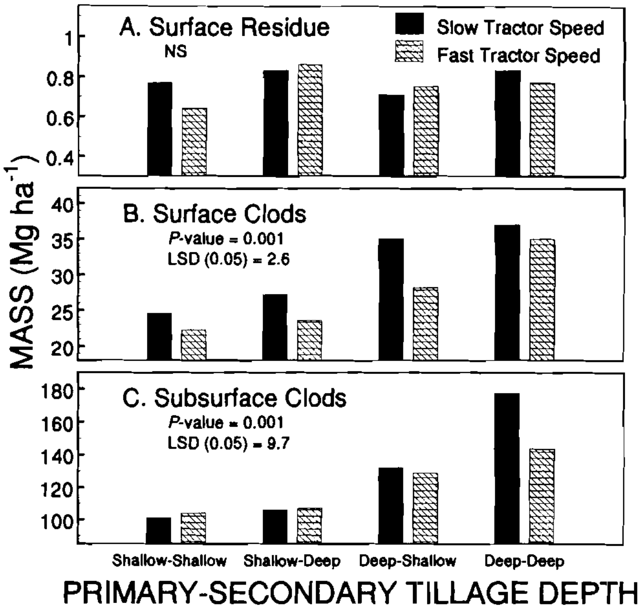

Fig. 6. Surface residue, surface clods >50-mm diameter, and subsurface clods >12-mm diameter of fallow in August 1995 as affected by tillage mulch depth and tractor speed.

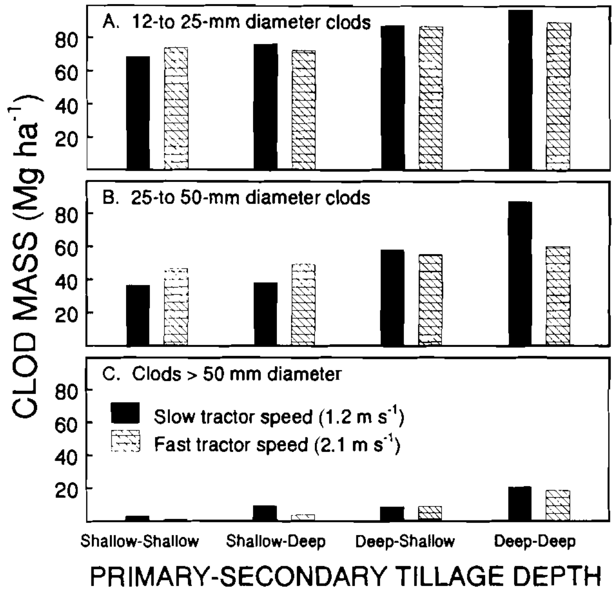

Fig. 7. Mass and size distribution of small, medium, and large clods in the 0- to 100-mm subsurface layer of the fallow mulch in August 1995 as affected by tillage mulch depth and tractor speed.

provide a more friable soil condition, allowing grain drill openers to penetrate deeper into wetter soil. Seedzone water adequate for seedling emergence can generally be retained just below rodweeding depth throughout the summer regardless of tillage mulch depth after wet winters.

We feel the ideal summer fallow mulch for wind erosion problem areas of the PNW would maximize surface residue, clods, and roughness for erosion control but contain finely divided soil aggregates beneath the soil surface to optimize seed-zone water conservation. More work is needed to determine how a mulch with these characteristics can best be created and maintained.

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