Increased Dryland Cropping Intensity with No-Till Barley

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ABSTRACT

For most of a century, the wide spread practice of growing only one crop every other year in a tillage-based wheat (*Triticum aestivum* L.)–fallow rotation has degraded soils and contributed to environmental problems in low-precipitation (<350 mm annual) dryland regions of the inland Pacific Northwest of the USA. Many growers in this 2-million-ha cropland area are increasing the intensity of cropping with spring crops, but most use conventional tillage (CT) for seedbed preparation. The agronomic performance of spring barley (*Hordeum vulgare* L.), sown into CT seedbeds with double-disk drills or into standing stubble with several types of no-till (NT) drills (hoe, single disk, and notched coulter), was determined in two experiments conducted both in 1996 and 1997 where the previous crop was either winter wheat or spring barley. We measured stand establishment, seed-zone temperature, soil water, dry biomass accumulation, rhizoctonia root rot, surface residue retention, and grain yield components. Plant stand (r^2 = 0.60), dry biomass accumulation (r^2 = 0.63), and spike density (r^2 = 0.62) as single independent variables, and combined in a multiple regression model (R^2 = 0.81), were strongly correlated (P < 0.001) to grain yield. Early-season seed-zone temperatures were cooler under NT, but seed-zone water was slightly higher with CT. Low spike density consistently occurred in a wide row spacing (406 mm) NT drill treatment, and the highest overall yields were obtained with NT drills with rows spaced 255 mm or less. Rhizoctonia root rot was severe on seminal roots in all treatments in three out of four trials, but did not appear to limit yields, possibly due to healthy crown roots and favorable growing conditions. No-till spring sowing into undisturbed standing stubble (2420–5230 kg ha^{-1}) can produce grain yields equal to or exceeding those under CT and can provide environmental and potential soil quality benefits for low-precipitation dryland farming areas in the inland Pacific Northwest.

Farming in the dryland areas of the Pacific Northwest (<350 mm annual precipitation) has been mostly an intensive tillage-based wheat–fallow system since the land was broken out of native grassland and sage in the 1880s. Tillage is well known to accelerate the loss of soil organic matter by increasing biological oxidation and often by increasing soil erosion. The loss is exacerbated with fallow, because oxidation of carbon exceeds carbon input from crop residues during the two-year cycle (Rasmussen and Parton, 1994). Because of the decline in organic matter and associated soil quality, most tillage-based farming systems in dryland environments are not sustainable in the long term (Papendick and Parr, 1997). Options for maintaining and improving soil quality in the drylands are to simultaneously increase the cropping intensity and reduce or eliminate tillage. The use of spring cropping in combination with no-till sowing would appear to offer the best approach for increasing cropping intensity, improving soil quality, and controlling erosion in the conventional fallow areas (Papendick, 1998). However, research with spring crops, and in particular with no-till in the dry areas of the inland Pacific Northwest, is limited.

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Ciha (1983), in studies with annual spring wheat over four years and at two low-precipitation (240 and 305 annual) sites in eastern Washington, reported that fall chiseling plus light spring tillage consistently produced higher yields than from spring tillage alone or no-till. This study showed that, even with the best yields, the annual spring wheat was not competitive on an economic basis with conventional winter wheat–fallow, because grain yields were not sufficient to offset increased production costs with spring cropping unless winter annual grassy weeds were a major problem in winter wheat. However, Ciha (1983) used a hoe drill with 360-mm row spacing, which is now considered excessively wide for spring cereals. There has since been rapid development and improvement of (i) no-till drill technology, (ii) higher-yielding spring cereal cultivars, (iii) effective and affordable herbicides, and (iv) the understanding for timely and effective elimination of volunteer cereals (*green bridge*) for root disease control. Furthermore, research efforts to develop intensive and diversified cropping systems using no-till in low-precipitation dryland areas have been renewed (Schillinger et al., 1998; Young et al., 1998).

Spring barley is another option with no-till spring sowing and is well adapted to the dry zones. One cropping sequence that has potential is winter wheat–spring barley–fallow, or even barley for two years in a row, with the barley no-tilled into the crop stubble. Minimum or delayed minimum tillage fallow or chemical fallow practices can be applied after the barley crop, which provides a management option with a high potential for erosion control for the spring cropping system.

Rhizoctonia root rot [caused by *Rhizoctonia solani* (Kühn) AG8] is the most important disease of spring barley sown directly into cereal stubble under Pacific Northwest conditions (Ogoshi et al., 1990; Pumphrey et al., 1987; Weller et al., 1986). This is ordinarily a minor disease of wheat and barley grown with conventional tillage, but it can be devastating on these crops in no-till cropping systems (Smiley et al., 1992), as has also been seen in Australia (Rovira, 1986). The two most effective practices shown to limit the severity of this disease in no-till cropping systems are (i) elimination of volunteer and other grass hosts of the pathogen 2 to 3 wk and preferably 2 to 3 mo before sowing the barley or wheat (Smiley et al., 1992), and (ii) soil disturbance in the seed row 50 to 60 mm below the seed at the time of sowing (Roget et al., 1996).

Abbreviations: CT, conventional tillage; JD, John Deere; NT, no-till.

The objective of our study was to develop one-pass methods of sowing spring barley directly into undisturbed standing stubble that are equal (or superior) to conventional sowing methods involving tillage. Specific objectives were to determine the effects of no-till vs. conventional tillage-based sowing methods on stand establishment, seed-zone temperature, seed-zone water loss, dry biomass accumulation, rhizoctonia root rot, residue retention for erosion control, and grain yield components.

MATERIALS AND METHODS

Two studies were conducted at two sites in 1996 and 1997 on the Donald and Doug Wellsandt farm in Adams County, Washington. Annual precipitation at the sites averages 322 mm, with 70% occurring between 1 August and 31 March (Table 1). The soil is a Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll) derived from loess overlying basalt bedrock. The depth of the soil is greater than 2 m.

Treatments and Field Layout

In both years, the two experiments were on adjacent 3-ha parcels where the previous crops were winter wheat and spring barley, respectively. Stubble from the previous crops was left undisturbed from harvest in August through February. In early March, 0.32 kg a.e. ha^{-1} glyphosate herbicide [*N*-(phosphonomethyl)glycine] was applied to both plot areas to control winter annual grassy weeds and volunteer from the previous crop.

The experimental design for both experiments each year was a randomized complete block with four sowing treatments replicated four times. Plots were 90 m long by 21 m wide on average, although the plot width for each treatment varied from 10 to 28 m, according to the size of field machinery and drills. The treatments were (i) conventional tillage (CT) and fertilization to create a relatively bare soil surface, followed by sowing barley with a double-disk drill; (ii) direct sowing with a hoe-type no-till (NT) drill that aggressively disturbed the soil beneath the seed and moved residue from the seed row; (iii) direct sowing with a single-disk or coulter-blade NT drill, where slight disturbance beneath the depth of seed placement was limited to that caused by the single disk or coulter blade; and (iv) direct sowing with a modified John Deere HZ deep-furrow hoe-type drill with wide (406 mm) row spacing. The John Deere HZ is the standard drill for sowing winter wheat into tilled summer fallow in the inland Pacific Northwest.[1] Specifications of each drill used in the study and method of fertilizer delivery are shown in Table 2.

Table 1. Annual precipitation during the 1995–1996 and 1996–1997 crop cycles near Ritzville, WA, along with the 20-yr average.†

Time period	Precipitation		
	1995–1996	1996–1997	20-yr avg.
	mm		
Aug.–Mar.	254	406	227
Apr.	33	35	29
May	23	29	31
June	26	13	21
July	0	7	14
12-mo total	336	490	322

† Precipitation during the study period was measured at the study site, whereas 20-yr precipitation avg. is from the Carico Hills weather station located 5 km east of the site.

Baseline surface residue in March (i.e., undisturbed from the previous crop) was 2420 and 3180 kg ha^{-1} for barley stubble and 3610 and 5230 kg ha^{-1} for winter wheat stubble in 1996 and 1997, respectively. Land preparation for the CT treatment in 1996 for both winter wheat and spring barley stubble was single tillage passes using farm-size equipment through the plot with (i) a five-bar super-harrow with 450-mm-long tines; (ii) a cultivator operating 75 mm deep with overlapping V-blades spaced 180 mm apart with an attached short-tooth harrow; (iii) fertilizer injection with 20-mm-wide shanks spaced 300 mm apart with an attached short-tine five-bar harrow. In 1997, CT seedbed preparation was single passes through the plots with (i) a tandem disk with 610-mm-diameter blades spaced 230 mm apart and set to a soil depth of 75 mm with an attached five-bar flex harrow and (ii) fertilizer injection with shanks spaced 300 mm apart and 100 mm deep with an attached five-bar harrow.

Fertilizer and seed rate in all plots was held constant across

[1] Mention of product and equipment names does not imply endorsement by the authors or by Washington State University.

Table 2. Specifications of conventional and no-till seed drills used to sow spring barley in research trials conducted near Ritzville, WA, in 1996 and 1997.

Drill	Year	Sowing condition	Opener type	Row spacing	Fertilizer delivery
				mm	
John Deere 8350†	1996	Conventional	Double disk	190	Pre-sowing aqua NH_3 + S injection. Granular N + P as starter with seed.
Flexi-coil 5000‡	1996	No-till	Hoe, paired row	255	Granular N, P, and S, delivered 30 mm below seed at sowing.
John Deere 752†	1996	No-till	Single disk	190	Aqua NH_3 + S injected behind fluted coulter between rows; granular N and P as starter with seed.
John Deere HZ†	1996, 1997	No-till	Hoe	406	Solution 32 N + P + S delivered 38 mm below seed at sowing.
John Deere 455†	1997	Conventional	Double disk	190	Pre-sowing Solution 32 N + P + S injection.
Concord 1100§	1997	No-till	Hoe, paired row	229	Granular N, P, and S delivered 38 mm below and between paired seed rows at sowing.
Cross-slot¶	1997	No-till	Notched coulter blade	255	Solution 32 N + P + S delivered 10 mm to the side of seed (on the other side of coulter blade) at sowing.

† John Deere Co., Moline, IL 61265.
‡ Flexi-coil, Saskatoon, SK S7K 3S5, Canada.
§ CaseIH-Concord, Fargo, ND 58102; equipped with Anderson openers, Anderson Machine Inc., Andover, SD 57422.
¶ Baker No-Tillage Ltd., 50 Nannestad Line, RDS, Fellding 5600, New Zealand.

Table 3. Soil water in the 1.8-m soil profile in 1996 and 1997, measured just before sowing spring barley (March) and at grain harvest (August) with two different previous crops.

Previous crop	1996 March	1996 August	1996 ΔH_2O	1997 March	1997 August	1997 ΔH_2O
	mm					
Spring barley	362	136	−226	397	179	−218
Winter wheat	407	172	−235	344	159	−185

treatments each year. Barley seed was treated in both years with a broad-spectrum fungicide and insecticide formulation of tebuconazole {α-[2-(4-chlorophenyl)ethyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol} thiram [bis(dimethylthiocarbamoyl)disulfide], and lindane [1,2,3,4,5,6-hexachlorohexane]. The fertilizer rate (based on soil test with a yield goal of 4000 kg ha^{-1}) was 78 kg N, 16 kg P, and 11 kg S ha^{-1} in 1996 and 84 kg N, 15 kg P, and 10 kg S ha^{-1} in 1997. In the CT treatment, all N and S were applied as liquid in either aqua NH_3 plus ammonium thiosulfate (1996) or urea–ammonium nitrate solution (320 g N kg^{-1}) plus ammonium thiosulfate (1997). Phosphorus was applied with the seed as granular monoammonium phosphate at the time of sowing in 1996, and before sowing as ammonium polyphosphate solution in 1997. All NT drills delivered seed and all fertilizer in one pass through the plots (Table 2). Plots were sown to barley at 78 kg ha^{-1} with 'Baronesse' between 28 and 31 March in 1996, and with 'Camelot' on 7 and 8 April in 1997. Soil covering seed was ≈30 mm in all treatments during both years. Broadleaf weeds were effectively controlled during the growing season with 0.56 kg a.i. ha^{-1} bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) applied in the tillering stage of growth.

Root Disease Assessment

Plants were collected from the plots at Feekes growth stage 5 (leaf sheaths strongly erect) in 1996 and at Feekes growth stage 10.5 (anthesis) in 1997 (Large, 1954). Rhizoctonia root rot is predominantly confined to the top 100 mm of soil. Roots from at least five plants in the top 150 mm of soil (0.004 m^3 soil volume for each sample) were dug from each of five separate locations within every plot. This composite sample typically amounted to 30 to 40 plants per plot, from which 25 plants were selected at random. The roots were washed with water in preparation for assessment of the incidence and severity of rhizoctonia root rot. We concentrated on the seminal roots, counting both the total number and the number girdled or severed by a rhizoctonia lesion and then dividing the number infected by the total number to determine percentage infection. We also rated the seminal roots on each plant for severity of rhizoctonia root rot on a scale of 0 to 8, where 0 = no lesion evident; 1 = <50% roots with a single typical sunken lesion; 2 = <50% roots with a few brown sunken lesions; 3 = >50% roots with a few brown sunken lesions; 4 = <50% roots with brown sunken lesions within 10 mm from the seed; 5 = >50% roots with brown sunken lesions within 10 mm from the seed; 6 = >50% roots shorter than 30 mm from the seed; 7 = >50% roots shorter than 10 mm from the seed; 8 = almost no roots with stunting or death of seedling.

Water, Soil Temperature, Stand Establishment, Dry Biomass, and Residue Measurements

Water content in the 1.8-m soil profile was measured in all plots each spring before sowing and again after harvest. Soil volumetric water content in the 0- to 0.3-m depth was determined from two 0.15-m core samples using gravimetric procedures, and in the 0.3- to 1.8-m depth in 0.15-m increments by neutron attenuation (Gardner, 1986). Additionally, mass

Table 4. Plant stand establishment of spring barley in 1996 and 1997 as affected by conventional tillage and no-till sowing method and the previous crop. Measurements were obtained 25 d after sowing.

Sowing treatment (and drill type)	Spring barley plant establishment: Spring barley stubble	Winter wheat stubble
	plants m^{-2}	
	1996	
Conventional tillage (double disk)	142	179a†
Flexi-coil 5000 (hoe, paired row)	113	95b
John Deere 752 (single disk)	107	76c
John Deere HZ (hoe)	97	105b
P-value	NS	0.001
	1997	
Conventional tillage (double disk)	139b	111b
Cross-slot (notched coulter)	175a	142a
Concord 1100 (hoe, paired row)	144b	137a
John Deere HZ (hoe)	88c	95c
P-value	0.001	0.001

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

water content in the 0- to 50-mm, 50- to 100-mm, and 100- to 150-mm soil depths in the seed row was measured on several sampling dates within 6 wk after sowing on three soil cores per plot.

Soil temperature at seed depth was determined on the same dates as surface soil water measurements (i.e., several times within 6 wk after sowing). Eight soil thermometers were placed with sensors 30 mm below the soil surface in the seed row at the depth of seed placement of each plot and allowed to equilibrate for 4 min before recording readings and moving to the adjoining plot. Temperature readings generally took five hours to obtain (eight readings × four treatments × four replications × two trials) during which time soil temperatures fluctuated; within each replication, however, readings were completed within 30-min intervals.

Barley stand establishment was measured by counting individual plants in 1-m row segments 25 d after sowing. Three row segments were selected and marked within each plot prior to seedling emergence. Barley dry biomass accumulation was determined by clipping all aboveground plant material in three 1-m-long row segments, and then making a unit area conversion based on row spacing, for each treatment several times during the growing season.

Surface residue from the previous crop was measured from all plots prior to sowing, soon after sowing, and again after grain harvest in August by gathering all aboveground dry biomass within a 1-m-diameter hoop. In the August sampling, current year (i.e., newly harvested) residue was separated from year-old residual residue. Samples were placed in paper bags and allowed to air-dry in a low-humidity greenhouse before weighing.

Yield Components

Yield was determined by harvesting a 7.6-m-wide swath through each 90-m plot with a commercial combine and then augering grain into a weigh wagon. Spike density and total dry biomass production were measured by hand-cutting the aboveground plant from 1-m row segments in three locations in each plot at harvest in August. Unit area for the clipped

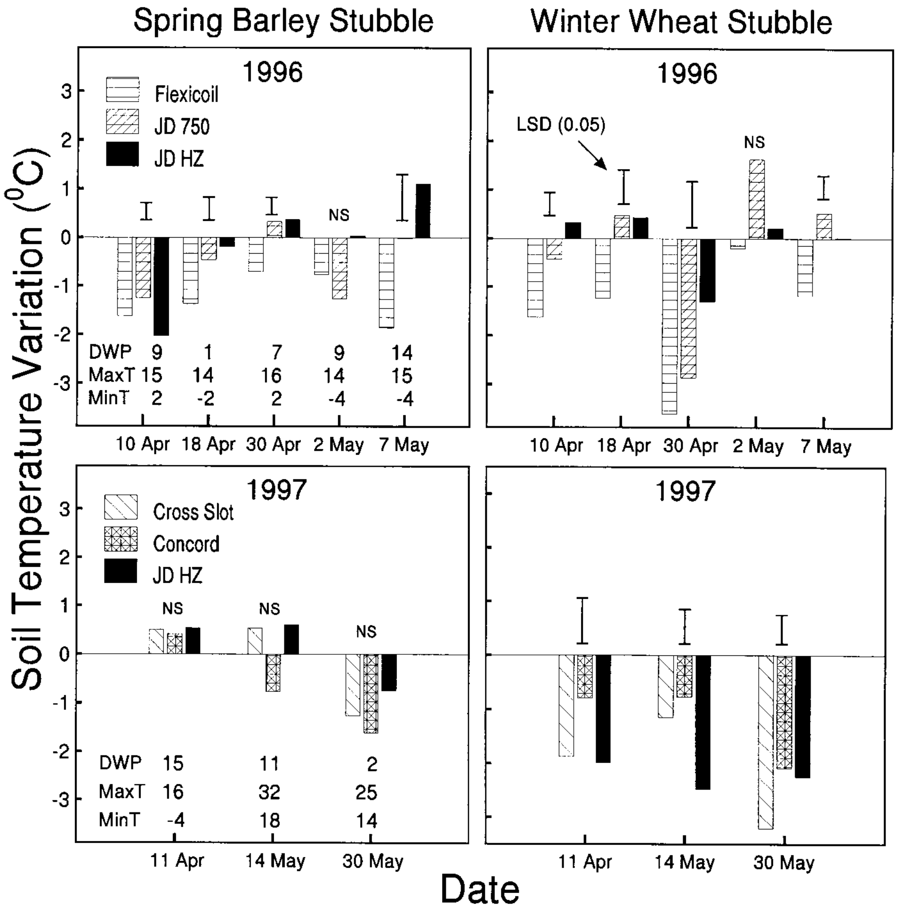

Fig. 1. Early-season soil temperature variation 30 mm below soil surface at depth of seed placement in no-till sowing treatments compared with conventional tillage (zero line) on five dates in 1996 and three dates 1997 where the previous crop was spring barley or winter wheat. Numbers below bars indicate days without precipitation (DWP) preceding soil temperature measurement dates and maximum (MaxT) and minimum (MinT) air temperature on the days soil temperatures were recorded.

row of each treatment was then calculated based on drill row spacing. Kernels per spike was calculated based on spikes per unit area (m^2) and 1000-kernel weight after passing spikes though a hand-fed thresher.

Analysis of Data

Analysis of variance was conducted for treatment differences in barley stand establishment, seed-zone temperature, seed-zone water content, total water in the 1.8-m profile, severity of rhizoctonia root rot, dry biomass accumulation, surface residue, and grain yield components. Treatment means were separated using Fisher's protected least significant difference. Treatments were considered significantly different if the *P*-value was <0.05. Simple and multiple regression models were calculated to determine the association of plant stand, dry biomass accumulation, spike density, kernels per spike, kernel weight, and rhizoctonia severity to grain yield.

RESULTS AND DISCUSSION

Precipitation, Water Storage, and Air Temperature

Over-winter (August–March) precipitation at the study site was 254 mm in 1995–1996 and 406 mm in 1996–1997, compared with the 20-yr average of 227 mm (Table 1). Soil water in the 1.8-m soil profile ranged from 344 to 407 mm in early spring before sowing in 1996 and 1997 (Table 3), respectively, which is wetter than average (≈260 mm) for the area. Growing-season precipitation (April–July) in 1996 and 1997 was slightly below the 20-yr average (Table 1), but May and June rains were timely. Maximum air temperature rarely exceeded 30°C during either the 1996 or 1997 growing season (data not shown), which probably raised the yield potential.

Plant Stand Establishment

Soil surface roughness, method of sowing, and seed opener configuration on the drill each affected barley stand establishment in both years. In 1996, there were no differences in stand establishment after sowing into the relatively smooth-surfaced barley-stubble seedbed, whereas stands were significantly better with CT than with any of the NT treatments after sowing into the deep-furrowed winter wheat stubble seedbed (Table 4). Plant stands in winter wheat stubble were lowest for the John Deere 752 disk drill, because uniform soil penetration and seed placement could not be maintained while sowing perpendicular to the deep, 406-mm-wide winter wheat furrows. Stands were better with the Flexicoil 5000 and John Deere HZ drills equipped with hoe openers that more aggressively penetrated through furrow ridges and disturbed the soil in the seed row (Tables 2 and 4).

Highly significant differences in plant stand among

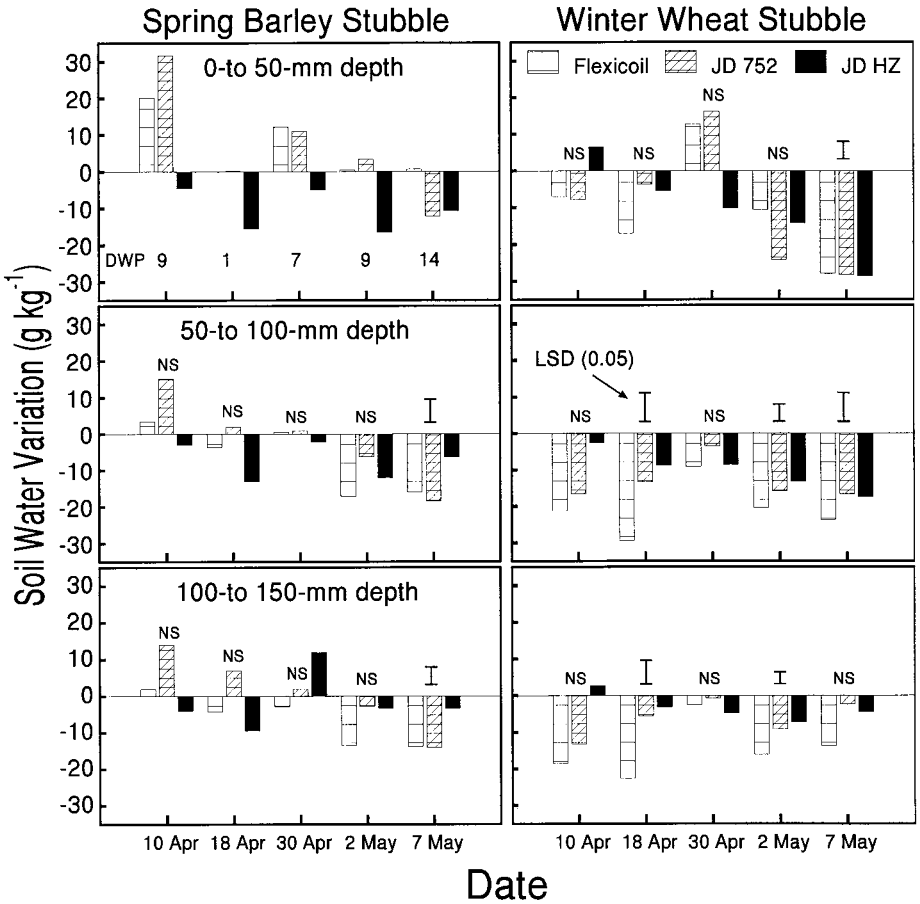

Fig. 2. Early-season soil water variation at three depths in no-till treatments compared with conventional tillage (zero line) on five dates in 1996 where the previous crop was spring barley or winter wheat. Numbers below bars indicate days without precipitation (DWP) preceding each soil water measurement date.

treatments were measured in 1997. The best stands were achieved with the Cross-slot and Concord NT drill treatments (Table 4). The CT treatment received fewer tillage operations in 1997 than in 1996 and therefore had a rougher, more cloddy seedbed than in the previous year, possibly accounting for the poorer stand. Stand density was lowest for the John Deere HZ drill with the wide row spacing.

Surface Soil Temperature and Water Content

Soil temperature at the depth of seed placement varied among NT treatments relative to CT during the early growing season, but was generally cooler with NT. Differences between one or more of the NT treatments compared with CT were obtained on four of five measurement dates in 1996 in both barley stubble and winter wheat stubble (Fig. 1). In 1997, there were no differences in soil temperature in barley stubble, but all NT treatments were cooler than CT on all sampling dates in winter wheat stubble (Fig. 1). The high quantity (up to 5180 kg ha^{-1}) of surface residue remaining after sowing probably increased solar reflectivity and soil surface insulation (Johnson and Lowery, 1985; Ross et al., 1985) in the NT treatments relative to CT.

Shallow soil water content during the early growing season was variable among treatments and measurement dates, especially in the 0- to 50-mm depth, but tended to be wetter with CT at the 50- to 100-mm and 100- to 150-mm depths for both years (Fig. 2 and 3). Early growing season (1 April–15 May) precipitation was 38 and 37 mm in 1996 and 1997, respectively, compared with the long-term average of 30 mm. Nontilled soils are considered more efficient for water conservation of spring-sown crops, because tillage of moist soils in the early spring breaks soil capillary and macropore continuity and accelerates soil drying above the depth of tillage. Additionally, infiltration generally is less through tilled than nontilled soils, because a greater amount of precipitation is required to wet the dry tillage layer, and to reestablish capillary continuity before water penetrates to deeper layers (Steiner, 1994). On the other hand, breaking soil capillary continuity with tillage has long been known to be effective in retarding evaporative loss of soil water from beneath the tillage depth (McCall, 1925). Barley seed in the CT treatment was placed ≈15 mm below the tilled layer (i.e., into nontilled soil), and we speculate that water conservation was not diminished relative to the NT treatments because the abrupt break of soil capillary with tillage helped to conserve water in the seed zone.

Rhizoctonia Root Rot

Rhizoctonia root rot generally was severe on the seminal roots of spring barley in both 1996 and 1997, regardless of the method of sowing or previous crop (Table 5). In previous studies, we have not found a yield impact

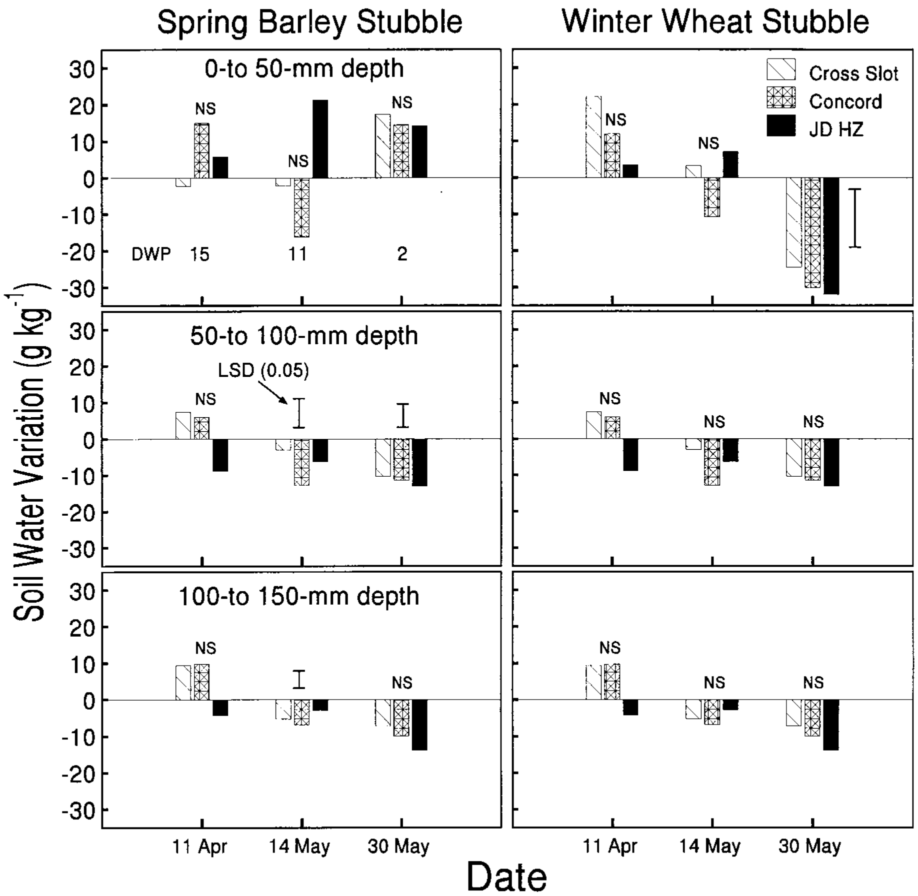

Fig. 3. Early-season soil water variation at three depths in no-till treatments compared with conventional tillage (zero line) on three dates in 1997 where the previous crop was spring barley or winter wheat. Numbers below bars indicate days without precipitation (DWP) preceding each soil water measurement date.

with rhizoctonia severity ratings below 3.0, but have shown limitations to yield with ratings of 4 to 5 and above (R.J. Cook, unpublished data). In contrast to the high percentages of infection of seminal roots, the crown roots, although not included in the assessment, were free of infections, presumably because the inoculum potential of the pathogen in the soil had declined by the time these roots were formed. Each lesion that collectively makes up rhizoctonia root rot is a separate infection initiated from the primary inoculum in the soil and, because the viability of this primary inoculum declines over time, there can be markedly less primary inoculum when crown roots form than when seminal roots form. One exception was in 1996, when the disease on seminal roots was relatively mild following spring barley (Table 5). In that same year, with severe disease after winter wheat, rhizoctonia was more acute in the CT treatment, where seed was sown ≈15 mm below the tilled layer into undisturbed soil with double-disk openers, than in the Flexi-coil and JD HZ treatments equipped with hoe-type openers that aggressively disturb the soil below the seed.

Rhizoctonia infection was again limited to the seminal roots in 1997, where it was severe regardless of whether the site was in winter wheat or spring barley the previous year and regardless of the method of sowing. Plants from plots sown with the JD HZ drill had the highest rhizoctonia root rot severity rating, but otherwise there were no differences among the treatments (Table 5).

Table 5. Influence of method of sowing on severity of rhizoctonia root rot of spring barley in 1996 and 1997 where the previous crop was either spring barley or winter wheat. Plant samples were collected at Feekes growth stage 5 (leaf sheaths strongly erect) on 16 May 1996, and at Feekes growth stage 10.5 (anthesis) on 17 June 1997.

	Rhizoctonia severity rating†	
Treatment	Spring barley stubble	Winter wheat stubble
	1996	
Conventional tillage (double disk)	1.9	5.4a‡
Flexi-coil 5000 (hoe)	1.6	3.9b
JD 752 (single disk)	2.0	5.0ab
JD HZ (hoe)	1.6	3.9b
	NS	0.007
	1997	
Conventional tillage (double disk)	4.1c	4.4b
Concord 1100 (hoe)	4.3bc	4.5b
Cross-slot (notched coulter)	4.8b	4.6b
John Deere HZ (hoe)	5.7a	5.8a
P-value	0.001	0.001

† Severity rated on a scale of 0 to 8, where 0 = no lesion evident; 1 = <50% roots with a single typical sunken lesion; 2 = <50% roots with a few brown sunken lesions; 3 = >50% roots with a few brown sunken lesions; 4 = <50% roots with brown sunken lesions within 10 mm from the seed; 5 = >50% roots with brown sunken lesions within 10 mm from the seed; 6 = >50% roots shorter than 30 mm from the seed; 7 = >50% roots shorter than 10 mm from the seed; 8 = almost no roots with stunting or death of seedling.

‡ Within columns and years, means followed by the same letter are not significantly different at the 0.05 probability level.

Table 6. Total above-ground dry biomass accumulation of spring barley on several sampling dates in 1996 and 1997. The barley was sown either conventionally (CT) (i.e., after several tillage operations to prepare a seedbed) or with no-till equipment (described in Table 2) into either barley stubble or winter wheat stubble from the previous crop year.

Date	Total barley aboveground biomass									
1996 equipt: / 1997 equipt:	CT / CT	Flexi-coil / Cross-slot	JD 752 / Concord	JD HZ / JD HZ	*P*-value	CT / CT	Flexi-coil / Cross-slot	JD 752 / Concord	JD HZ / JD HZ	*P*-value
	kg ha^{-1}					kg ha^{-1}				
1996	Sown into spring barley stubble					Sown into winter wheat stubble				
9 May	200b†	280a	260a	150b	0.001	170b	230a	230a	80c	0.001
22 May	3660b	3270c	4340a	2470d	0.001	3720a	2900b	2300b	2240b	0.001
29 May	4930ab	5190ab	5930a	4060b	0.012	5200a	4670ab	3640bc	3480c	0.015
17 June	6450a	5610b	6810a	3960c	0.001	7070a	5250b	4980b	3760c	0.001
1997	Sown into spring barley stubble					Sown into winter wheat stubble				
27 May	710b	970a	960a	400c	0.001	450b	580a	660a	370b	0.001
1 June	1090b	1460a	1340a	780c	0.001	910b	990b	1210a	790b	0.002
8 June	2050b	2580a	2260ab	1530c	0.001	1700bc	1940ab	2160a	1330c	0.003
19 June	3910b	5110a	4910a	3570b	0.001	3140c	4490a	4140ab	3840b	0.001
3 July	5180b	7490a	7080a	5480b	0.001	4870b	6690a	6870a	4750b	0.001
14 July	6010b	8680a	8150a	6930b	0.001	5970b	8760a	9400a	6290b	0.001

† Within-row means followed by the same letter are not significantly different at the 0.05 probability level. Comparisons cannot and should not be made within a column.

Dry Biomass Accumulation and Yield Components

Aboveground dry biomass accumulation during the growing season was strongly influenced by stand establishment ($r^2 = 0.92$, $P < 0.001$; data not shown). There were highly significant differences in dry biomass among treatments on all sampling dates during both years, and the rank order among treatments remained the same, with few exceptions, throughout both growing seasons (Table 6). Dry biomass for the John Deere HZ was lowest of any of the NT treatments in all four sowing trials, except for CT in 1997 (Table 6).

Analyzed across locations, grain yield was significantly greater when the previous crop was spring barley rather than winter wheat for CT (1996 and 1997), the single disk JD 752 (1996), and the notched-coulter Cross-slot (1997) treatments, but yield with hoe opener drill treatments (i.e., Flexi-coil 5000, JD HZ, and Concord 1100) was not affected by previous crop (Table 7; combined ANOVA not shown). Yield reductions with the non–hoe-opener treatments may be largely due to the hard, less penetrable surface soil and the deep furrows in the winter wheat stubble, whereas the spring barley stubble seedbeds had a smoother, mellower surface soil condition.

Grain yield generally improved in the two experiments in both years proportional to increased spike density (Table 7). Spike number per unit area is considered the most important yield component for wheat and barley under dryland conditions when severe water stress is not a factor (Arnon, 1972). The John Deere HZ treatment always had the lowest spike density and, although it compensated with greater kernel weight and numbers per spike, was not competitive for grain yield with other NT treatments, except when sown into winter

Table 7. Grain yield components of spring barley in 1996 and 1997 sown either conventionally (CT) or with no-till equipment (described in Table 2) into spring barley stubble and winter wheat stubble.†

	1996 equipt: CT / 1997 equipt: CT	Flexi-coil / Cross-slot	JD 752 / Concord	JD HZ / JD HZ	*P*-value
1996			Sown into spring barley stubble		
Grain yield, kg ha^{-1}	4036a	3744b	3811b	3049c	0.023
Spikes m^{-2}	581a	506a	538a	430b	0.001
Kernels spike^{-1}	19.2ab	19.3ab	18.4b	19.5a	0.044
1000 kernel wt., g	39.8c	41.9b	41.0b	43.3a	0.001
1996			Sown into winter wheat stubble		
Grain yield, kg ha^{-1}	3699a	3228b	3049b	2870b	0.001
Spikes m^{-2}	58a	549ab	527b	420c	0.001
Kernels spike^{-1}	19.2	19.3	18.4	19.5	NS
1000 kernel wt., g	38.7a	38.7a	37.2b	39.7a	0.017
1997			Sown into spring barley stubble		
Grain yield, kg ha^{-1}	3696b	4323a	4077a	3405b	0.023
Spikes m^2	473a	506a	463a	366b	0.001
Kernels spike^{-1}	19.3bc	18.4b	19.6b	21.0a	0.001
1000 kernel wt., g	40.8b	38.3c	39.7bc	43.1a	0.001
1997			Sown into winter wheat stubble		
Grain yield, kg ha^{-1}	3315b	3830a	3852a	3136b	0.044
Spikes m^2	420b	463a	441ab	334c	0.001
Kernels spike^{-1}	20.5ab	20.0ab	19.5b	21.3a	0.050
1000 kernel wt., g	42.0b	42.5b	42.0b	43.4a	0.001

† Within-row means followed by the same letter are not significantly different at the 0.05 probability level. Comparisons cannot and should not be made within a column.

Table 8. Correlation coefficients of simple and multiple determination for regression models to describe the relationship of plant stand, dry biomass production, spike density, kernels per spike, kernel weight, and rhizoctonia root rot severity to grain yield in 1996, 1997, and 1996 plus 1997 combined.

Independent variable	1996 Coef.	1996 *P*-value	1997 Coef.	1997 *P*-value	1996 + 1997 Coef.	1996 + 1997 *P*-value
Simple regression, r^2						
Stand	0.39	0.05	0.87	0.001	0.60	0.001
Dry biomass	0.78	0.004	0.55	0.035	0.63	0.001
Spike density	0.53	0.040	0.78	0.004	0.62	0.001
Kernels per spike	—†	NS	0.83	0.002	—	NS
Kernel weight	—	NS	—	NS	—	NS
Rhizoctonia severity	—	NS	—	NS	—	NS
Multiple regression, R^2						
Stand + dry biomass + spike density	0.79	0.048	0.92	0.012	0.81	0.001

† Missing values: coefficients of determination not reported when not significant at the 0.05 probability level.

wheat stubble in 1996. The CT treatment produced more grain than any of the NT treatments in 1996 when the previous crop was either barley or winter wheat, but the Cross-slot and Concord NT treatments out-produced CT in 1997 (Table 7).

Simple linear regression models show that stand establishment, dry biomass accumulation, and spike density were significantly related to grain yield in both years and in a combined 1996 plus 1997 analysis (Table 8). In multiple regression models, stand, dry biomass, and spike density collectively accounted for 79, 92, and 81% of yield variability in 1996, 1997, and 1996 plus 1997, respectively (Table 8). Kernels per spike was related to yield differences in 1997, but not in 1996 or in the combined 1996 plus 1997 regression analysis. Kernel weight and rhizoctonia root rot severity were not correlated with yield differences among treatments during either year (Table 8).

Crop Residue

Only 550 to 900 kg ha^{-1} of year-old residue remained in the CT treatment, compared with 1320 to 5180 kg ha^{-1} for the NT treatments during the two years (Table 9). The ultra-low-disturbance Cross-slot drill retained more surface residue (except that the JD HZ equaled Cross-slot after barley stubble) and disturbed the soil less than the other NT drill treatments. Mass of newly harvested residue in the NT treatments was less than or equal to that of the CT treatment during both years. Total residue was higher for all NT treatments compared with CT in 1997, but not in 1996 (Table 9). Maintenance of barley residue on the soil surface is of particular importance to growers practicing a winter wheat–spring barley–fallow rotation in low-precipitation dryland areas of the inland Pacific Northwest because barley residue decomposes faster than wheat residue (Smith and Peckenpaugh, 1986). This often makes it difficult to meet minimum residue requirements for erosion control if soils are tilled during the 13-mo fallow cycle.

SUMMARY AND CONCLUSIONS

Plant stand establishment, rapid plant biomass accumulation, and thick spike density contributed to high spring barley grain yields during two years with favorable growing conditions. When uniform stands were achieved, no-till sowing into standing stubble was equal or superior for grain yield compared with conventional tillage. A no-till drill with wide (406 mm) row spacing was not competitive with other treatments, because of low spike density and associated low yield, but yield did not decline with other no-till treatments with row spacing as wide as 255 mm.

Rhizoctonia root rot was limited largely to seminal roots, where infections were severe in three of the four sowing trials. The severity of rhizoctonia root rot on the seminal root system did not affect grain yield among

Table 9. Year-old surface residue, newly harvested surface residue, and total surface residue in August of 1996 and 1997 as affected by type of seedbed (conventional till, CT, or with no-till equipment, described in Table 2) and method of sowing spring barley.†

Residue type	Surface residue mass									
1996 equipt:	CT	Flexi-coil	JD 752	JD HZ		CT	Flexi-coil	JD 752	JD HZ	
1997 equipt:	CT	Cross-slot	Concord	JD HZ	*P*-value	CT	Cross-slot	Concord	JD HZ	*P*-value
	kg ha^{-1}					kg ha^{-1}				
1996		Sown into spring barley stubble					Sown into winter wheat stubble			
Year-old	850c‡	1490b	1320b	1760a	0.003	900b	1520a	1610a	1590a	0.001
Newly harvested	4140a	3650a	3740a	3070b	0.006	3980a	3450b	2920c	2960c	0.018
Total	4990a	5140a	5060a	4830a	NS	4880a	4970a	4530b	4550b	0.016
1997		Sown into spring barley stubble					Sown into winter wheat stubble			
Year-old	550c	2330a	1810b	2030ab	0.001	890c	5180a	4210b	3720b	0.005
Newly harvested	3910a	4100a	3900a	3740a	NS	4240a	4170a	3940a	3610a	NS
Total	4460b	6430a	5710a	5770a	0.001	5130c	9350a	8150b	7330b	0.003

† Baseline residue in March (i.e., undisturbed stubble from the previous crop) was 2420 and 3180 kg ha^{-1} for barley stubble and 3610 and 5230 kg ha^{-1} for winter wheat stubble in 1996 and 1997, respectively.

‡ Within row means followed by the same letter are not significantly different at the 0.05 probability level. Comparisons cannot and should not be made within a column.

treatments, nor did it appear to limit yields, possibly because crops were sustained by the healthy crown roots during relatively nonstressful growing conditions. There was no consistent effect of sowing method on severity of rhizoctonia root rot in any of the four experiments.

Early spring soil temperature was cooler with no-till, but seed-zone soil water was slightly higher with conventional tillage. Spring barley yields were always best for the disk-drill-type treatments (both CT and NT) when the previous crop was spring barley, compared with winter wheat, probably because the winter wheat seedbed was harder, rougher, and less penetrable. No-till drill treatments retained from 1320 to 5180 kg ha^{-1} surface residue after sowing.

Soil organic carbon decline, soil erosion, and air and water pollution are major problems in low-precipitation dryland farming areas, where tillage is often intensive and, historically, only one crop is produced every two years. Priority long-term research needs for development of continuous no-till and reduced-till systems include further refinement of no-till drills that are effective under a variety of sowing conditions; agronomic and economic assessment of broadleaf alternative crops in cereal-based cropping patterns; better understanding of how increased cropping intensity and diversity affects pressures for soilborne pathogens and weeds; and documentation of biological and ecological soil changes that occur during the transition to no-till management systems.

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