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Straw Production and Grain Yield Relationships in Winter Wheat

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ABSTRACT

Winter wheat (*Triticum aestivum* L.) –fallow is the predominant cropping system in low-precipitation regions (<250 mm annually) of the inland Pacific Northwest (PNW) in the USA. Wind erosion is a recurrent problem during and after fallow periods when inadequate crop residue amounts are retained on the soil surface. Management options that optimize both grain yield and straw production are needed. A 3-yr field study was conducted to determine sowing rate and sowing date effects on straw and grain yield, and grain yield components of winter wheat cultivars with semidwarf, standard height, or tall growth habit. Four winter wheat cultivars were evaluated at three sowing rates (65, 130, and 195 seeds m^{-2}) and three sowing dates in August, September, and October. A split plot design was used, with sowing dates as main plots and sowing rate × cultivar combinations as subplots. The greatest effect of sowing date was on straw production. Straw biomass from mid-August sowing averaged 6.70 Mg ha^{-1} compared with 4.65 and 2.78 Mg ha^{-1} from mid-September and mid-October sowing, respectively. Grain yield was highest for mid-August sowing during two years and lowest for mid-October sowing all years. Averaged across years, the semidwarf cultivar produced the highest grain yield on all sowing dates and was equal to the standard height and tall cultivars for straw production. Path coefficient analysis showed that variation in grain yield was due primarily to differences in spikes per unit area (SPU) and kernels per spike (KPS). Late sowing resulted in a large reduction in SPU and, therefore, grain yield. For cropland susceptible to wind erosion in east-central Washington, early sowing results in increased wheat straw production and generally higher grain yield compared with mid-to-late sowing dates.

RESIDUE ON THE SOIL SURFACE is often the only protection against wind erosion on poorly aggregated soils in the 150- to 250-mm annual precipitation dryland wheat production zone of east-central Washington. Winter wheat–fallow is the dominant cropping pattern in use. Growers often have difficulty maintaining the minimum (390 kg ha^{-1}) residue cover on the soil surface because of the low quantities of straw produced and the use of traditional intensive tillage practices during fallow (Papendick, 1998). During most years, use of summer fallow allows growers to sow winter wheat into adequate carryover soil water for seed germination during mid-to-late August. Sowing must sometimes be delayed due to insufficient seed–zone soil water (Schillinger et al., 1998), or the need to control winter annual grass weeds (Ogg, 1993). Early stand establishment is an important factor for increasing grain yield, and it is strongly influenced by seed–zone water content and depth of soil covering the seed (Lindstrom et al., 1976). Because of frequent dry seed–zone conditions and the need for seedlings to emerge from deep sowing depths, tall and standard height cultivars predominate in east-central Washington, while only the best-emerging semidwarf cultivars are grown (Donaldson, 1996).

Harvest index (HI) is defined as percentage grain in the total plant biomass. Genetic improvement of grain yield in winter wheat has been closely associated with increases in HI, but not with increases in total biomass (Slafer and Andrade, 1991). Thus, the adoption of semidwarf wheat cultivars is due to their increased biological efficiency, as these shorter cultivars tend to produce less straw per unit of grain than conventional height cultivars. Wallace et al. (1993) warned that the trend of achieving higher grain yield by increasing HI is not sustainable, and recommended total biomass be considered in breeding programs to assure long-term yield improvement.

Sowing rate and date effects on grain yield of wheat have been reported from major wheat-producing regions in the USA and Canada (Paulsen, 1987). Of the three grain yield components — SPU, KPS, and kernel weight (KW) — SPU and KPS generally are the most important determinants of grain yield (Knapp and Knapp, 1978; Shah et al., 1994). Although KW does exert an influence on grain yield, numerous sowing rate experiments have demonstrated that its influence is generally smaller than that of SPU or KPS (Guitard et al., 1961; Shah et al., 1994). Maximum grain yield results from an optimum balance of the three yield components,

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Abbreviations: HI, harvest index; KPS, kernels per spike; PNW, Pacific Northwest; SPU, spike number per unit area; KW, kernel weight.

which are competing for fixed resources during critical stages of development (Grafius, 1972). Higher sowing rates in wheat result in increased SPU and associated decreases in KPS (Johnson et al., 1988) because of yield component compensation. Tompkins et al. (1991) found that the increase in SPU with higher sowing rate was proportionately greater than the decrease in KPS.

In the PNW, early sowing of winter wheat is associated with high SPU, high KW, and low KPS (Thill et al., 1978). Reduced interplant competition related with low sowing rates generally results in concomitant increases in KPS and KW; however, these may not fully compensate for low SPU (Joseph et al., 1985). The relative contribution of SPU on grain yield becomes less important with delayed sowing (Blue et al., 1990). Baker (1982) found that cultivars varied in their response to sowing rate, but the best grain yields were generally obtained from the highest sowing rate, and highest HI from the intermediate sowing rate. Ciha (1983) observed yield reduction in the PNW with higher sowing rates due to increased lodging; however, this is generally limited to areas receiving >400 mm annual precipitation.

Emphasis on the need to reduce water and wind erosion has heightened the importance of maintaining protective residue cover on the soil surface in crop production systems. Wheat cultivars grown in dryland areas of the PNW vary greatly in plant height and may differ in straw production and HI. Few previous studies have assessed both grain yield and straw production in low-precipitation environments. This study was conducted to determine the optimum combination of sowing rate and sowing date for semidwarf, standard height, and tall winter wheat cultivars, and the effects on straw production, grain yield, and yield components.

MATERIALS AND METHODS

A 3-yr study involving the 1994 to 1995, 1995 to 1996, and 1996 to 1997 growing seasons was conducted at the Washington State University Dryland Research Station at Lind, Washington. Annual precipitation at the site averages 244 mm (Table 1). The soil is a Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) which has less than 10 g kg^{-1} organic matter in the surface 0.1 m. The Shano soil is considered one of the most susceptible to wind erosion and to suspended dust emissions in the Columbia Plateau of eastern Washington (Saxton et al., 2000).

Treatments consisted of four winter wheat cultivars evaluated at three sowing rates and three sowing dates. Cultivars were Buchanan, Hatton, Moro and Eltan; sowing rates were 65, 130, and 195 seeds m^{-2} (≈22, 44, and 66 kg ha^{-1}), respectively; and sowing dates were ≈20 August, 16 September, and 21 October, respectively. Sowing dates for each month varied by a few days among years (1994–1996).

The experimental design was a split plot in randomized complete block arrangement with four replications. Main plots were sowing dates, and subplots were cultivar × sowing rate combinations. Buchanan and Hatton are tall and standard height hard red winter wheat cultivars, respectively. Moro is a standard height, club–spike, soft white winter wheat, and Eltan is a semidwarf, common–spike soft white winter wheat. Hatton has stiff straw, midsized spikes, and moderate tillering. Buchanan and Eltan have a finer, more limber straw, smaller spikes, and profuse tillering. Moro has large spikes, large diameter straw, and low-to-moderate tillering. These cultivars are representative of the different market classes and phenotypes grown in the low-precipitation dryland cropping region of the inland PNW.

Table 1. Precipitation at Lind, Washington, during the study period compared with the long-term average.

Month	1993–1994†	1994–1995	1995–1996	1996–1997	80-yr avg.
	mm				
August	10	0	6	0	9
September	0	6	21	5	14
October	13	37	28	57	22
November	6	39	30	63	32
December	33	33	48	48	32
January	33	48	41	51	26
February	8	27	38	22	22
March	1	56	10	35	21
April	26	24	25	25	18
May	39	8	28	27	20
June	7	42	12	23	20
July	5	15	1	21	8
Annual total	181	335	288	377	244

† 1993–1994 was the fallow year prior to beginning the experiment.

Plots were prepared during the fallow cycle each year using a wide-blade, V-shaped sweep for primary tillage in March, application of 45 kg N ha^{-1} as anhydrous NH_3 in April, and two or three rodweeding operations as needed to control Russian thistle (*Salsola iberica* Sennen & Pau) and other weeds from May to August. Plot locations among years were separated by <200 m. Soil water content in the total 180-cm profile in mid-August was measured in 15-cm increments using neutron attenuation (Gardner, 1986). Seed–zone water content at the time of sowing (August and September only) was determined gravimetrically in 2-cm increments to a depth of 22 cm using an incremental soil sampler. For both total soil profile and seed–zone water measurements, five samples within the plot area were taken and averaged to obtain each value.

Certified seed of all four cultivars was treated with difenoconozole fungicide {3-chloro-4-[4-methyl-2-(1*H*-1,2,4-triazol-1-yl-methyl)-1,3-dioxolan-2-yl]phenyl 4-chlorophenyl ether}. Each 6-m-long by 3.3-m-wide plot was sown with a deep-furrow, split-packer drill with 40-cm spacing between rows. Broadleaf weeds were controlled during the growing season with bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) applied at 0.42 kg ai ha^{-1} in mid-April. Weeds that germinated subsequently were removed by hand.

In late July, mature plants from 1-m row sections from each plot were clipped and SPU determined. Spikes were threshed and a subsample was used to determine 1000 KW, using an electronic seed counter. KPS was calculated from the 1000 KW and SPU. Grain yield and straw production was determined by taking a 1.2-m swath (outside of the hand sample area) through each plot with a plot combine. The combine cutting bar was operated at ground level and residue was collected on a tarp attached to the back of the combine, and then weighed.

An analysis of variance was conducted in which all effects were considered fixed. Path analysis was performed to quantify causal effects among variables (Loehlin, 1987). Path coefficients are standardized regression coefficients, and have the same interpretations as regression coefficients except that they are expressed in standard deviation units.

RESULTS AND DISCUSSION

Precipitation and Soil Water

Precipitation during the study was greater than the long-term average, except for the 1993 to 1994 fallow cycle, which was drier than average (Table 1). Available water for winter wheat in the 180-cm soil profile at the end of fallow in mid-August was 5.5, 11.5, and 9.5 cm in 1994, 1995, and 1996, respectively (Fig. 1a). Volumetric soil water content at depth of seed placement for August and September was 11.5, 12.7, and 13.4 cm^3 cm^{-3} in 1994, 1995, and 1996, respectively. Seed–zone water content was barely sufficient for stand establishment in August and September of 1994 (minimum 11 cm^3 cm^{-3} required; Lindstrom et al., 1976), but was adequate in 1995 and 1996 (Fig. 1b). Depth of soil covering the seed for sowing dates in August and September was 16 cm in 1994, 10 cm in 1995, and 10 cm in 1996. Sowing during October in all years occurred after the surface soil had been wetted by rain and only 3 cm of soil covered the seed. Wheat survived the relatively mild winters with little or no cold injury.

Sowing Rates, Sowing Dates, and Cultivars

Altering sowing rate caused significant changes in all variables measured (Table 2), and effects were consistent across cultivars, as the cultivar × sowing rate interaction was not significant for any trait. Apparently, effects on plant growth and development resulting from sowing rate were so large that they masked any genotypic differences that might cause cultivars to respond differently. Grain yield was not decreased by low sowing rate in August, but was reduced compared with medium and high sowing rates in September and October (Fig. 2c). The low sowing rate reduced straw production at all sowing dates, but straw production was similar at medium and high sowing rates (Fig. 2a). HI was generally highest for low sowing rate in August and September, but had no effect in October (Fig. 2b). There were no differences in SPU (Fig. 2d) among sowing rates for August sowing, but SPU rose incrementally with increased sowing rate for the September and October sowing dates. Sowing rate had no influence on KPS for the August sowing, but KPS decreased incrementally for the September and October sowing dates (Fig. 2f). Higher sowing rates caused a slight decrease in KW in the August and September sowing dates, but had no effect in October (Fig. 2e).

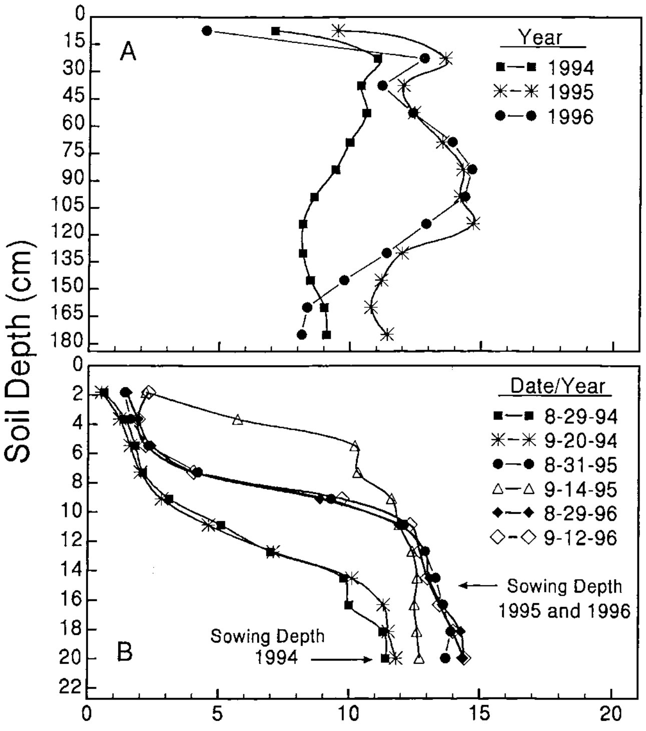

Fig. 1. Soil water distribution in fallow in late summer during 3 yr at Lind, Washington. (A) Total soil profile (0–180 cm) water in August 1994, 1995, and 1996. Available water for winter wheat in the total profile after a year of fallow was 5.5, 11.5, and 9.5 cm in 1994, 1995, and 1996, respectively. (B) Seed–zone (0–22 cm) water and sowing depth on six sowing dates in August and September in 1994, 1995, and 1996.

For both grain yield and straw production, the effects of sowing rate depended on the year in which the crop was grown, as indicated by the significant year × sowing rate interaction for those variables (Table 2). Maximum grain yield was obtained from the low and medium sowing rates in 1995, and from the medium and high rates in 1996 and 1997 (Fig. 3c). In all years, the low sowing rate resulted in the lowest straw production (Fig. 3a) and lowest SPU (Fig. 3d). There were no differences in KW within any year (Fig. 3e), and KPS for the low rate was equal to or greater than that of the higher sowing rates (Fig. 3f).

Marked increases in straw production always resulted from early sowing, more than doubling straw produced from the October sowing in all years (Fig. 4a). The quantity of straw decreased ≈30% per month, resulting in 71 and 42% of the August amount for September and October, respectively. HI was inversely related to straw production (i.e., early sowing always resulted in the lowest HI) (Fig. 4b). Grain yield was highest with early sowing in 1995 and 1997, and better than October sowing in all years (Fig. 4c). Spikes per unit area was consistently higher for August vs. October sowing and was also higher compared with September sowing in 1995 (Fig. 4d). There were no consistent sowing date relationships in KW or KPS (Fig. 4e and 4f).

Table 2. Analysis of variance for straw production, grain yield, and yield components for four winter wheat cultivars sown on three dates and at three sowing rates at Lind, WA, for three crop years 1995, 1996, 1997.

Source	df	Straw wt.	Spikes m^2	Kernels $spike^{-1}$	Kernel wt.	Grain yield	Harvest index
Year (Y)	2						
Date (D)	2	**	**		**	**	**
Rep (YD)	27						
Cultivar (C)	3	**	**	**	**	**	**
Rate (R)	2	**	**	**	**	*	**
C × R	6						
Y × C	6	**	**	*	**	**	**
Y × R	4	**				**	
C × D	6	*	**		**		*
R × D	4				**	**	**
Y × D	4	**	**		**	**	**
Y × C × R	12						*
Y × C × D	12	**	*		**	**	**
C × R × D	12						
Y × R × D	8	**		**		**	
Y × C × R × D	24			*			

*, ** Significant at the 0.05 and 0.01 levels, respectively. Blank values indicate no significant effect.

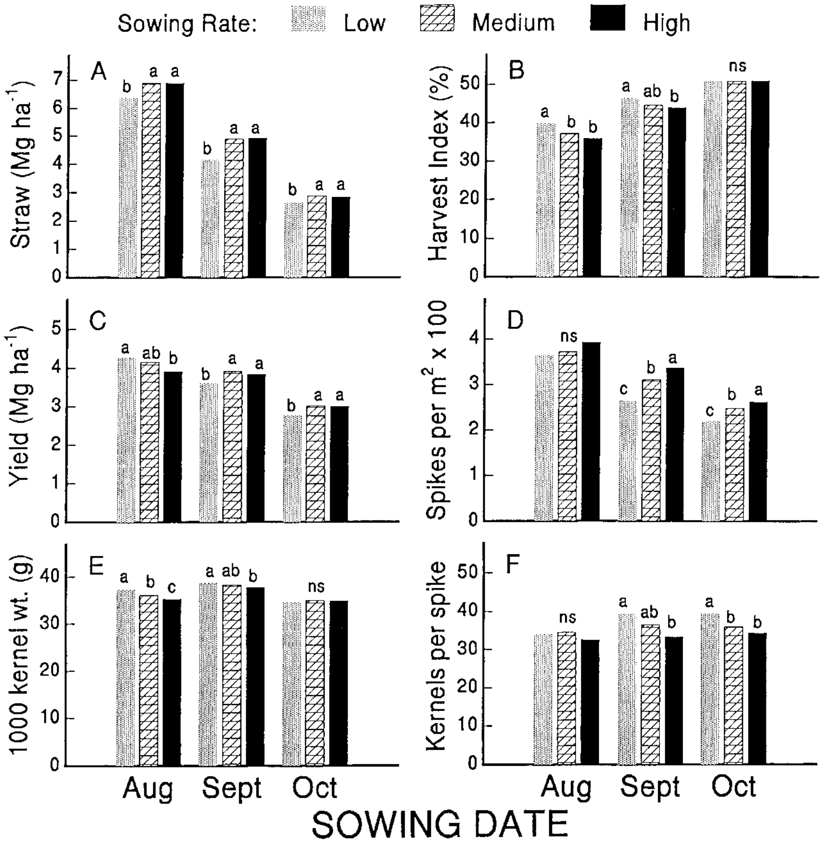

Fig. 2. Straw production, harvest index, grain yield, and yield components, at Lind, WA, as influenced by sowing rate averaged across four winter wheat cultivars and 3 yr. Within-month means followed by the same letter are not significantly different at $P < 0.05$.

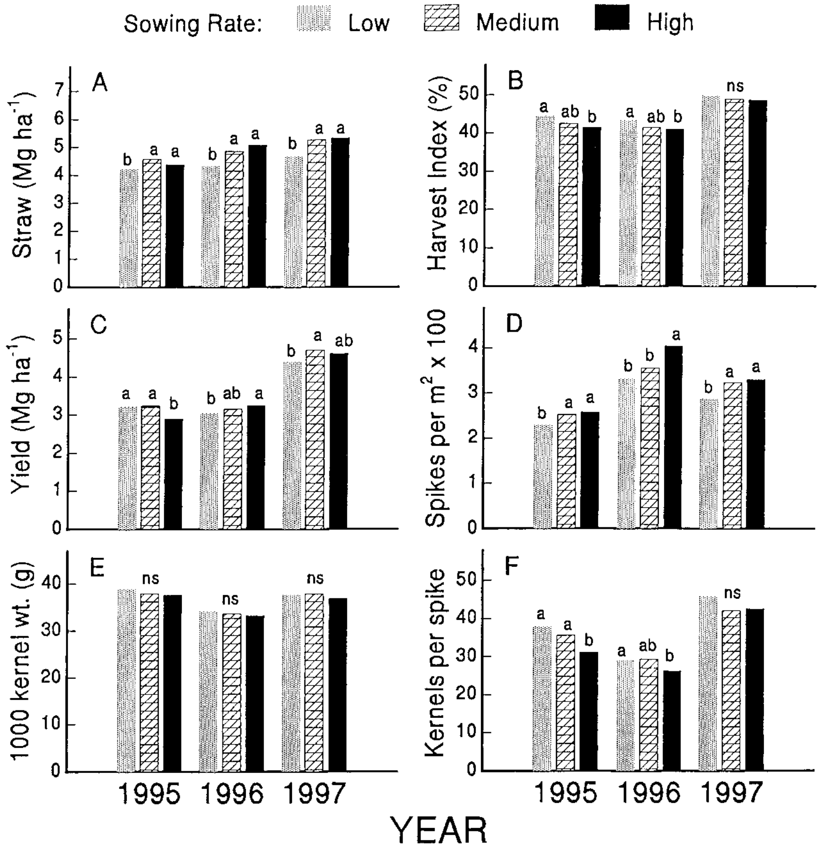

Fig. 3. Straw production, harvest index, grain yield, and yield components in 1995, 1996, and 1997 at Lind, WA, as influenced by sowing rate averaged across four winter wheat cultivars and three sowing dates. Within-year means followed by the same letter are not significantly different at $P < 0.05$.

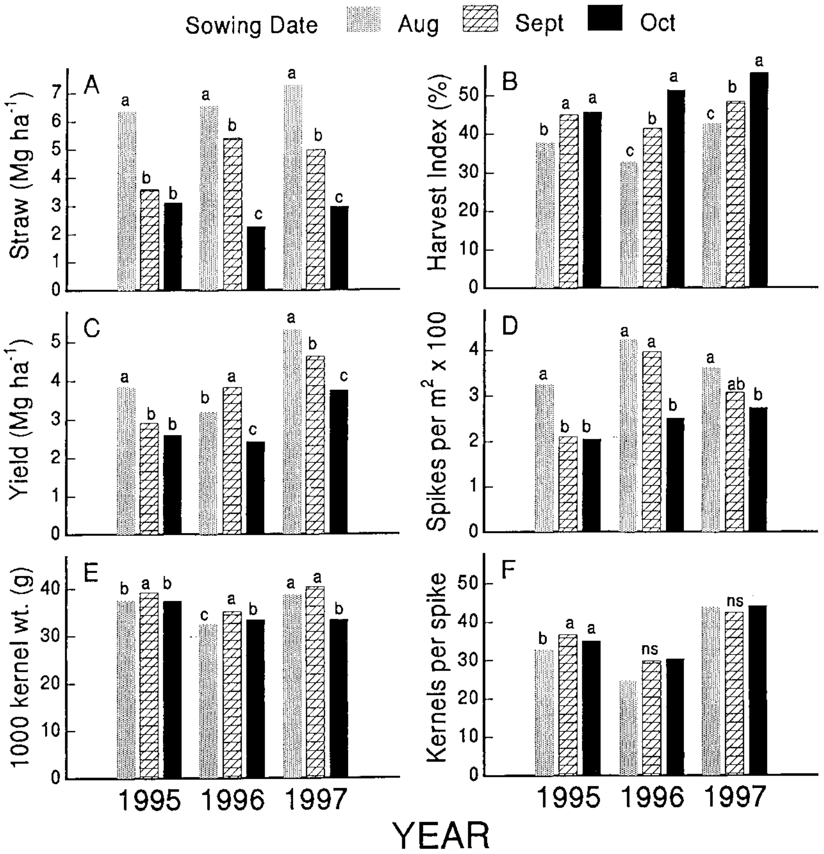

Fig. 4. Straw production, harvest index, grain yield, and yield components in 1995, 1996, and 1997, as influenced by sowing date averaged across four winter wheat cultivars and three sowing rates. Within-year means followed by the same letter are not significantly different at $P < 0.05$.

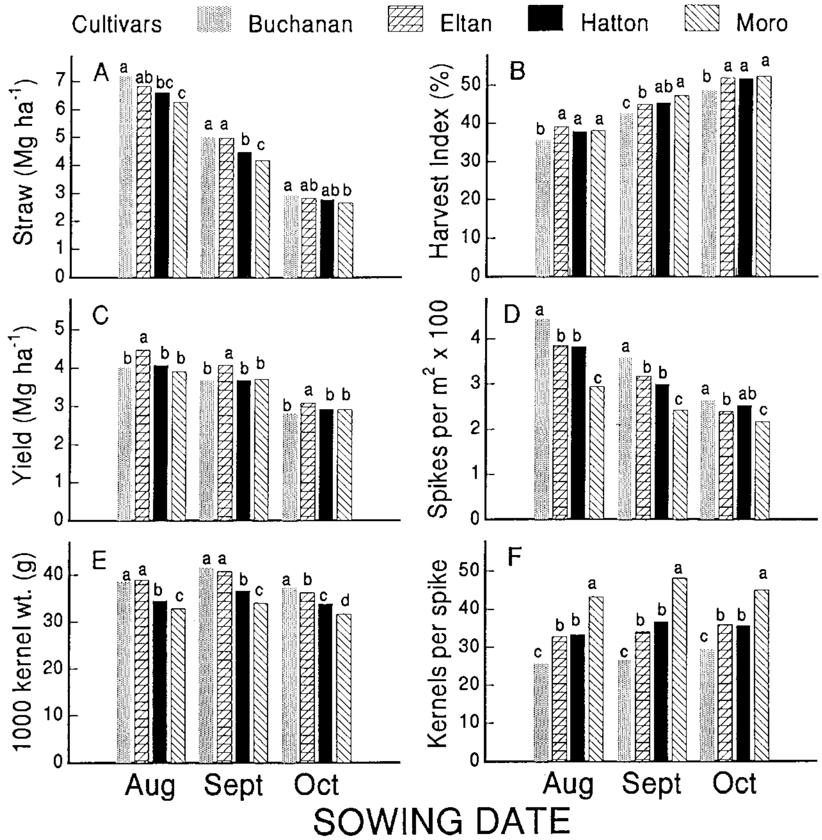

Fig. 5. Straw production, harvest index, grain yield, and yield components of four winter wheat cultivars sown in August, September, and October, averaged across three sowing rates and three years. Within-month means followed by the same letter are not significantly different at $P < 0.05$.

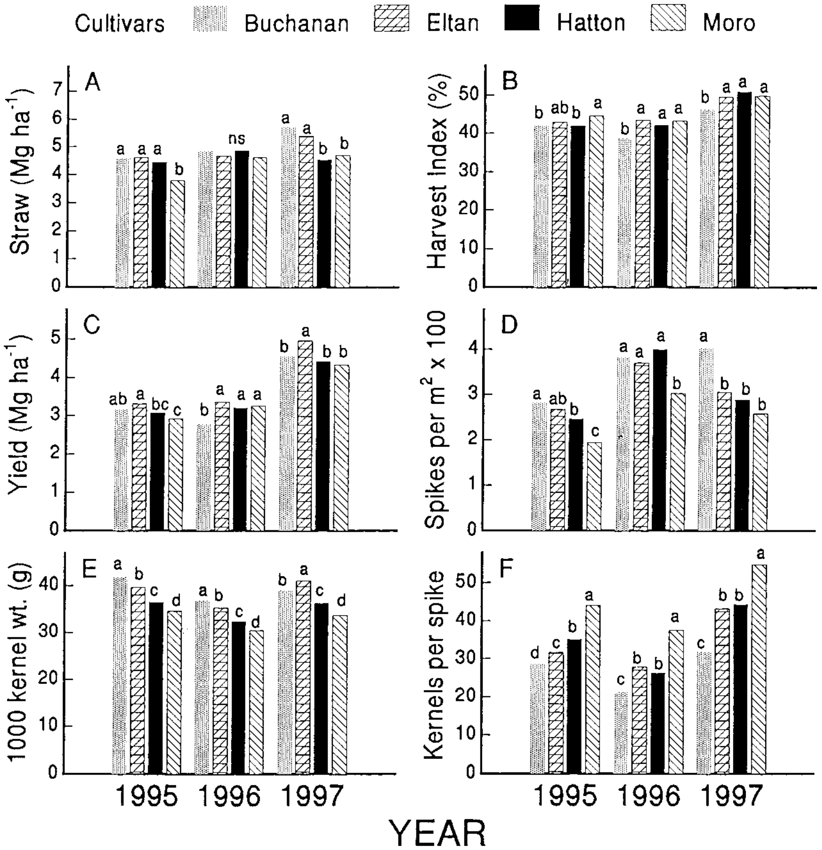

Fig. 6. Straw production, harvest index, grain yield, and yield components of four winter wheat cultivars in 1995, 1996, and 1997, averaged across three sowing rates and three sowing dates. Within-year means followed by the same letter are not significantly different at $P < 0.05$.

All cultivars consistently produced less straw as sowing date was delayed (Fig. 5a); however, the significant cultivar × date interaction for straw production, along with SPU, KW, and HI (Table 2), indicates that cultivar effects differ across sowing dates. Moro generally produced the least straw, but not significantly less than Hatton in two years. HI was consistently low with the tall cultivar Buchanan (Fig. 5b). Grain yield was always highest for the semidwarf Eltan, whereas there were no differences between Hatton and Moro on any sowing date (Fig. 5c). Moro invariably had the lowest SPU (Fig. 5d) and KW (Fig. 5e), but compensated with high KPS (Fig. 5f). Conversely, Buchanan consistently produced an abundant number of spikes with high KW, but with low KPS.

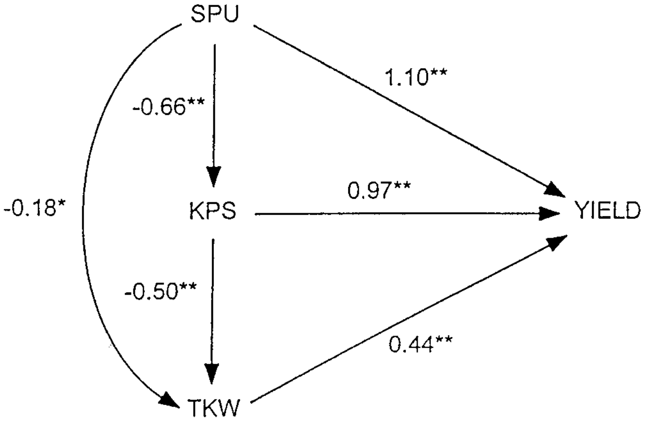

Fig. 7. Path coefficient analysis of grain yield and yield components for four winter wheat cultivars grown during 3 yr at three sowing rates and three sowing dates at Lind, WA.

Averaged across sowing dates and rates, straw production (Fig. 6a) remained relatively constant (within 1.5 Mg ha^{-1}) among cultivars within each year. Buchanan had a lower HI than any other cultivar in 1996 and 1997 (Fig. 6b). Eltan produced the overall highest grain yield, but there was no consistent trend (Fig. 6c). Similar to the sowing rate × cultivar comparisons in Fig. 5, Moro always had the lowest SPU (Fig. 6d) and KW (Fig. 6e), but compensated with the greatest KPS (Fig. 6f).

Path coefficient analysis (Fig. 7) demonstrated that grain yield was a function primarily of SPU and KPS, with less influence from KW. Higher SPU induced a large decrease in KPS, and a small reduction in KW. Higher KPS resulted in relatively large decreases in KW. Data from this model underscore the importance of SPU in the determination of grain yield under low-precipitation conditions.

SUMMARY

Crop residue retained on the soil surface is often the only defense against wind erosion in the low-precipitation, wheat–fallow region of east-central Washington.

This study showed that sowing date and sowing rate can be effectively used to maximize straw and grain production. Growers are advised to sow winter wheat early in mid-to-late August using a medium sowing rate. Early sowing of winter wheat always resulted in the greatest straw production, and the highest grain yield in 2 out of 3 yr.

If seed–zone water is plentiful (>12.5 cm cm^{-3}), and when production of straw is not a determining factor, sowing may generally be delayed until mid-September without yield penalty. When seed–zone water is insufficient for seedling emergence (<11 cm cm^{-3}), or sowing is otherwise delayed to perform grass weed control measures, growers should sow as soon as conditions allow, using a medium sowing rate. The high sowing rate for either (medium) September, or (late) October sowing dates had no advantage for straw or grain yield. The low sowing rate produced the least straw on all sowing dates.

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