Sustainability **2011**, *3*, 1224-1233; doi:10.3390/su3081224

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Adaptability of Wheat Cultivars to a Late-Planted No-Till Fallow Production System

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Received: 12 July 2011; in revised form: 3 August 2011 / Accepted: 3 August 2011 / Published: 10 August 2011

Abstract: In Washington, over fifty percent of the wheat produced under rainfed conditions receives less than 300 mm of annual precipitation. Hence, a winter wheat-summer fallow cropping system has been adopted to obtain adequate moisture for winter wheat production. Current tilled fallow systems are exposed to significant soil degradation from wind and water erosion. As a result, late-planted no-till fallow systems are being evaluated to mitigate erosion concerns. The objective of this study was to evaluate current cultivars under late-planted no-till fallow systems to identify whether current breeding schemes in tilled fallow systems could select productive cultivars in late-planted no-till fallow systems. Thirty cultivars were planted in a split-plot design with fallow type as the main plot and genotype as the sub-plot. Fallow types evaluated were a tilled fallow system and a late planted no-till fallow system. Data were collected on heading date, plant height, grain volume weight, grain yield, and grain protein content. Analysis of variance was conducted on data across locations. Results were significant for all traits except for grain protein content. The late-planted no-till fallow system headed 16 days later was 5 cm shorter, yielded 36% less, and had a grain volume weight 3% less than the tilled fallow system. The lower yield and grain volume weight potential is hypothesized to be due to the 16 day delay in heading date leading to warmer temperatures during grain fill and a shorter duration. In order to breed wheat to be highly productive under a late-planted no-till fallow

system, directly selecting in this system for early spring growth and earlier heading dates will be essential.

Keywords: *Triticum aestivum* L.; late-planted no-till fallow; tilled fallow; soil erosion; wheat breeding

1. Introduction

Over fifty percent of the wheat (*Triticum aestivum* L.) producing acreage in Washington State receives less than 300 mm of annual precipitation [1]. The majority of this precipitation falls during the winter and early spring. With this limiting amount of precipitation, it is not economically viable for growers to continuously crop their land [2,3]. As a result, growers have adopted a rotation of tilled summer fallow followed by winter wheat. By leaving the ground fallow for a crop cycle, enough moisture is retained (about 30%) from the fallow year to establish and support a crop the following year [4]. Sowing is typically done in late August to early September using split-packers with a hoe type opener. Seed may be planted more than 150 mm deep to reach adequate moisture for germination [5,6]. If adequate moisture cannot be reached with a deep furrow drill, growers may opt to wait for additional precipitation before planting but risk losing grain yield [7], or, they might seed into soil with insufficient moisture and risk poor stand establishment, which necessitates another planting operation.

Wind erosion and blowing dust have been the major environmental concerns affecting much of the semiarid wheat producing areas of Washington since farming began [8]. In 1970, the US government passed the Clean Air Act, later amended in 1990, requiring the Environmental Protection Agency (EPA) to establish ambient air quality standards pertaining to human source pollutants [9]. Due to the intensive tillage of summer fallow, less crop residue is retained on the soil surface and the resulting fine, dry soil particles are prone to erosion by wind [10] and water [11]. These airborne dust particles exceed the average acceptable daily limits of 150 $\mu g\ m^{-3}$. Blowing dust poses traffic hazards due to low visibility and can be a human health risk when inhaled into the lungs [12]. Dust also can drift into furrows, increasing the amount of soil that the wheat must emerge through, thereby hindering seedling emergence. These concerns have prompted evaluation of alternative cropping systems to control annual soil erosion.

One option for growers in the drier regions is to use a chemical fallow and no-till planting system. Ground is left fallow for a year and weeds are managed with herbicides rather than tillage. Although the use of herbicides for weed control are of environmental concern, most herbicides used are of low mammalian toxicity and pose much less of an environmental concern in Washington than soil erosion [8]. Commonly used no-till drills in Central Washington lack the ability to create deep furrows to prevent soil from silting back onto planted seed, which hinders emergence at the typical late August to early September planting time (AGPRO Marketing & Manufacturing, Inc., Lewiston, ID, USA). As a result, planting must be delayed until after fall rainfall events have provided adequate moisture for planting, typically in October or early November. Delayed planting dates reduce the ability of wheat to compete with weeds during spring growth and lead to an increase in weed pressure [13].

Due to its small size, late-planted winter wheat also is more vulnerable to freezing temperatures during the winter [14,15].

The major advantage of a no-till fallow rotation is that more crop residue is left on the soil surface, which reduces soil erosion [16]. Research has also shown no-till cropping systems to increase soil organic carbon [17], earthworm populations [18] and soil permeability [19]. With fewer tillage operations being conducted, chemical fallow and no-till reduce the amount of fuel used by a producer, thereby reducing input costs [20,21]. Unfortunately, in the traditional deep-furrow planting areas of the Pacific Northwest, little research has been conducted to evaluate whether the benefits of late-planted no-till fallow systems outweigh the risks.

Given adequate moisture and timely plantings, it is well documented that winter wheat cultivars perform equally well in both conventional and no-till planting systems [18,19,22]. However, in drier areas where limited moisture necessitates the delay of no-till plantings until later in the fall, the performance of current cultivars planted late into no-till fallow is not well known. Given that breeding lines in the Pacific Northwest are selected in a tilled summer fallow production system, they may not perform well in a late-planted no-till fallow system and a different selection scheme may be warranted. Cox [23] concluded that selection for superior yielding cultivars in a no-till system could be conducted under either no-till or conventional-till systems. However, Cox [23] evaluated production systems with the same planting date; unlike the late-planted no-till fallow system described above. The purpose of this research was to determine if the current breeding scheme, with cultivars selected from a tilled summer fallow production system, is capable of producing cultivars that perform well in a late-planted no-till fallow production system in the dry areas of the Pacific Northwest.

2. Materials and Methods

Two research sites, Kahlotus, WA and Lind, WA, were established on land with a history of winter wheat/summer fallow production. Fertility, tillage and pre-planting weed control was managed by the farmer cooperators with nitrogen and sulfur rates applied equally for both fallow systems (Table 1). Phosphorus was applied at a rate of 34 kg ha^{-1} to the no-till fallow treatments [24,25]. A four-row deep furrow drill (custom fabricated) with split packers and 40.6 cm row spacing was used to plant the tilled fallow plots in August of 2008 and 2009 at a seeding rate of 45 kg ha^{-1}. A five-row, no-till drill (custom fabricated) with 25.4 cm row spacing and New Zealand cross-slot openers was used to plant and fertilize in one pass the late-planted no-till fallow plots in November and October of 2008 and 2009, respectively (Table 1). Seeding rate for the no-till fallow treatment was 67 kg ha^{-1}. Seeding rates were adjusted between planter types to maintain comparable seed spacing within rows. Plots were planted in a split-plot design with fallow type as the main plot and genotype as the sub plot. Four replications of each fallow type were evaluated and plot dimensions were 1.5 meters by 4.6 meters. Sub plot treatments consisted of twelve soft white, four soft white club, ten hard red, and four hard white winter wheat cultivars (Table 2). Weeds were controlled during the growing season by herbicides (2,4-D [2,4-dichlorophenoxyacetic acid] ester) and hand removal.

Table 1. Winter wheat 2009–2010 agronomic data for Kahlotus, WA and Lind, WA under both a conventional tilled fallow and late-planted no-till fallow system.

Location:	**Kahlotus, WA 2009**		**Lind, WA 2010**		**Kahlotus, WA 2010**	
Treatment	Tilled fallow	No-till fallow	Tilled fallow	No-till fallow	Tilled fallow	No-till fallow
Date of seeding	Aug. 21, 2008	Nov. 5, 2009	Aug. 25, 2009	Oct. 19, 2009	Aug. 18, 2009	Oct. 19, 2009
Rate of seeding	45 kg ha^{-1}	67 kg ha^{-1}	45 kg ha^{-1}	67 kg ha^{-1}	45 kg ha^{-1}	67 kg ha^{-1}
Fertility (kg ha^{-1})	56N-11S [z]	56N-34P-11S	56N-11S	56N-34P-11S	56N-11S	56N-34P-11S
Precipitation: 9/1 to 8/31	270 mm		244 mm		247 mm	
Planting depth	140 mm	≤ 25 mm	165 mm	≤ 25 mm	152 mm	≤ 25 mm
Harvest date	July 16, 2009	July 28, 2009	July 28, 2010	July 28, 2010	July 26, 2010	July 26, 2010

[z] N = nitrogen; P = phosphorous; S = sulfur.

Table 2. Winter wheat cultivars/breeding lines which were bred for conventional tilled fallow systems and tested for performance in a late-planted no-till fallow system.

Variety	**Source**	**Market class** [y]		**Variety**	**Source**	**Market class**
Madsen	PI 511673	SWW		Finley	PI 586757	HRW
Eltan	PI 536994	SWW		Bauermeister	PI 634717	HRW
Finch	PI 628640	SWW		Eddy	Westbred	HRW
Tubbs06	PI 629114	SWW		Paladin	Syngenta	HRW
Masami	PI 634715	SWW		Farnum	PI 638535	HRW
Xerpha	PI 645605	SWW		WA8068	WSU	HRW
Stephens	PI 658243	SWW		WA8095	WSU	HRW
Lewjain	CItr 17907	SWW		WA8022	WSU	HRW
WA8065	WSU [z]	SWW		Buchanan	PI 532994	HRW
WA8064	WSU	SWW		Hatton	CItr 17772	HRW
WA8066	WSU	SWW		MDM	PI 634716	HWW
WA8094	WSU	SWW		Palomino	Syngenta	HWW
Bruehl	PI 606764	Club		WA8096	WSU	HWW
Chukar	PI 628641	Club		WA8097	WSU	HWW
Edwin	PI 606765	Club				
Moro	CItr 13740	Club				

[z] WSU = Washington State University; [y] Market Class: SWW = soft white winter; Club = soft white winter club; HRW = hard red winter; HWW = hard white winter.

Data were collected on various agronomic characteristics throughout the season. The heading date was measured in Julian days and plots were deemed headed when 50% of the heads had emerged from the boot (Feekes 10.3; [26]). A mechanical small plot combine (Nurserymaster Classic, Wintersteiger Co., Salt Lake City, UT) was used to harvest plots. Grain yield was measured from seed collected from the combine as grams per plot and reported as kg ha^{-1}. Grain ranged from 9 to 10% moisture when harvested. Grain volume weight was measured using a Seedburo filling hopper and stand (Seedburo Equipment Co., Chicago, IL, USA). Grain volume weight was measured in lb bu^{-1} and reported as kg hL^{-1}. Grain protein was determined by an Inframatic 9200 NIR grain analyzer (Perten Instruments Co., Huddinge, Sweden).

Statistical analysis of agronomic data was performed using the statistical package SAS V9.1 (SAS Institute, Raleigh, NC, USA). Data were analyzed across environments and locations using PROC GLM and analysis of variance computed. Random effects were location and block whereas fixed effects were genotype and fallow type. Least significance difference (LSD) was used to calculate differences between fallow types. The 2009 Lind site was not included in analysis as an early fall crusting event and very dry spring resulted in plant stands of only 5–20%. Data for heading date, plant height and grain protein were not collected for the 2009 Kahlotus site. Data shown for these parameters are only from Lind and Kahlotus in 2010.

3. Results and Discussion

Due to a lack of fall precipitation in 2008, the no-till planting was delayed until early November (Table 1). Despite late planting, good emergence was noted at all locations in both fallow types except for Lind. Precipitation at the Kahlotus site during the 2008–2009 growing season was higher than the 2009–2010 season (Table 1). Frequent spring rains in 2010 provided adequate moisture for early growth in both the conventional tilled and late-planted no-till fallow systems. Extensive downy brome (*Bromus tectorum* L.) pressure was observed at all locations in all plots and was controlled with cultivation and hand weeding. The 2010 Kahlotus site had a high incidence of stripe (yellow) rust (*Puccinia striiformis*), which produced differential grain yield responses between resistant and susceptible cultivars.

The main effect of fallow type was significant for yield ($P < 0.001$), grain volume weight ($P < 0.001$), heading date ($P < 0.001$) and plant height ($P < 0.05$) (Table 3). Protein was not affected by fallow type (Table 3). Genotype was a significant source of variation for all parameters ($P < 0.001$). The main effect of location and the location *X* fallow type interaction also were significant ($P < 0.001$) (Table 3). The 2009 Kahlotus site received 25 mm more precipitation than the 2010 sites, leading to a 471 kg ha^{-1} average yield increase for both fallow types (data not shown). This precipitation difference, combined with the inherent year to year environmental variability observed in field research, likely contributed to the significant source of variation accounted for by location.

Table 3. Analysis of variance for heading date (Julian), plant height (cm), yield (kg ha^{-1}), grain volume weight (kg hL^{-3}), and grain protein content (%) for wheat cultivars grown under conventional tilled fallow and late-planted no-till fallow systems.

	Pr > F				
Source of variation	**Heading Date**	**Plant Height**	**Grain Yield**	**Grain Volume Weight**	**Grain Protein Content**
Fallow-type	<0.0001	0.0304	0.0003	0.0002	0.8625
Genotype	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Location	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Genotype *X* Fallow type	<0.0001	0.0318	<0.0001	<0.0001	0.0562
Location *X* Fallow type	<0.0001	0.0005	<0.0001	<0.0001	<0.0001
Location *X* Genotype	0.0574	0.0192	<0.0001	<0.0001	0.3684
Location *X* Fallow type *X* Genotype	<0.0001	0.6565	0.0014	0.0017	0.4665

Table 3. *Cont.*

	Pr > F				
Source of variation	**Heading Date**	**Plant Height**	**Grain Yield**	**Grain Volume Weight**	**Grain Protein Content**
Block	0.1306	0.3654	0.2908	0.3687	0.2207
Overall Mean	150	79	2471	75.6	11.3
C.V.	0.59	6.08	20.9	1.6	8.22
R^2	0.99	0.79	0.76	0.81	0.75

When averaged across all entries and locations, the tilled fallow system provided the best agronomic performance (Table 4). Grain yield in the tilled fallow system was significantly ($P < 0.001$) higher than the late-planted no-till fallow system with a difference of 1170 kg ha^{-1} (Table 4). Grain volume weight also was significantly ($P < 0.001$) higher in the conventional system by 2.1 kg hL^{-3} (Table 4). Plant height differed significantly (5 cm) between the two fallow systems (Table 4) and is likely due to the difference in planting dates, although probably not of practical importance. The late no-till planting resulted in smaller plants going into winter and that difference was observed throughout the growing season. Perhaps the largest factor contributing to the better performance of the conventional system is the difference in heading date between the two systems.

Table 4. Winter wheat differences between conventional tilled and late-planted no-till fallow systems heading date (Julian), plant height (cm), yield (kg ha^{-1}), grain volume weight (kg hL^{-3}), and grain protein content (%), averaged over all locations.

Fallow Type	**Heading Date (Julian Days)**	**Plant Height (cm)**	**Grain Yield (kg ha^{-1})**	**Grain Volume Weight (kg hL^{-3})**	**Grain Protein Content (%)**
Conventional tilled fallow	142	81	3262	76.6	11.3
Late-planted no-till fallow	158	76	2092	74.5	11.3
Difference †	16 ***	5 *	1170 ***	2.1 ***	0
LSD (0.05)	0.6	3.8	316	0.3	0.6

† * = significant at $P < 0.05$; ** = significant at $P < 0.01$; *** = significant at $P < 0.001$.

Genotypes in the late-planted no-till fallow system headed 16 days later than those in the conventional tilled fallow system (Table 4). This later heading date provided plants with less time to fill heads before air temperatures reached levels that lead to decreased grain fill [27,28]. This is visible in the decline of both grain yield and grain volume weight in the late-planted no-till system. Wiegand and Cuellar [29] demonstrated that for every 1°C increase in mean daily air temperature above the optimum of 15°C during grain filling, there is a 3.1 day shortening in the duration of grain filling. This shortening of grain filling period was associated with a decrease in yield and grain volume weight. Mean daily air temperature during grain fill for the conventional tilled and late-planted no-till fallow systems differed by approximately 1°C (Washington Agricultural Weather Network, Washington State University, Prosser, WA, USA) with the higher temperature observed during grain fill in the late-planted no-till system. This may help explain a portion of the decrease in grain yield and grain

volume weight observed in the late-planted no-till system. Our results indicate that the late planted no-till fallow system yields 36% less than the tilled fallow system and grain volume weight is lowered by 3% when averaged across years and locations. This is mostly attributed to the difference in planting date (conventional *vs.* late) and not to the difference in tillage systems.

Late-planted no-till fallow systems offer many agronomic benefits for the producer, but the economic benefits are not as clear. In many past studies, no-till systems have been shown to be less profitable than conventional tillage systems in semiarid regions because of increased weed control costs and production costs [30-32]. Research comparing continuous no-till spring wheat *versus* conventional tilled winter wheat-summer fallow have shown lower economic returns for the continuous spring wheat ranging from −148 to −363 ($/rotational hectare) [33,34]. The difference in wheat yield between the spring and winter wheat averaged 44% [33,34], similar to the 36% reduction in the late planted wheat in the current study. Past research in the semiarid areas of central Washington predict the 2005 variable costs of tilled fallow systems to be $384.78, slightly higher than the cost of $369.24 for minimum tillage operations per rotational hectare [35]. In a five-year systems study presented by Young *et al.* [36], the average cost per rotational hectare was $362.57 for no-till fallow-winter wheat systems versus $394.43 for tilled fallow-winter wheat systems. At current soft white wheat prices of $240 per metric ton [37] and similar yields as in previous years, the average profit per rotational hectare of late-planted no-till fallow and tilled fallow would be $−157.76 and $75.35, respectively. The lower input costs for the late-planted no-till system does not appear to compensate for the reduction in yield experienced under the later planting date.

In the conventional tilled fallow system, winter wheat has accumulated significant growth before winter dormancy. Conversely, the late planted winter wheat has little time for growth before winter dormancy is initiated. After dormancy breaks in the spring, the late-planted cultivars are already at a disadvantage; thus a different growth mechanism is needed for late planted winter wheat to compete with conventional planting. Busch *et al.* [38] suggested that earlier heading genotypes may perform better in late planted systems. The majority of current winter wheat cultivars in the Pacific Northwest are photoperiod sensitive [39], requiring long days for induction of flowering. Photoperiod insensitive lines, which flower independent of day length, may exhibit a faster growth habit in the spring and may allow them to 'catch up' to the conventionally planted cultivars. However, if early unseasonably warm weather causes the wheat to break dormancy, subsequent cold temperatures may lead to frost/cold damage. Haro and Allan [40] demonstrated that photoperiod insensitivity is not a requirement for early heading and intrinsic earliness varies in wheat. Thus, direct selection for earlier heading date in photoperiod sensitive lines could also improve grain yield and grain volume weight potential.

Joshi *et al.* [41] examined the need for breeding crops for reduced tillage management in intensive rice-wheat systems in South Asia. Joshi *et al.* [41] highlight differences in tillage operations regarding soil factors, water requirements, and host-pathogen interactions. Although not directly measured in the current study, similar differences probably exist under the two tillage systems evaluated. Joshi *et al.* [41] conclude that to develop wheat cultivars for no-till rice-wheat systems, new cultivars need to be selected under no-till systems rather than conventional tillage systems. Kronstad *et al.* [42] suggested that to develop cultivars with improved performance in reduced-tillage systems, growth factors influenced by tillage need to be identified, genetic variability created, and selection performed. These suggestions maintain importance in our system, where both tillage and planting date are factors. With

the increasing adoption of no-till systems across the globe, plant breeding programs need to continue to develop new cultivars that fit these systems. In many cases this means directly selecting breeding lines for traits enhancing agronomic performance for the new system. This is extremely important in Central Washington where the switch to no-till systems also can result in a delay in planting date.

4. Summary

Our results indicate late-planted no-till fallow systems are not as agronomically productive as conventional tilled fallow systems. One explanation is that current cultivars are not adapted to growth in the late-planted situation required under a no-till fallow system. Aside from tillage differences, there are major environmental differences and plant growth stage differences with the delay in planting date. Cultivars bred and selected for performance in a tilled fallow system may not be well suited for the environmental conditions observed in late-planted no-till fallow systems. It is our conclusion that in order to produce a winter wheat crop capable of maintaining competitive grain yields in a less erodible late-planted no-till fallow production system, breeding and selection of cultivars directly for that fallow system needs to be conducted.

Acknowledgements

We thank Steve Lyon, Kerry Balow, and Gary Shelton for technical support of field plots and data processing. Funding was provided by the WSU Agricultural Research Center through Hatch Project 0232 and by USDA-AFRI through a Special Grant to the Columbia Plateau PM_{10} Project.

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