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Seven rainfed wheat rotation systems in a drought-prone Mediterranean climate

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ABSTRACT

Increasing cropping intensity and use of no-till fallow (NTF) has been successful in many rainfed Mediterranean agricultural regions around the world, including of the Inland US Pacific Northwest (PNW) where annual precipitation exceeds 290 mm. However, in the low-precipitation (<290 mm annual) region east-central Washington and north-central Oregon, these practices have not been widely adopted and a 2-year winter wheat (*Triticum aestivum* L.)-tilled summer fallow rotation is practiced by the vast majority of farmers. The objective here was to evaluate the productivity of seven wheat rotation systems that reduce or eliminate tillage and increase cropping intensity in a 6-year study at Lind, WA. The study included: (i) soft white, hard red, and hard white market classes of wheat; (ii) both NTF and undercutter conservation-tillage summer fallow (UTF), and; (iii) continuous annual no-till cropping of wheat. Crop-year (September 1–August 31) precipitation over the six years averaged just 217 mm. Across years, market class, and rotation system, spring wheat (SW) grain yield was only 33% of winter wheat (WW) after UTF. Thus, although only one crop was produced every other year with WW-UTF, this system had water use efficiency (WUE) of 5.5 grain/mm precipitation versus as low as 3.0 kg grain/mm precipitation for SW with no preceding fallow year. Possible mechanisms for differences in grain yield and WUE among rotations were: (i) Russian thistle (*Salsola tragus* L.) weed infestation was at least eleven times greater in the various SW systems and much greater still with WW after SW with no fallow year compared to in WW after NTF and UTF, and; (ii) precipitation storage efficiency (PSE) in the 180 cm soil profile during fallow for NTF-WW-SW was only 30% compared to 39 and 42% for the UTF-WW-SW and UTF-WW treatments, respectively. Critically, the seed zone of NTF was too dry for early planting of WW in most years whereas adequate seed-zone water was present every year in the UTF systems. Primarily due to late planting necessitated from lack of seed-zone water, grain yield of WW after NTF was reduced 35% compared to WW after UTF. Optimum grain yields and soil conservation are both required for sustainable agriculture, and WW with the UTF method was the clear winner of systems evaluated in this study.

1. Introduction

A major problem with tillage-based fallow in all semiarid regions of the world is soil erosion. In the drylands of the PNW, wind erosion is of particular concern because soils are generally weakly structured and subject to pulverization with tillage. Soils also contain high quantities PM-10-sized particulates that are easily suspended and carried long distances in the wind stream (Sharratt and Vaddella, 2012).

Wheat has always been the dominant crop throughout the Inland PNW as it can be grown over a range of climatic and soil conditions (McGregor, 1982). Pioneer farmers and scientists soon learned that growing wheat after a year of fallow (i.e., only one crop every other year) increased and stabilized grain yields as well as helped control weeds and diseases compared to "recrop" wheat that was planted without a preceding year of fallow (McCall and Holtz, 1921).

In the US Great Plains, where summer rain is frequent, there is general agreement that an equal or slightly greater quantity of water is stored in the soil during the 14 month fallow period with no-till fallow (NTF) compared to tillage-based fallow (Nielsen and Vigil, 2010). The opposite is the case during 13 month fallow period in the PNW where summers are dry (Hammel et al., 1981; Wuest and Schillinger, 2011; Schillinger and Young, 2014).

Abbreviations: HRSW, hard red spring wheat; HWSW, hard white spring wheat; NTF, no-till summer fallow; PNW, Pacific Northwest of the United States; SW, generic term for spring wheat; SWSW, soft white spring wheat; WW, soft white winter wheat; UTF, undercutter conservation tillage summer fallow.

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Winter wheat in the low-precipitation region of east-central Washington needs to be planted into carryover moisture in fallow in late summer to achieve optimum grain yield potential. Farmers till the soil in the spring of the fallow year to disrupt capillary pores and channels to retard evaporation of stored soil water to enable planting winter wheat into a moist seed zone in late August to early September (Wuest, 2010). With NTF, the seed zone generally dries to a deeper depth that mostly prevents timely planting of WW into stored fallow moisture (Hammel et al., 1981), in which case planting must be delayed until the arrival of fall rains in mid-October or later. Late planting of WW (i.e., mid-October or later) has, on average, reduced grain yield by 35% or more compared to early-planted WW in east-central Washington (Higginbotham et al., 2013).

Conservation tillage methods have been developed that better retain surface residue, soil clods, and surface roughness during fallow to reduce wind erosion compared to traditional tillage practices (Papendick, 2004), and these conservation methods are successfully practiced by many regional farmers (Young and Schillinger, 2012). Compared to traditional high-soil-disturbance primary spring tillage methods, the UTF method has proven equally effective in conserving seed-zone water, total-profile water, and achieving WW grain yield with the advantage of a significant increase in surface clods and residue retention (Schillinger, 2001) that reduce blowing dust emissions by 50% or more (Sharratt and Feng, 2009). The undercutter implement is equipped with narrow-pitched and overlapping 80 cm wide V blades to slice beneath the soil with minimum surface lifting or disturbance and simultaneously deliver liquid fertilizer, all in one pass. The UTF method causes less soil disturbance and retains more surface residue than other tillage-based fallow methods so far tested and is considered a best management practice for conservation-tillage farming (Papendick, 2004). However, major blowing dust storms still occur (Sharratt and Lauer, 2006) and are most common in the <250 mm annual precipitation areas where grain and residue production is modest to low.

With technological advances in no-till farming, current performance may exceed what was observed previously and may provide opportunity for more intensive crop rotations. A focused effort was needed to reevaluate wheat production systems with the goal to increase cropping intensity using no-till and/or the practice of NTF. Optimism for the experiment was spurred by the advent of modern no-till drills with precise seed and fertilizer placement capability and new wheat cultivars better suited to withstand abiotic stress. Specific objectives of the study were to compare seven wheat rotation systems that differed in tillage, rotation sequence, cropping intensity, and cultivar market class. Soft white WW and soft white SW (SWSW) were grown in 2 and 3-year rotations using UTF and NTF methods and SWSW, HRSW (hard red), and HWSW (hard white) market classes of SW were grown continuously on an annual basis using no-till.

2. Materials and methods

2.1. Overview

A 6-year dryland cropping systems experiment was conducted from 2003 to 2008 at the Washington State University Dryland Research Station near Lind, Washington. Long-term (95-year) average annual precipitation at the site is 242 mm. Average pan evaporation from April through September is 1412 mm. Crop-year (September 1–August 31) precipitation during the study period ranged from 174 to 304 mm and averaged 217 mm; 90% of the long-term average (Table 1). Precipitation was measured at an official U.S. National Weather Service recording site located <50 m from the study. The soil is Shano silt loam (coarse-silty, mixed, superactive, mesic, Xeric Haplocambids) with uniform texture throughout the profile. Slope is <2%. There is a thin, weak layer of calcium carbonate "caliche" accumulation at a depth about 50 cm, but otherwise no restrictive layers or rocks within the 180 cm profile. Soil textural size distribution is 10% clay, 51% silt, and 39% fine sand. Shano soils, and closely-related soil series, are common throughout much of the low-precipitation farming region of east-central Washington and north-central Oregon.

Table 1
Crop-year (September 1–August 31) precipitation at Lind, Washington from 2003 to 2008 as well as 95-year average.

Month	2003	2004	2005	2006	2007	2008	95-year avg.
	(mm)						
September	1	7	15	8	2	4	13
October	2	7	15	27	8	17	21
November	21	17	17	29	63	28	32
December	52	52	27	43	45	30	33
January	69	26	17	85	10	41	28
February	18	33	1	19	31	6	22
March	18	8	22	12	17	21	22
April	29	15	9	20	13	5	19
May	5	15	24	37	8	3	20
June	0	7	10	25	14	12	21
July	0	0	9	0	4	0	8
August	1	18	6	0	13	7	8
Total	215	205	174	304	229	174	242

The experiment was discussed, designed, and approved as the "most promising" approach to test potential wheat monoculture rotations by a 16 member committee of regional farmers along with university and federal scientists in February 2001. The driving theme for the experiment was to test methods to increase cropping intensity (i.e., reduce the frequency of fallow) using both conservation-till and no-till practices for both crop and fallow years. Three market classes of wheat were included in the experiment because each class differs in optimum grain protein content and market price. The crop rotations chosen and implemented over the 6-year period were:

1. A 2-year rotation of winter wheat-undercutter tillage fallow (WW-UTF)
2. A 3-year rotation of WW-SWSW-UTF
3. A 3-year rotation of WW-SWSW-no-till fallow (NTF)
4. A 3-year no-till rotation of WW-SWSW-SWSW
5. Continuous annual no-till hard white spring wheat (HWSW)
6. Continuous annual no-till soft white spring wheat (SWSW)
7. Continuous annual no-till hard red spring wheat (HRSW).

The cultivars used were 'Eltan' WW, '377S' HWSW, 'Alpowa' SWSW, and 'Scarlet' HRSW. Certified seed for all cultivars was used every year and seed was treated with a fungicide as well as an insecticide for wireworm (*Agriotes lineatus*) control.

Experimental design was a randomized complete block with four replications of all treatment combinations. Each phase of all rotations was present every year for a total of 56 individual plots. Size of individual plots of crop rotation treatments that were exclusively no-till were 3 × 70 m, whereas those involving the UTF method were 10 × 70 m to accommodate undercutter and rod-weeder tillage implements.

Annual no-till SWSW was grown on the entire experiment area for the five consecutive years prior to initiation of the experiment, except for 12 plots left in either NTF or UTF during 2002; i.e., the year before the start of the experiment. Throughout the 6-year experiment, glyphosate herbicide was applied in March to standing undisturbed stubble from the previous crop at a rate of 0.43 kg acid equivalent (ae)/ha to control weeds. Primary spring tillage plus 56 kg/ha aqua NH_3–N + 11 kg/ha thiosol S fertilizer injection was