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Evaluating decision rules for dryland rotation crop selection

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ABSTRACT

No-till dryland winter wheat (*Triticum aestivum* L.)-fallow systems in the central Great Plains have more water available for crop production than the traditional conventionally tilled winter wheat-fallow systems because of greater precipitation storage efficiency. That additional water is used most efficiently when a crop is present to transpire the water, and crop yields respond positively to increases in available soil water. The objective of this study was to evaluate yield, water use efficiency (WUE), precipitation use efficiency (PUE), and net returns of cropping systems where crop choice was based on established crop responses to water use while incorporating a grass/broadleaf rotation. Available soil water at planting was measured at several decision points each year and combined with three levels of expected growing season precipitation (70, 100, 130% of average) to provide input data for water use/yield production functions for seven grain crops and three forage crops. The predicted yields from those production functions were compared against established yield thresholds for each crop, and crops were retained for further consideration if the threshold yield was exceeded. Crop choice was then narrowed by following a rule which rotated summer crops (crops planted in the spring with most of their growth occurring during summer months) with winter crops (crops planted in the fall with most of their growth occurring during the next spring) and also rotating grasses with broadleaf crops. Yields, WUE, PUE, value-basis precipitation use efficiency ($PUE), gross receipts, and net returns from the four opportunity cropping (OC) selection schemes were compared with the same quantities from four set rotations [wheat-fallow (conventional till), (WF (CT)); wheat-fallow (no-till), (WF (NT)); wheat–corn (*Zea mays* L.)-fallow (no-till), (WCF); wheat–millet (*Panicum miliaceum* L.) (no-till), (WM)]. Water use efficiency was greater for three of the OC selection schemes than for any of the four set rotations. Precipitation was used more efficiently using two of the OC selection schemes than using any of the four set rotations. Of the four OC cropping decision methods, net returns were greatest for the method that assumed average growing season precipitation and allowed selection from all possible crop choices. The net returns from this system were not different from net returns from WF (CT) and WF (NT). Cropping frequency can be effectively increased in dryland cropping systems by use of crop selection rules based on water use/yield production functions, measured available soil water, and expected precipitation.

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1. Introduction

Dryland cropping systems in the Great Plains are subject to wide variations in productivity and profitability (Dhuyvetter et al., 1996) due to the highly variable nature of the limited precipitation across the region (Nielsen et al., 2010). The traditional wheat-fallow production system of the region was developed in the 1930s as a strategy to minimize incidence of crop failures resulting from erratic precipitation (Hinze and Smika, 1983). The use of herbicides for weed control in this system reduced or eliminated tillage, and led to greater precipitation storage efficiencies (Farahani et al., 1998; Nielsen et al., 2005; Nielsen and Vigil, 2009), such that more frequent cropping could occur (Halvorson and Reule, 1994; Peterson et al., 1993; Anderson et al., 1999; Norwood et al., 1990; Smika, 1990). In particular, both Farahani et al. (1998) and Nielsen and Vigil (2009) pointed out the extremely inefficient precipitation storage that occurred during the second summer fallow period (May through September) during the last 5 months of the 14-month fallow period of the wheat-fallow system. In many instances precipitation storage efficiency during these hot and windy months which can have many days and sometimes weeks between precipitation events was negative, indicating evaporative loss of all of the precipitation occurring during those 5 months plus evaporative loss of some soil water stored earlier in the fallow period.

Abbreviations: OC, opportunity cropping; PUE, precipitation use efficiency; $PUE, value-basis precipitation use efficiency; WUE, water use efficiency; WF (CT), wheat-fallow (conventional till); WF (NT), wheat-fallow (no till); WCF (NT), wheat-corn-fallow (no till); WM (NT), wheat-millet (no till).

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Table 2
Water use/yield production functions (kg ha^{-1} = a × [mm-b]) and yield reporting moisture content for dryland crops in the central Great Plains.

Crop	Production function slope a (kg ha^{-1} mm^{-1})	Production function intercept b (mm)	Source for production function	Grain or dry matter yield reporting moisture content (kg kg^{-1})
Corn	25.67	232	Nielsen (1995)	0.155
Winter wheat	12.49	132	Nielsen (2006b)	0.125
Proso millet	10.44	88	Nielsen (2006b)	0.120
Pea	8.00	22	Nielsen (2001)	0.125
Canola	7.73	158	Nielsen (1998)	0.080
Sunflower	6.64	175	Nielsen (1999)	0.100
Soybean	6.53	17	Nielsen (1990)	0.130
Forage triticale	33.00	86	Nielsen et al. (2006)	0.000
Foxtail millet	29.30	78	Nielsen et al. (2006)	0.000
Forage pea	24.77	32	Nielsen (2006a)	0.000

anticipated water use while incorporating a grass/broadleaf, summer crop/winter crop rotation scheme.

2. Materials and methods

This study was conducted at the USDA Central Great Plains Research Station, 6.4 km east of Akron, CO (40°09′ N, 103°09′ W, 1384 m). The soil type was a Weld silt loam (fine, smectitic, mesic Aridic Argiustoll). Average annual precipitation at this location is 417 mm. In 1990, several rotations were established to investigate the possibility of cropping more frequently than every other year, as done with the traditional winter wheat-fallow system. A description of the plot area, tillage systems, and experimental design are given in Bowman and Halvorson (1997) and Anderson et al. (1999). Briefly, rotation treatments were established in a randomized complete block design with three replications. All phases of each rotation were present every year. Individual plot size was 9.1 m by 30.5 m, with east–west row direction. The current study analyzes data from the 2001 through 2005 time period. Crop varieties and planting, harvesting, and fertilizing dates and rates are given in Table 1. Nitrogen fertilizer rates varied slightly from year to year as those rates were based on typical application rates for dryland production in this region, adjusted occasionally for expected residual N amounts. Seed yield sample size was generally between 35 and 42 m^2, and biomass (seed and forage) sample size was between 2.9 and 3.8 m^2. Grain and dry matter yields are reported with the moisture contents shown in Table 2.

Four OC systems were evaluated, with the decision to plant a crop based on predicted yield exceeding an established threshold (Table 3) which was established in consultation with local producers. The predicted yield was calculated using a spreadsheet yield calculator (available at http://www.ars.usda.gov/Services/docs.htm?docid=19206, verified 4/1/2010) which employed water use/yield production functions (Table 2) established at Akron, CO. Water use was assumed to be the sum of measured available soil water just prior to planting and expected growing season precipitation, where expected growing season precipitation ranged from 70% of average to 130% of average (Table 3). The OC1 system was considered to be a conservative system, where only 70% of average growing season precipitation was expected, and only the traditional dryland crops of winter wheat, corn, proso millet, and foxtail millet for forage were allowed as crop choices. The other three OC systems allowed for all possible crop choices that we had established production functions for, but expected growing season precipitation was 100% (OC2), 70% (OC3), or 130% (OC4) of average.

Soil water was measured to a depth of 1.65 m in 0.30-m intervals using a neutron probe for all depths except the 0.0–0.3-m layer. Soil water in this surface layer was determined using time-domain reflectometry with 0.3 m waveguides installed vertically to average the water content over the entire layer. The neutron probe was calibrated against gravimetric soil water samples taken in the plot area. Gravimetric soil water was converted to volumetric water by multiplying by the soil bulk density for each depth. Two measurement sites were located near the center of each plot and data from the two sites were averaged to give one reading of soil water content for each plot. Available water per plot was calculated as

$$(\text{Volumetric water} - \text{lower limit}) \times \text{layer thickness}$$

where volumetric water = m^3 water m^{-3} soil from neutron probe or time-domain reflectometry measurements, lower limit = lowest volumetric water observed under these crops in the plot area (Ritchie, 1981; Ratliff et al., 1983), and layer thickness = 0.3 m. The lower limits used to calculate available water are given in Table 4. Available water for each plot was calculated as the sum of available water from all six measurement depths. The soil water measurements were made at several decision points during the year (mid-September for winter wheat and forage triticale decision; end of March for canola, pea, and forage pea decision; end

Table 3
Crop choice decision rules, available crop choices, and yield thresholds.

Opportunity cropping system	Estimated water use used to calculate crop choice yield	Available crop choices[a]
OC1	Measured available soil water + 70% of average growing season precipitation	Wheat, corn, proso millet, foxtail millet
OC2	Measured available soil water + 100% of average growing season precipitation	Wheat, corn, proso millet, foxtail millet, sunflower, soybean, canola, pea, forage pea, forage triticale
OC3	Measured available soil water + 70% of average growing season precipitation	Wheat, corn, proso millet, foxtail millet, sunflower, soybean, canola, pea, forage pea, forage triticale
OC4	Measured available soil water + 130% of average growing season precipitation	Wheat, corn, proso millet, foxtail millet, sunflower, soybean, canola, pea, forage pea, forage triticale

[a] Yield thresholds needed to determine crop selection in opportunity cropping system: wheat (2688 kg ha^{-1}), corn (3763 kg ha^{-1}), proso millet (2016 kg ha^{-1}), foxtail millet (4256 kg ha^{-1}), sunflower (1232 kg ha^{-1}), soybean (2352 kg ha^{-1}), canola (1120 kg ha^{-1}), pea (1568 kg ha^{-1}), forage pea (4256 kg ha^{-1}), forage triticale (4256 kg ha^{-1}).

Table 7
Measured grain and dry matter yields for four opportunity cropping systems and four set rotations at Akron, CO.

Year	OC1	OC2	OC3	OC4	WF (CT)	WF (NT)	WCF		WM	
	Crop and Yield (kg ha⁻¹)									
2001	Foxtail millet	Wheat	Pea	Canola	Wheat	Wheat	Wheat	Corn	Wheat	Millet
	4545	2813	1191	169	3494	3926	3661	4527	2472	2415
2002	Wheat	Sunflower	Foxtail Millet	Proso Millet	Wheat	Wheat	Wheat	Corn	Wheat	Millet
	1034	0	0	0	1628	2062	2005	0	594	0
2003	Corn	Corn	Fallow	Sunflower	Wheat	Wheat	Wheat	Corn	Wheat	Millet
	2915	3138	0	352	3872	4406	4789	3073	4365	2563
2004	Fallow	Forage Pea	Forage Pea	Proso Millet	Wheat	Wheat	Wheat	Corn	Wheat	Millet
	0	3862	3502	390	896	2116	1807	3096	310	2647
2005	Wheat	Foxtail Millet	Foxtail Millet	Pea	Wheat	Wheat	Wheat	Corn	Wheat	Millet
	2302	4717	2611	564	2163	2819	2256	2278	599	562

OC1–OC4 refer to opportunity cropping systems 1 through 4 as designated in Table 1.
WF (CT) is wheat-fallow, conventional tillage; WF (NT) is wheat-fallow, no-till; WCF (NT) is wheat-corn-fallow, no-till; WM (NT) is wheat–proso millet, no-till.

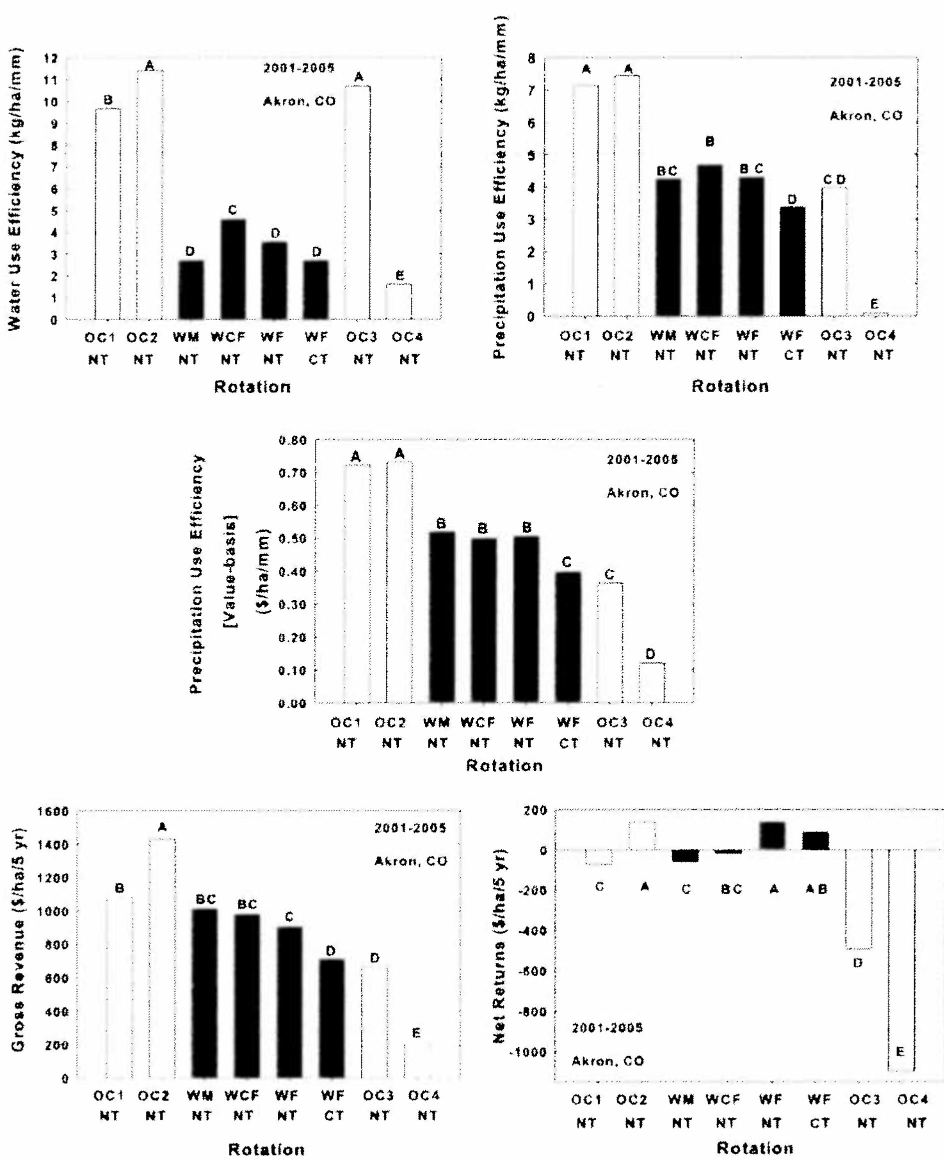

Fig. 1. Water use efficiency, precipitation use efficiency, value-basis precipitation use efficiency, gross revenue, and net returns for four opportunity cropping (OC) systems (defined in Table 2) and four set rotations at Akron, CO. W = winter wheat, M = proso millet, C = corn, F = fallow, NT = no till, CT = conventional till.

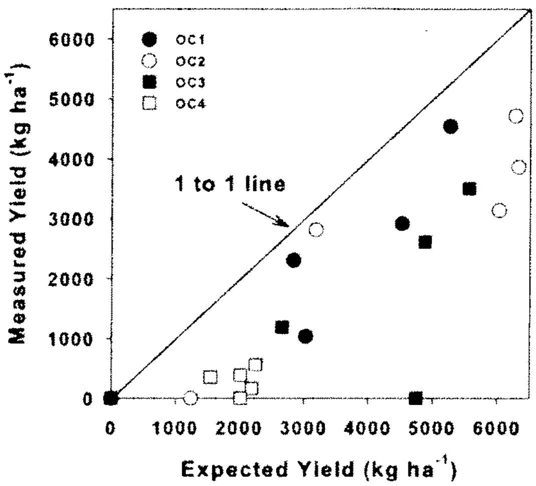

Fig. 2. Comparison of expected crop yield (generated prior to growing season from water use/yield production functions) and measured yields for four opportunity cropping (OC) systems (defined in Table 2).

found in the current study. Lyon et al. (2003) also cautioned that different conclusions regarding profitable dryland corn populations for western Nebraska could be drawn depending on whether studies were conducted during the relatively wetter 1990s period vs. the drier early 2000s.

The OC4 decision rules could be considered a non-viable crop selection strategy as evaluated by any one of the measures shown in Fig. 1. The assumption of 130% of average growing season precipitation was not met even once in the 5 years of the study. The year that came closest to meeting that assumption was 2004 when the millet growing season precipitation was 116% of average. Clearly, basing a cropping decision on a continuing optimistic prediction of above-average growing season rainfall is not wise in this semi-arid climate where annual precipitation records indicate rainfall amounts fluctuating widely about the mean on a nearly annual basis (Nielsen and Vigil, 2009). On the other hand, the OC2 strategy that based crop choice on available soil water at planting and a prediction of average growing season rainfall resulted in continuous cropping (although no crop was produced in 2002 because of severe drought) producing a cropping sequence that was highly efficient in terms of water and precipitation use, more profitable than WM and WCF, and equal in profitability to WF (CT) and WF (NT).

Surprisingly, none of the four OC systems resulted in measured yields greater than the expected yields generated by the production functions combined with the measured available soil water and expected precipitation (Fig. 2). In fact, most of the measured yields were far below the expected yields. In only three instances (two for OC1 and one for OC2) did measured yield fall within 20% of expected yield. This result of always obtaining measured yields lower than expected yields was not expected because measured growing season precipitation was above expected growing season precipitation in 3 years for OC1, 2 years for OC2, and 4 years for OC3. This lack of ever achieving a measured yield greater than expected may indicate that (1) the production functions need to be refined or (2) water stress during critical stages of development are more detrimental to yield than can be accounted for by this simple yield prediction system or (3) all of the available soil water measured at the decision points is not really ultimately available to the crop during the growing season and different lower limits of water availability will need to be established. Two recent analyses of dryland corn yield sensitivity to water deficits during pollination and grain filling explain why the measured corn yields may be lower than expected (Nielsen et al., 2009, 2010).

5. Conclusions

Using estimated crop water use (measured available soil water at several decision points during the year plus 70–100% of average growing season precipitation) with established water use/yield production functions can assist farmers in making a crop choice that can increase cropping frequency, WUE, PUE, and $PUE over that obtained with set rotations. The crop prices and production costs used in the economic analysis of this study did not reveal a net revenue advantage for an OC system over a set WF rotation, but did indicate an advantage over the WM and WCF rotations. Even though none of the OC crop selection methods resulted in a net revenue advantage of the WF systems, producers may want to consider using the OC2 method to increase cropping frequency over the WF systems because of the potential benefits associated with increasing surface soil organic carbon and particulate organic matter levels (Mikha et al., 2010), greater carbon sequestration (Halvorson et al., 2002), reducing exposure to wind erosion (McMaster et al., 2000), reducing surface soil compaction (Blanco-Canqui et al., 2010), and improvement to other physical properties of the soil (Benjamin et al., 2007). An OC decision support system would benefit from combining the method described in this paper with economic factors (estimated costs and revenues) for the various crops for which pre-season yield estimates are made.

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