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Intensifying a semi-arid dryland crop rotation by replacing fallow with pea☆

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ABSTRACT

Increasing dryland cropping system intensity in the semi-arid central Great Plains by reducing frequency of fallow can add diversity to cropping systems and decrease erosion potential. However elimination of the periodic fallow phase has been shown to reduce yields of subsequent crops in this region. The objective of this experiment was to determine how productivity of a 4-yr WCMF rotation [wheat (W, *Triticum aestivum* L.); corn (C, *Zea mays* L.); proso millet (M, *Panicum miliaceum* L.); fallow (F)] was affected when the fallow phase was replaced with pea (P, *Pisum sativum* L.). The effect of this intensification of the WCMF rotation on the available soil water content at planting, the water use, and the yield of each crop, and on total system productivity and net income was quantified by analyzing data over a 20-yr period from a long-term crop rotation experiment at Akron, CO. Large year-to-year variations were found for available soil water at planting, water use, and yield for all four crops. Pea water use resulted in significant reductions in available soil water at planting, water use, and yield for wheat and corn, but had little effect on those quantities in the millet crop. Total production on a seed mass basis was not different between the WCMF and WCMP rotations, but system net income for the WCMP rotation was 32% lower than for WCMF. Intensification of the WCMF rotation by replacing the fallow phase with pea production could be recommended as an alternative production method if pea seed costs and nitrogen fertilizer applied to the subsequent wheat crop can be reduced.

1. Introduction

Fallow has been used for centuries as a crop production technique throughout the world (Karlen et al., 1994) for a variety of reasons. It has been used in the semi-arid central Great Plains of the United States in the decades since the 1930s Dust Bowl (Greb, 1979). The primary goal of fallow in this region has been yield stability. Because precipitation received in the Great Plains is erratic and inconsistent, the yields of crops grown in the region are also quite variable from one year to the next. The fallow period extends the time between crops so more precipitation can be received and stored in the soil for subsequent crop production. However, this extended period of precipitation collection has been shown to be highly inefficient in storing precipitation (Farahani et al., 1998; Nielsen and Vigil, 2010). Additionally, use of fallow subjects the soil surface to increased risk of erosion.

Intensifying dryland cropping systems by reducing the frequency of fallow (i.e., moving from a system of producing one crop in two years to two crops in three years, three crops in four years, or continuous cropping) uses precipitation more efficiently than less intense cropping because the fraction of total system time that is in fallow (with its inefficient precipitation storage efficiency) declines (Farahani et al., 1998). Nielsen and Calderón (2011) stated that systems that reduce or eliminate fallow frequency generally result in greater amounts of surface crop residues remaining during fallow periods, and that those residue increases generally produce posi-

Abbreviations: W, wheat; C, corn; M, millet; P, pea; F, fallow; S, sunflower; FrM, forage millet; FrP, forage pea.

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tive effects on soil quality for crop production while reducing soil loss by erosion.

Longer rotational sequences allow for greater cropping system diversification. Such systems provide the advantage of spreading farmer workloads throughout a growing season and afford the opportunity to rotate weed control strategies. Growing a variety of crops also hedges a grower's risk against low prices for one or two commodities. Legumes are often mentioned as potential crops to be rotated in systems with wheat (Hayer et al., 2009; Anderson, 2010; Allen et al., 2011; Zentner et al., 2004; Miller et al., 2006; Kirkegaard et al., 2008).

Both Zentner et al. (2004) in Saskatchewan and Allen et al. (2011) in North Dakota reported that waiting too long to terminate Indianhead lentil (*Lens culinaris* Medikus) green manure crops reduced the yields of the following spring wheat crops compared with wheat after fallow due to greater water use by the green manure crop compared with evaporative water losses in fallow. In the 12-yr study presented by Zentner et al. (2004) spring wheat yields were improved during the second half of the study due primarily to improved soil water availability (from earlier termination of the prior lentil crop) and not to improved available N. In the 12-yr study presented by Allen et al. (2011), they reported that Indianhead lentil grown in place of fallow in a spring wheat-fallow system in Montana used about the same amount of water as lost to evaporation during the fallow period of the WF cropping system when the lentil was terminated at full bloom. However wheat yields following lentil were greater than following fallow because of the N supplied to the wheat by the lentil crop. They reported that three complete cycles of wheat-lentil (6 yr) were required for lentils to increase soil nitrate, wheat yield, and grain protein to comparable levels of conventionally fertilized WF plots.

Kirkegaard and Ryan (2014) presented data from southern New South Wales, Australia that demonstrated that effects of a crop grown in year 1 of a rotation could have impacts on yield of subsequent crops in years 2, 3, and 4 of the rotation, particularly when precipitation was below average for the region. They attributed these prior-crop effects to persistent residual N, water, and disease legacies. They concluded that the longer-term impacts of previous crops on subsequent yields would be difficult to predict in semi-arid environments with variable rainfall.

There have been no reports that directly report the effects on subsequent crop yields and system productivity when the fallow phase of a 4-yr rotation is replaced with pea or other legume production for seed in the central Great Plains. The objective of this experiment was to determine how replacing the fallow phase of a 4-yr WCMF rotation with pea affected yields of the subsequent wheat, corn, and proso millet crops. In particular, we desired to quantify the effect of this intensification of the WCMF rotation on the available soil water content at planting, the water use, and the yield of each crop, and to determine the effect of fallow replacement with pea production on total system productivity and net income.

2. Materials and methods

Data were collected over a 20-yr period from 1997 to 2016 from two rotations (WCMF, WCMP) in an ongoing long-term crop rotation experiment conducted at the USDA-ARS Central Great Plains Research Station (40°09′ N, 103°09′ W, 1383 m elevation above sea level) located near Akron, CO. The soil was a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls) (National Cooperative Soil Survey, 2006). The long-term experiment was established in the fall of 1990 and has been previously described by Anderson et al. (1999), Bowman and Halvorson (1997), and Nielsen and Vigil (2010). 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 by 30.5 m with east-west row direction.

All rotations in the current study were managed under no tillage management with weed control during both cropped and non-crop periods consisting of contact and residual herbicide applications applied at recommended rates. Herbicides used were glyphosate (N-phosphonomethyl)glycine); paraquat (1,1′-dimethyl-4,4′-bipyridinium dichloride); atrazine (1-chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine); 2,4-D (2,4-dichlorophenoxyacetic acid); dicamba (3,6-dichloro-2-methoxybenzoic acid); fluroxypyr ([4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)oxy] acetic acid); imazamox (2-[4,5-dihydro-4-methyl-4-(1-methyethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid); and carfentrazone (ethyl-alpha-2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-,2,4-triazol-1-yl]-4-fluorobenzenepropanoate).

Planting and harvest dates, cultivars and hybrids are given in Table 1. Row spacing was 0.76 m for corn and 0.19 m for wheat, millet, and pea. Wheat was planted at 66 to 73 kg ha^{-1}. Corn was planted at 34,580 to 41,000 seeds ha^{-1} from 1997 to 2002, and then reduced to 29,640 seeds ha^{-1} for the remaining years of the study. Millet was planted at a rate of 17 kg ha^{-1}. Pea was planted at 134 kg ha^{-1} from 1997 to 1999, and then increased to 202 kg ha^{-1} for the remaining years to better compete with weeds early in the growing season. Fertilizers were applied at planting at rates of 45–67 kg N ha^{-1} and 17–22 kg P_2O_5 ha^{-1} for wheat; 33–90 kg N ha^{-1} and 0 to 22 kg P_2O_5 ha^{-1} for corn; 39–56 kg N ha^{-1} and 17–22 kg P_2O_5 ha^{-1} for millet. Pea crops were inoculated at planting with *Rhizobium leguminosarum* and fertilized with 17–22 kg P_2O_5 ha^{-1}. Harvest sample areas were approximately 28–31 m^2 for millet, and 37–42 m^2 for wheat, corn, and pea. Moisture contents for reported yields were 125 g kg^{-1} for wheat and pea yields, 120 g kg^{-1} for millet yields, and 155 g kg^{-1} for corn (which are standard reporting seed moisture contents for these commodities in the United States).

Soil water was measured at two locations near the center of each plot at 0.3-m intervals using a neutron probe (Model 503 Hydroprobe, CPN International, Martinez, CA). The depth intervals were 0.3–0.6 m, 0.6–0.9 m, 0.9–1.2 m, 1.2–1.5 m, and 1.5–1.8 m, with the neutron probe source centered on each interval. Soil water in the 0.0–0.3 m surface layer was determined using time-domain reflectometry (Trase System I, Soil Moisture Equipment Corp., Santa Barbara, CA) 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. Bulk density was determined from the dry weight of the soil cores (38 mm diameter by 300 mm length) taken from each depth at the time of neutron probe access tube installation.

Available soil water at planting was computed by subtracting the lower limit of water availability at each soil water measurement depth (Ritchie, 1981; Ratliff et al., 1983) from the calculated volumetric water at that depth and multiplying the difference by the soil layer thickness (30 cm). The lower limit of water availability at each of the six measurement depth intervals was determined previously in the plot area as the lowest volumetric water value observed for each crop over a period of several years (Nielsen et al., 2011). The individual values of available water at each of the six depths in each plot were summed to give the profile plant-available soil water in each plot.

Full season water use was calculated as the difference between soil water readings at planting and physiological maturity plus growing season precipitation. Precipitation was manually measured daily at two locations in the plot area and averaged. Runoff