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Searching for synergism in dryland cropping systems in the central Great Plains

David C. Nielsen*, Merle F. Vigil

USDA-ARS, Central Great Plains Research Station, 40335 County Road GG, Akron, 80720, CO, United States

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ABSTRACT

Previously published research reported a "synergistic effect" of corn (*Zea mays* L.) on winter wheat (*Triticum aestivum* L.) and proso millet (*Panicum miliaceum* L.) water use efficiency (WUE) when corn (C) was the preceding crop for dryland cropping systems in the central Great Plains, i.e., less water was required to grow a unit of wheat (W) or proso millet (M) when corn was the preceding crop. A similar synergistic effect of field pea (*Pisum sativum* L.) for seed (P) or forage (FrP) on winter wheat water use and yield has also been reported. The purpose of this study was to examine a long-term cropping systems yield and water use data set in order to determine if WUE is altered by rotational sequence (i.e., previous crop). Yield and water use data (computed by water balance using neutron probe and time-domain reflectometry measurements) were acquired from a crop rotation study conducted at Akron, CO from 1996 to 2011 using the following rotation sequences: W–fallow (F), W–C–F, W–M–F, W–C–M, W–M, W–W–C–M,W–C–M–F, W–C–M–P, W–C–M–FrP and W–M–Sunflower (S, *Helianthus annuus* L.)–F. Water use efficiency was computed as grain yield divided by water use. Changes in WUE due to crop rotation were also evaluated based on slopes of water use/yield production functions. The analysis of these data did not support a conclusion that corn has a synergistic effect of improving WUE of wheat or millet production nor the conclusion that pea has a synergistic effect on wheat.

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1. Introduction

Anderson (2005a) asked the question, "Are some crops synergistic to following crops?" and presented data indicating that the answer to that questions was "Yes." In that paper synergism was defined as improved crop WUE in response to a specific preceding crop in a rotational sequence. He concluded that corn in a crop rotation improved the WUE of the subsequent winter wheat crop, i.e., wheat yielded greater for the same water use when corn was in the rotation compared with when proso millet was in the rotation. The mechanism for this improved WUE was not identified. A similar conclusion was stated in Anderson (2004) regarding corn improving proso millet yield, and dry pea grown as a forage improving winter wheat WUE compared with winter wheat or proso millet as the previous crop.

Kirkegaard et al. (2008) provided an extensive literature review of previous crop effects on wheat yield from studies done in North America, southern Australia, and northern Europe. These systems were identified as "break crop" systems and generally showed increased wheat yield compared with continuous wheat yield. However, data regarding changes in WUE were not presented. The yield increases were attributed to fewer diseases, greater residual fertility (*N* and *P*), and greater available soil water at planting following the break crop than following a previous wheat crop. The reviewed studies that were conducted in the semi-arid regions of

* Corresponding author.
E-mail addresses: david.nielsen@ars.usda.gov, dcnielsen55@gmail.com (D.C. Nielsen).

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North America, particularly the northern Great Plains of the United States, did not consistently show the positive yield benefits of the break crop, most likely because of the overriding influence of available soil water on wheat yield combined with the highly variable nature of precipitation amount and timing in this region.

In a 4-year study conducted in eastern Montana, USA, Lenssen et al. (2007) reported spring wheat grain WUE ranging widely from 0.3 to 12.3 kg ha^{-1} mm^{-1}. The wide range in values was attributed to water availability effects on yield. They did not report consistent effects of previous crop type on WUE of spring wheat, but WUE was generally lower when wheat was preceded by a crop than when wheat was preceded by a fallow period. Lyon et al. (2007) reported results from a 2-year study conducted at two central Great Plains locations (Nebraska Panhandle, northeastern Colorado) in which the effects of preceding crop (triticale [*X Triticosecale* Wittmack], pea, foxtail millet [*Setaria italica* L. Beauv.], proso millet) and starting soil water content on subsequent winter wheat yield and water use were determined. Their data also showed that WUE varied widely over the course of the study (1.45 to 8.71 kg ha^{-1} mm^{-1}) and that greater WUE was observed when soil water contents at wheat planting were high. Those initial soil water contents were more influenced by precipitation amounts prior to wheat planting than by specific crop preceding winter wheat. In particular they did not report greater WUE for wheat following pea than for wheat following triticale, foxtail millet, or proso millet.

Results from a rotation study conducted in Swift Current, SK, Canada (Miller et al., 2003) indicated that 3-year average spring wheat WUE was improved when wheat followed a broadleaf crop (pea, lentil, chickpea, mustard) compared with wheat following wheat grown on a clay soil, but this difference was not seen when grown on a silt loam soil. The significant WUE improvement noted on the clay soil was attributed mainly to low yields for the wheat-following-wheat system which may have suffered from increased soil-borne pathogens during above-average precipitation years.

Tanaka et al. (2005) reported yield data from a cropping matrix study conducted at Mandan, ND in which previous crop effects on subsequent crop yields were analyzed over a 2-year period for 10 crop species. Some statistically significant yield differences due to previous crop species were presented, but the results were not consistent between the two years. For example, in one year spring wheat yield was unaffected by previous crop species, while in the second year spring wheat yields were significantly greater when the previous crop was crambe (*Crambe abyssinica* H.), dry bean (*Phaseolus vulgaris* L.), pea, or safflower (*Carthamus tinctorius* L.), but not with any of the other six plant species grown ahead of the wheat crop. Unfortunately no soil water or WUE data were provided so it is impossible to determine if these four species had the synergistic effect on wheat yield that Anderson (2005a) defined as improved WUE.

Hatfield et al. (2001) reviewed literature regarding soil management effects on WUE. They stated that increasing soil water availability to the crop in the absence of any other yield-limiting factors can lead to increased WUE. This can occur as a result of employing no-till management that leads to lower evaporative losses of soil water, increased precipitation infiltration on some soil types, and greater snow catch in standing crop residues. It is possible that different preceding crops will produce different amounts and orientations of crop residues that could lead to differences in soil water content at wheat planting. These differences in soil water content at wheat or millet planting could lead to plants under differing water stress during critical flowering and grain filling stages that could result in WUE differences in differing rotational sequences. Additionally there may be differing amounts of previous crop residue on the soil surface during the wheat or millet growing seasons which could lead to differing ratios of evaporation to transpiration resulting in WUE differences.

Hatfield et al. (2001) noted the difficulty in interpreting results from WUE studies because of the variation among seasons. These seasonal variations are, in semi-arid climates, mostly a result of the effects of the widely varying timing, amount, and form of precipitation (rain/snow) on both the previous crop and the current crop. Nielsen and Halvorson (1991) reported 30% greater WUE for non-N-stressed winter wheat in a year with 39% of growing season precipitation occurring during heading and flowering compared with a year with only 8% of growing season precipitation occurring during that critical developmental period (10.39 and 7.99 kg ha^{-1} mm^{-1}, respectively). Consequently short-term studies may lead to erroneous conclusions regarding crop effects on subsequent crop WUE.

In the absence of sufficiently long-term studies that could adequately identify synergistic effects of cropping practices to improve WUE, cropping systems simulation models may be used. Kirkegaard and Hunt (2010) used the Agricultural Production Systems Simulator (APSIM, Keating et al., 2003) to simulate multiple management effects (minimum tillage, weed control, crop rotation, planting date, and genotype selection) on wheat yield and WUE in southeastern Australia. They found combinations of management practices simulated over a 48-year period increased yields more than implementing any single practice, and that WUE increased from 6.0 kg ha^{-1} mm^{-1} for a baseline conventional till W–F system to 15.2 kg ha^{-1} mm^{-1} for a system in which all five of the suggested management practices were employed. Saseendran et al. (2010) simulated several central Great Plains dryland cropping systems and reported 16-year average wheat yields that were the same for the W–F and W–C–F no-till systems. The simulated average wheat yield for the W–M–F rotation was numerically greater than for W–F or W–C–F, but not significantly so. The simulated WUE values were 3.13, 4.51, and 3.89 kg ha^{-1} mm^{-1} for W–F, W–C–F, and W–M–F, respectively.

Winter wheat yields from an alternative crop rotation (ACR) study at Akron, CO (Anderson et al., 1999) were averaged over the 1994 to 1999 time period and found to be 8% greater (non-significant) in a wheat–corn–fallow system than in a wheat-fallow system, but yields in a wheat–proso millet-fallow system were the same as in the wheat-fallow system. Anderson (2005a) also concluded that dry pea improved WUE of winter wheat compared with winter wheat, proso millet, or fallow preceding winter wheat based on data from Anderson (2002). Tanaka et al. (2005) stated that WUE of winter wheat increased 56% when following dry pea (W–C–P rotation) compared with following proso millet (W–C–M rotation). Data presented in Anderson (2010, 2011) indicated that the 2-year average winter wheat WUE was 12% greater following pea compared with following fallow (comparing data from the W–C–M–P and W–C–M–F rotations at Akron, CO).

The objective of this paper was to re-examine some of the data presented in the literature cited above from Akron and compare it with a larger data set from the ACR study at Akron and determine if the conclusion regarding crop synergism (enhanced WUE due to specific previous crop) is consistently observed.

2. Materials and methods

The data presented in this paper come from the long-term ACR study conducted at the USDA-ARS Central Great Plains Research Station, 6.4 km east of Akron, CO (40° 09′ N, 103° 09′ W, 1384 m a.s.l). The soil type was a Weld silt loam (fine, smectitic, mesic Aridic Argiustoll). The experiment was established in the fall of 1990 to compare tillage, rotational sequence, and cropping intensity/frequency effects on soil properties, precipitation storage efficiency, crop water use, and crop production under the dryland, semiarid conditions of this region of the central Great Plains. More