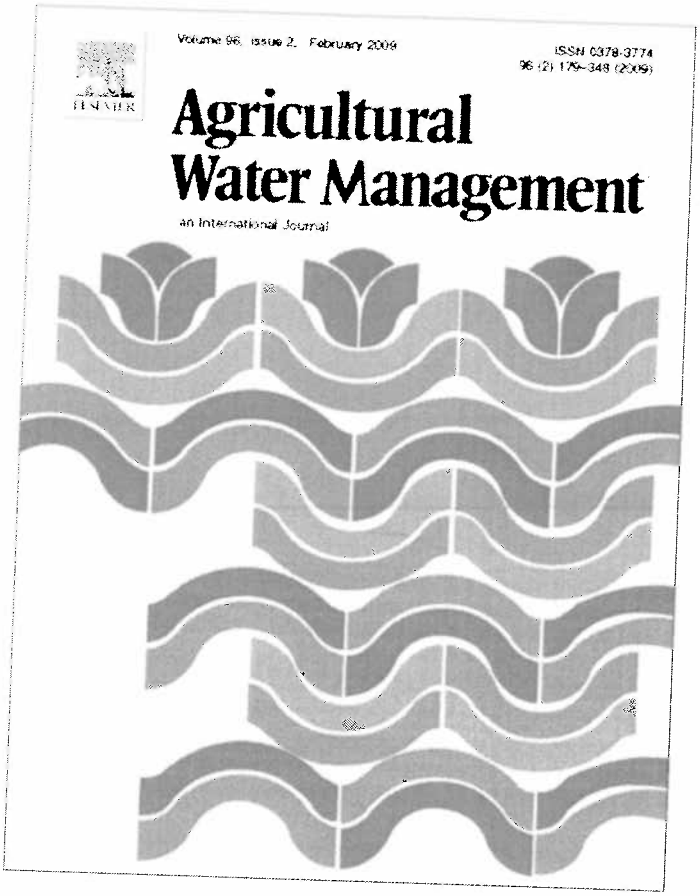
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Previous research has shown relationships between available soil water content at planting and subsequent yields of some crops. Nielsen et al. (1999) reported that winter wheat (*Triticum aestivum* L.) yields were reduced by 7.9 kg ha$^{-1}$ for each mm that soil water at wheat planting was reduced by the previous sunflower (*Helianthus annuus* L.) crop. Later Nielsen et al. (2002) showed that the response of winter wheat to available soil water at planting could be more accurately described by two linear relationships, one with a slope of 14.1 kg ha$^{-1}$ mm$^{-1}$ which was applicable to most growing season environmental conditions (87% of years), and one with a much less responsive slope of 5.0 kg ha$^{-1}$ mm$^{-1}$ that was seen when growing season conditions were very dry (April through June pan evaporation–precipitation $>$ 65 cm). Norwood (2000) also reported reductions in winter wheat yields in Kansas related to lower soil water at planting. Lyon et al. (1995) showed that soil water at planting in western Nebraska was strongly correlated with dryland yield of short-season summer crops [pinto bean (*Phaseolus vulgaris* L.), proso millet (*Panicum miliacium* L.)], but only weakly related to yield of long-season summer crops [sunflower, grain sorghum (*Sorghum bicolor* (L.) Moench), corn]. They attributed this result in part to shorter season crops having more soil water available at the critical reproductive growth stage than longer season crops, which used much of the initial soil water for stover production and did not have it available for grain development. Norwood et al. (1990) showed dryland grain sorghum yield was strongly and positively correlated with available soil water at planting (28.4 kg ha$^{-1}$ mm$^{-1}$) in western Kansas when averaged over 15 years, although the relationship was quite variable among years. Other factors that can influence dryland corn grain yield are plant population, fertility level, hail, and insect, disease, and weed pressures. But the primary factor controlling dryland corn grain yield in the semi-arid central Great Plains is available water from stored soil water and growing season precipitation (Campbell et al., 2005; Nielsen et al., 2005). The objective of this experiment was to quantify the dryland corn grain yield response to available soil water at planting to determine if a consistent predictive relationship exists that will aid farmers in making a crop choice at time of planting. If such a predictive relationship exists then a second objective was to use that relationship to determine the risk in producing profitable dryland corn.

**Table 1 – Crop rotations that included corn and years that they were grown in the Alternative Crop Rotation Experiment, Akron, CO**

| Rotation | Years |
|---|---|
| C–DB | 1995, 1996 |
| C–M | 1996 |
| C–FM | 1996 |
| C–S | 1992–1994 |
| C–O–W | 1995–1997 |
| C–P–W | 1998–2005 |
| C–M–W | 1992–2005 |
| C–F–W | 1992–2005 |
| C–M–P–W | 1997–2005 |
| C–M–FP–W | 1998–2005 |
| C–M–W–W | 1997–2005 |
| C–M–F–W | 1996–2005 |
| C–S–F–W | 1996–2005 |
| OC | 1995–2000 |

C = corn, DB = dry bean, M = proso millet, FM = foxtail millet (*Setaria italica* L. Beauv.), S = sunflower, O = oat (*Avena sativa* L., Poaceae), W = winter wheat, P = field pea (*Pisum sativum* L.), F = fallow, FP = forage pea (*Pisum sativum* L.), OC = opportunity cropping.

## 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) approximately 200 cm deep. 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

**Table 2 – Planting, harvesting, and fertilizing details for corn in the Alternative Crop Rotation Experiment, Akron, CO, 1992–2001**

| Year | Variety | Planting date | Harvest date | Seeding rate (seeds ha$^{-1}$) | Fertilizer | |
|---|---|---|---|---|---|---|
| | | | | | (kg N ha$^{-1}$) | (kg $P_2O_5$ ha$^{-1}$) |
| 1992 | Pioneer 3732 | 4 May 1992 | 2 November 1992 | 36,800 | 94 | – |
| 1993 | Pioneer 3732 | 10 May 1993 | 27 October 1993 | 36,800 | 90 | – |
| 1994 | Pioneer 3732 | 6 May 1994 | 14 October 1994 | 39,770 | 90 | – |
| 1995 | Pioneer 3732 | 18 May 1995 | 21 October 1995 | 36,800 | 66 | – |
| 1996 | Pioneer 3732 | 1 May 1996 | 7 October 1996 | 36,800 | 78 | – |
| 1997 | Pioneer 3732 | 1 May 1997 | 7 October 1997 | 36,800 | 45 | 17 |
| 1998 | DK 493BT | 12 May 1998 | 5 October 1998 | 39,780 | 67 | 17 |
| 1999 | DK 493BT | 7 May 1999 | 12 October 1999 | 39,780 | 34 | 17 |
| 2000 | DKC49-92 | 10 May 2000 | 12 September 2000 | 39,780 | 84 | 17 |
| 2001 | NK4242BT | 16 May 2001 | 23 October 2001 | 41,020 | 90 | 22 |
| 2002 | NK4242BT | 5 May 2002 | No harvest | 41,000 | 67 | 22 |
| 2003 | NK4242BT | 21 May 2003 | 7 October 2003 | 34,580 | 67 | 22 |
| 2004 | N42B7 | 3 June 2004 | 26 October 2004 | 29,640 | 67 | 22 |
| 2005 | N42B7 | 18 May 2005 | 3 November 2005 | 29,640 | 77 | – |

**Table 3 – X-axis offsets ($a$), slopes ($b$), and coefficients of determination ($R^2$) for linear regressions (model $\text{kg ha}^{-1} = b \times [\text{mm} - a]$) of corn grain yield on available soil water at planting shown in Fig. 2b and c; and critical period precipitation classes for precipitation falling between 15 July and 25 August at Akron, CO**

| Years | $N$ | X-axis offset ($a$) ($\text{kg ha}^{-1}$) | Slope ($b$) ($\text{kg ha}^{-1}\ \text{mm}^{-1}$) | $R^2$ | Critical period precipitation[a] |
|---|---|---|---|---|---|
| 1999 | 9 | −2 | 67.3 | 0.91 | High |
| 1992 | 3 | 69 | 47.8 | 1.00 | High |
| 1996, 1998 | 19 | −19 | 22.9 | 0.43 | Medium, medium |
| 1993, 1997, 2001, 2004 | 28 | −7 | 13.1 | 0.87 | Medium, medium, medium, medium |
| 1994, 2003, 2005 | 19 | 65 | 12.9 | 0.69 | Low, low medium |
| 1995, 2000 | 14 | 129 | 9.9 | 0.57 | Low, low |
| 2002 | 8 | 163 | 0.0 | 1.00 | Low |

$N$ = number of observations.

[a] High = more than 125 mm precipitation falling between 15 July and 25 August; low = less than 70 mm precipitation falling between 15 July and 25 August.

another ($P = 0.50$), but the X-axis offsets were different from each other ($P < 0.01$). No obvious differences in precipitation amounts during vegetative development or late grain-filling (Table 4) appear to explain either the general differences in regression offset position or the higher yields for a given available soil water at planting for the 1993/1997/2001/2004 data than for the 1994/2003/2005 or 1995/2000 data. The slopes of the two high response data sets ($47.8\ \text{kg ha}^{-1}\ \text{mm}^{-1}$ [1992]; $67.3\ \text{kg ha}^{-1}\ \text{mm}^{-1}$ [1999]) were not different from each other ($P = 0.06$), but the offsets were different from each other ($P < 0.01$). The slope of the 1996/1998 data ($22.9\ \text{kg ha}^{-1}\ \text{mm}^{-1}$) −1) was different from the 1999 data ($P < 0.01$) with different offsets ($P < 0.01$). Likewise, the slope and the offset of the 1996/1998 data were different from the 1992 data ($P < 0.01$).

The variable corn grain yield response to available soil water at planting (regression slope) is seen clearly in Fig. 2. As amount of precipitation falling during the critical pre-tassel to mid-grain-filling period increased, so did the response of grain yield to available water. We fit two linear regressions to the data (Fig. 2):

$$\text{Slope} = -0.6492 + 0.16889\,\text{mm}, \quad R^2 = 0.85, \quad n = 4 \tag{1}$$

$$\text{Slope} = -52.9797 + 0.73337\,\text{mm}, \quad R^2 = 0.98, \quad n = 4 \tag{2}$$

The regressions intersect at a critical period precipitation value of 93 mm.

Lyon et al. (2003) simulated corn grain yields for another central Great Plains location (Sidney, NE) about 125 km north of the current study. Using the Agricultural Production Systems Simulator (APSIM; Keating et al., 2003) to simulate yield from 1948 to 2001, they found grain yield response to soil water at planting ranging from $8.25\ \text{kg ha}^{-1}\ \text{mm}^{-1}$ for a plant density of $3\ \text{plants m}^{-2}$ to $12.57\ \text{kg ha}^{-1}\ \text{mm}^{-1}$ for a plant density of $4\ \text{plants m}^{-2}$. The average seeding rate in the current study was $3.75\ \text{seeds m}^{-2}$. The average post-flowering precipitation reported for Sidney was 67 mm. Using 67 mm in Eq. (1) predicts a yield response to soil water of $10.67\ \text{kg ha}^{-1}\ \text{mm}^{-1}$, which is approximately the average of the two responses constructed from the Sidney simulations. These simulation results provide some additional evidence to validate the accuracy of Eq. (1).

**Table 4 – Precipitation at Akron, CO (1992–2005 and 42-year average)**

| Year | Planting-14 July (mm) | 15 July–25 August (mm) | 26 August–30 September (mm) | Total |
|---|---|---|---|---|
| 1992 | 154 | 132 | 5 | 291 |
| 1993 | 96 | 112 | 24 | 232 |
| 1994 | 66 | 58 | 12 | 136 |
| 1995 | 199 | 30 | 64 | 293 |
| 1996 | 234 | 77 | 106 | 417 |
| 1997 | 138 | 72 | 43 | 253 |
| 1998 | 54 | 124 | 8 | 186 |
| 1999 | 121 | 167 | 80 | 368 |
| 2000 | 54 | 70 | 71 | 195 |
| 2001 | 108 | 96 | 45 | 249 |
| 2002 | 55 | 15 | 111 | 181 |
| 2003 | 138 | 35 | 22 | 195 |
| 2004 | 82 | 99 | 50 | 231 |
| 2005 | 190 | 110 | 10 | 310 |
| Average (1964–2005) | 136 | 88 | 32 | 256 |

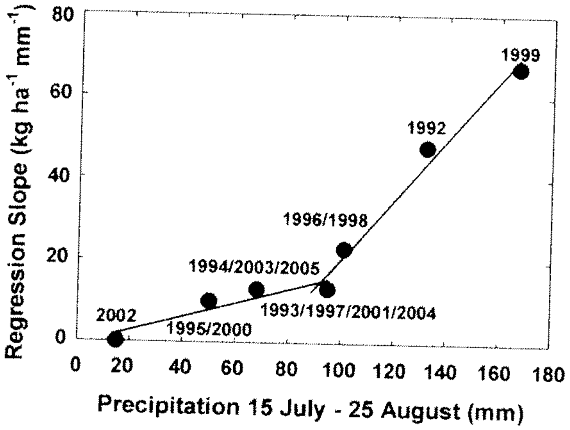

**Fig. 2 – Relationship between critical period (15 July to 25 August) precipitation and the slope of the regression of dryland corn grain yield on available soil water (0–180 cm profile) at planting, Akron, CO.**

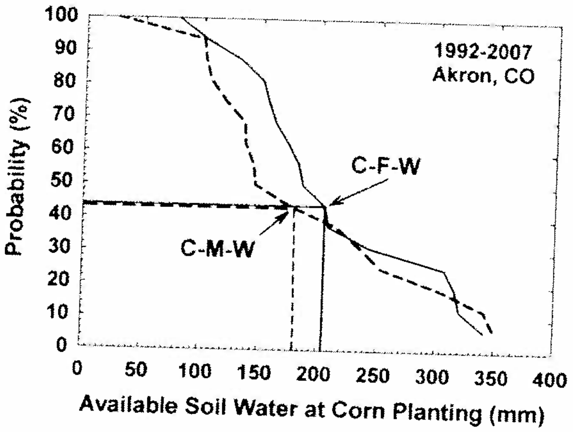

**Fig. 5 – Probability at least a given amount of available soil water (0–180 cm profile) at corn planting at Akron, CO in a corn-fallow-wheat (C-F-W) rotation or a corn-proso millet-wheat (C-M-W) rotation.**

51% of the time. Therefore the probability of achieving this break-even yield with average starting soil water would be 22%. With that same amount of soil water at planting a yield if 5000 kg ha$^{-1}$ would occur about 29% of the time, making the probability of achieving that yield with average starting soil water 15%. With a more intensive rotation of corn-proso millet-wheat, available soil water content at planting averaged 181 mm, occurring 44% of the time. With that amount of soil water at planting a yield of 2250 kg ha$^{-1}$ would be expected to occur only 35% of the time and the probability of achieving the break-even yield with average starting soil water would be 15%. A yield of 5000 kg ha$^{-1}$ would occur only about 16% of the time, making the probability of achieving that higher yield with average starting soil water only 7%.

## 4. Conclusions

The two relationships reported by Nielsen et al. (2002) for winter wheat grain yield response to available soil water at planting could be useful for tactical crop selection purposes because one relationship was applicable to most of the growing season conditions that would follow, while the second relationship was applicable to only the 13% driest, most water-demanding growing season conditions. In contrast, the data reported in the current study indicate that the response of corn grain yield to available soil water at planting is much more variable such that knowledge of amount of available water at planting without a reliable forecast of growing season precipitation is not sufficient information to adequately predict corn grain yield. The response of dryland corn yield to soil water at planting varies with amount of precipitation in the critical yield formation period (15 July to 25 August). The predictable nature of those responses to amount of critical period precipitation allow for an estimation of corn yield probability from the long-term precipitation record when an amount of available soil water at planting is specified. Similar probability estimates could be generated for other central Great Plains locations where long-term precipitation records exist. The yield probabilities generated from the Akron, CO critical period precipitation record confirm the highly risky nature of dryland corn production in the central Great Plains. On the other hand, the data from this study showed clearly that there is always a positive response of corn grain yield to increasing available soil water at planting under dryland conditions, confirming the recommendation that every effort should be employed to increase precipitation storage efficiency during non-crop periods through good residue management and weed control.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.agwat.2008.08.011.

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