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Cumulative deficit irrigation effects on corn biomass and grain yield under two tillage systems

J.G. Benjamin*, D.C. Nielsen, M.F. Vigil, M.M. Mikha, F. Calderon

Central Great Plains Research Station, 40335 Co. Road GG, Akron, CO 80720, USA

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ABSTRACT

Deficit irrigation (DI) is sometimes used to cope with dwindling irrigation water supplies or limited water allocations. A study at Akron, Colorado, USA from 2001 to 2006 investigated the effects of consecutive years of DI on soil water use, soil water content, biomass production, grain yield and water use efficiency (WUE) in a continuous corn system. In 2001, DI and full irrigation (FI) had the same grain yield. In 2002, DI reduced grain yield by 20% relative to FI. By 2006, continued DI reduced grain yield by 65% compared with FI. Significant increases in soil water storage during the non-crop period occurred only in 2005 and 2006. This resulted in a slow but continual decrease in soil water storage as the years progressed. By 2006, soil water storage in the 60- to 90-cm depth remained lower for DI than for FI during the entire growing season. WUE declined for DI compared with FI over the years. WUE was the same for DI and FI in 2001, but WUE for DI declined to only 65% of FI by 2006. DI may be an option for short term or emergency situations when insufficient irrigation water is available for FI in one year. However, long-term use of DI, without replenishment of stored soil water during the non-cropped period, was detrimental to both corn production and water use efficiency under these experimental conditions.

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1. Introduction

Greater demands for water due to urbanization and lower water table levels in aquifers in the central and western regions of the United States have led to lesser amounts of water available to agriculture. Investigations into irrigation scheduling and water needs through crop life cycles have shown that several crops, notably wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* L.), can be irrigated with less than full crop water requirements and suffer only mild reductions in crop yields with a corresponding increase in water productivity (Hanks et al., 1969; Geerts and Raes, 2009). Corn (*Zea mays* L.) suffered greater proportional yield loss due to deficit irrigation (DI). Corn, however, continues to be the predominant irrigated crop in the central Great Plains (Norwood, 2000).

Timing of water availability is critical for corn production. Denmead and Shaw (1960) noted that water stress during the vegetative stage of corn production reduced grain yield by 25%, water stress during silking reduced grain yield by 50%, while water stress during grain fill reduced grain yield by 21%. Saseendran et al. (2008) modeled corn production with limited irrigation in northeast Colorado and concluded that yields and water use efficiency were maximized when available irrigation amount was split with 20% applied during the vegetative growth stage and 80% during the reproductive growth stage. With rain-fed agriculture in the semi-arid west, the amount of rainfall during the critical tasseling to early dough stage of corn (VT to R4, growth stage as per Ritchie and Hanway, 1982) is highly correlated to overall grain production (Nielsen et al., 2009). They showed that planting time soil water content is poorly correlated to overall grain production, but a high level of planting time soil water allows for sufficient vegetative production to use rainfall later in the growing season. It would seem that relatively small amounts of irrigation during the critical tassel – silking period have the potential to greatly increase grain production in dry climates. Research on limited irrigation has focused on providing irrigation water to the critical period of corn production.

Some limited irrigation work has been done in relatively humid areas (Newel and Wilhelm, 1987; NeSmith and Ritchie, 1992), where recharge of soil water would be expected during the over-winter period. In semi-arid climates, one strategy for limited irrigation is to expect sufficient water recharge during the fallow period to provide water for the vegetative stage of corn production and little or no irrigation is added during vegetative growth. Irrigation then begins at corn tasselling and continues through grain fill (Hergert et al., 1993; Payero et al., 2006; Klocke et al., 2007). Another strategy for limited irrigation is to start water

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* Corresponding author. Tel.: +1 970 345 0518; fax: +1 970 345 2088.
E-mail address: Joseph.Benjamin@ars.usda.gov (J.G. Benjamin).

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Table 1
Details of cropping history for rotations, 2001–2006.

Year	Variety	Population (seeds ha^{-1})	N–P–K–Zn (kg ha^{-1})	Planting date
2001	Dekalb DK 493	80,000	160–22–0–0	May 14
2002	Dekalb DK 493	80,000	160–22–0–0	May 3
2003	NK N42-B7	86,000	215–22–0–0	May 5
2004	Laser L62-C2	86,000	215–22–0–0.6	May 4
2005	N65-C5	86,000	215–22–0–0.6	May 13
2006	NK N70-C7RR	86,000	215–22–0–0.6	May 5

applications at some pre-determined level of soil water depletion, such as 50% plant available water (Klocke et al., 2011), and then irrigate at some reduced level below full crop requirements.

Multi-year studies of limited irrigation sometimes place the plots in new areas of the field that were not subject to previous limited irrigation (Cakir, 2004; Payero et al., 2006) or corn is grown in rotation with an extended fallow period preceding the corn crop (Norwood, 2000; Baumhardt et al., 2013; Klocke et al., 2011).

Little work has been done to evaluate the cumulative effect of DI on soil water replenishment with continuous corn production. The objective of this study was to evaluate the effects of multiple years of DI on soil water replenishment, soil water availability during corn production, and the cumulative effect of DI on corn grain yield and WUE.

2. Materials and methods

The study was conducted at the USDA-ARS Central Great Plains Research Station near Akron, Colorado, USA. The station lies at 40.15° N lat and 103.15° W long. The elevation of the station is 1384 m above mean sea level. The research station location is within a semi-arid climate with approximately 400 mm annual precipitation and approximately 1600 mm pan evaporation. The soil is a Weld silt loam (fine, smectitic, mesic Aridic Paleustolls). This soil has a silt loam Ap horizon from about 0 to 120 mm with fine granular structure. A silty clay loam Bt1 horizon with fine to medium subangular blocky structure extends from about 120 to 240 mm with a smooth boundary to a silty clay loam Bt2 horizon, also with fine to medium subangular blocky structure to about 410 mm. A silty clay loam Btk horizon with fine to medium subangular blocky structure extends to about 640 mm.

The irrigation-tillage experiment started in 2001 and ended in 2006. Prior to the initiation of the experiment, the field had been in fully irrigated (FI), continuous corn production since 1997. The experiment was organized as a split-plot design with three replications. The main plot was an irrigation treatment of either FI or DI. Irrigation treatments in 2001–2003 and 2005–2006 included a FI treatment and a DI treatment. The FI treatment supplied irrigation water each week based on the evapotranspiration (ET) demand during the entire growing season. Credit was given for any rainfall each week. The DI treatment supplied no irrigation water during the vegetative portion of the growth cycle (from emergence to appearance of tassel) and then added irrigation water equivalent to the FI plots during the reproductive stage. In 2003, the DI plots showed severe water stress during the vegetative growth stage, which was attributed to depletion of soil water storage. In an attempt to compensate for previous water depletion, all the plots were FI in 2004. All irrigation was applied with a sprinkler irrigation system. Irrigation rates were based on calculated ET demands (Allen, 2000; Allen et al., 1998; Nielsen and Hinkle, 1996; Jensen et al., 1990).

Tillage subplots (18 m by 9 m) were randomized within the main irrigation plots. Two levels of tillage were: (1) a no-till system (NT) consisting of planting directly into the previous crop residues and (2) a chisel plow system (CP) consisting of a fall chisel plow operation 0.35 m deep with a parabolic shank deep ripper. The shanks on the ripper for CP had 0.6-m centers. CP was followed in the spring by one or two passes with a mulch treader 5 cm deep to break up clods and smooth the soil surface in preparation for planting. Plot size and machinery working widths were such that the wheel tracks for field operations followed a controlled wheel traffic pattern. All plots were in continuous corn planted approximately 5 cm deep in 0.76-cm rows. Corn varieties, planting populations, fertilizer treatments and planting dates are given in Table 1.

Soil water content measurements were taken during the 2002–2006 growing seasons with a neutron probe. Due to personnel constraints, no soil water content measurements were made with the neutron probe in 2001. One neutron access tube was installed in the center row of each plot shortly after planting. A delay occurred in 2003 such that the access tubes were not installed until the V6 growth stage. Water measurements were collected at 0.3 m, 0.6 m, 0.9 m, 1.2 m, 1.5 m, and 1.8 m depths immediately before irrigation and as soon after irrigation as field entry was possible, generally the next day. The neutron probe was calibrated against gravimetric soil samples taken at the time of access tube installation in an adjacent experiment with the same soil type. The gravimetric soil water contents estimated from the neutron probe measurements were converted to volumetric soil water contents by multiplying by the bulk density, also measured on the samples taken at the time of neutron probe access tube installation. Total water storage (S, cm) in the 1.8-m soil profile was calculated by

$$S = \sum_{d} 30\,\theta_d \tag{1}$$

where θ_d is the volumetric water content in each 30-cm depth increment d. Change in water content (ΔS_i) between sampling dates was calculated by

$$\Delta S_i = S_j - S_k \tag{2}$$

where S_j and S_k are the bounds of the interval of interest. Total water use for a growth interval (TWU_i, cm) for each growth stage was calculated by

$$TWU_i = \Delta S_i + I_i + R_i \tag{3}$$

where I_i is the irrigation that occurred for the interval and R_i is the rainfall that occurred for the interval i.

Growth stage measurements were made each week after emergence. Ten representative plants were identified in each plot and the leaf number for each plant was marked with an indelible marker as the leaf emerged from the whorl. Corn growth stage was evaluated as described in Ritchie and Hanway (1982). The growth stage was determined by averaging the growth stages of the individual plants. Plant biomass samples were collected at the plot average R1 growth stage in 2002 and at the V6, V12, and R1 growth stages in 2003–2006. Dates of biomass harvest are shown in Table 2. Four adjacent plants, representative of the plot area and approximately 1 m from the plants used for growth stage determination, were collected at each sampling time. Plant population (pop) was measured for each plot (plant ha^{-1}) and the biomass for four plants (b_{4s}, g) was converted to biomass per unit area for the growth stage interval (b_s, kg ha^{-1}) by

$$b_s = 0.00025\, b_{4s}\, pop \tag{4}$$