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Research Paper

Impact of irrigation and nitrogen fertilizer rate on soil water trends and maize evapotranspiration during the vegetative and reproductive periods

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ABSTRACT

Field research was conducted in 2011 and 2012 at the University of Nebraska-Lincoln South Central Agricultural Laboratory located near Clay Center, NE to evaluate maize actual evapotranspiration (ETa) during the vegetative and reproductive growth periods for 0, 84, 140, 196, and 252 kg ha^{-1} nitrogen (N) fertilizer treatments under full irrigation (FIT), limited irrigation (75% of FIT), and rainfed settings. Daily ETa values were greatest during the early reproductive period (silking to blister growth stages) with average values of 3.62, 5.18, and 5.91 mm d^{-1} in 2011 and 4.37, 5.92, and 6.12 mm d^{-1} in 2012 for rainfed, 75% FIT, and FIT, respectively. Maize ETa during the vegetative period was not significantly impacted by N fertilizer rate in 2011 ($P_{0.05}$ = *0.2357*) or 2012 ($P_{0.05}$ = *0.6341*). Whereas, reproductive period ETa for FIT and 75% FIT for the pooled years significantly increased with N fertilizer rate with slopes of 0.20 and 0.17, respectively. The rainfed regression slopes were not statistically different from zero in 2012 ($P_{0.05}$ = *0.1467*) or pooled years ($P_{0.05}$ = *0.0505*). The increase in reproductive ETa with N fertilizer and irrigation resulted in a positive grain yield response with slopes of 0.021, 0.048, and 0.104 Mg ha^{-1} mm^{-1} for the rainfed, 75% FIT, and FIT settings, respectively.

1. Introduction

In water-limiting agricultural environments, it is important to maximize yield with minimal water and nutrient inputs. Crop water use is commonly measured as evapotranspiration (ET), which varies based on a number of factors, including micrometeorological variables, nutrient (e.g., nitrogen) and water availability, and other environmental, soil, and biophysical factors. To effectively manage water-scarce areas a comprehensive understanding of hydrologic balance components, especially actual crop ET (ETa), is necessary, because in many cases ETa is the largest component of the hydrologic balance during a crop growing season.

The two major yield-limiting inputs for most agriculture crops are water and nitrogen (N) fertilizer. Several studies have investigated water availability and its influence on crop yield and ETa (Pandey et al., 2000; Zhang et al., 2004; Payero et al., 2009; Djaman and Irmak, 2012; Rudnick et al., 2016). Zhang et al. (2004) reported that soil water deficit, severe or slight, significantly decreased maize and winter wheat ETa as compared to normal available soil water conditions and the decrease in ETa was mainly dependent on irrigation amount. Payero et al. (2008) evaluated eight irrigation amounts, ranging from 53 to 356 mm in 2005 and from 22 to 226 mm in 2006, on maize ETa in the semiarid climate of west central Nebraska. They observed an increase in seasonal ETa with irrigation up to 221 mm in 2005 and 173 mm in 2006. The associated effects of reduced ETa on maize grain yield depends on crop growth stage due to growth stages varying in their susceptibility to water-stress. Furthermore, early season growth stages (i.e., during the vegetative period) are more susceptible to increased water loss through evaporation (E), due to incomplete canopy closure (Ogola et al., 2002).

Nitrogen availability can affect plant growth and functions such as leaf area index (LAI), crop photosynthetic rate, radiation interception, plant growth, shoot weight, grain yield, and plant N uptake (Novoa and Loomis, 1981; Eck, 1984; Pandey et al., 1984; Muchow,

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1988; McCullough et al., 1994). Consequently, this can influence ETa (Rudnick and Irmak 2014b). Benbi (1989) found that N fertilizer rate increased maize water uptake by 62 and 71 mm in a sandy loam and loam soil, respectively. Pandey et al. (2000) observed greater crop water use at high N fertilizer rates and under full irrigation as compared to low N rates and limited irrigation. Hati et al. (2001) observed greater ETa under fertilized treatments than unfertilized treatments at all stages of growth for all irrigation regimes. A significant water by N interaction for ETa and soil profile water extraction pattern was observed for maize and wheat by Lenka et al. (2009). They reported significantly greater profile soil water depletion for fertilized treatments as compared with the control (0 kg N ha^{-1}) treatment under all water regimes. Ogola et al. (2002) reported N fertilizer did not affect maize transpiration (T) efficiency, but increased maize crop water use efficiency by reducing E, through establishing a greater crop leaf canopy. However, for irrigation management strategies both E and T should be accounted for even though E is a non-beneficial use of water in crop production (Rudnick and Irmak, 2014a).

In a companion article, Rudnick and Irmak (2014b) developed alfalfa (K_{cr}) and grass (K_{co}) reference maize K_c values as a function of growing degree days (GDD) for various N fertilizer and irrigation treatments. They reported that on average greater K_c values existed for higher N fertilizer rates (196 and 252 kg N ha^{-1}) as compared with lower N rates. Furthermore, they investigated a stress factor (K_n) to account for the effects of N on K_c and observed that K_n changed over time, indicating that N fertilizer rate had an impact on maize ETa, but it was not constant throughout the growing season. In order to develop appropriate management practices to enhance crop water and N productivity a better understanding of the effects water, N, and their potential interactions have on ETa at different growth stages as well as the resulting impact of that ETa on grain yield is needed. As described above, several studies have evaluated the effects of water (e.g., irrigation) and N fertilizer on seasonal ETa; however, less information has been reported on their effects during the vegetative and reproductive periods. Thus, the research objectives were to evaluate how various N fertilizer rates under full irrigation, limited irrigation, and rainfed settings affect seasonal soil water trends, daily ETa at different growth stages, and cumulative ETa during the vegetative and reproductive periods of maize and their resulting impact on grain yield under typical south central Nebraska production settings.

2. Materials and methods

2.1. Site description, field management practices, and experimental design

Field experiments were conducted in 2011 and 2012 at the University of Nebraska-Lincoln South Central Agricultural Laboratory (SCAL) located near Clay Center, Nebraska, U.S.A., latitude 40.582°N and longitude 98.144°W, with an elevation of 552 m asl. The dominant soil type at the research site is a Hastings silt loam (fine, montmorillonitic, mesic Udic Argiustoll) and the climate is sub-humid/semi-arid with long-term (1981–2010) average growing season precipitation (May 1 to Sept. 30) of 469 mm (prism.oregonstate.edu; on Jan. 26, 2017). Pioneer maize (*Zea mays* L.) hybrid 541 AM-RR was planted in 2011 and hybrid P1498HR was planted in 2012. Maize phenology was visually observed throughout the growing seasons and is reported in Table 1.

The experimental design was a randomized complete block design, with irrigation rate as the main treatment and nitrogen fertilizer in the form of urea ammonium nitrate (UAN 32%) as the sub-treatment. Individual plots were eight rows (6.1 m) wide by 45.7 m in length, where the center 4 rows were harvested for yield

Table 1
Observed maize growth stages for the 2011 and 2012 growing seasons.

Growth Stage	2011	2012
Planting (P)	4 May	25 April
Emergence (E)	11 May	1 May
8 Leaf (V8)	30 June	18 June
Silking (R1)	18 July	9 July
Milk (R3)	3 August	24 July
Physiological Maturity (R6)	11 September	2 September
Harvest (H)	7 October	25 September

Table 2
Irrigation dates and amounts (mm) for the full irrigation (FIT), 75% of FIT, and rainfed treatments in 2011 and 2012.

	Irrigation		
Date	FIT	75% FIT	Rainfed
July 27, 2011	25	19	0
August 4, 2011	25	19	0
August 10, 2011	25	19	0
August 27, 2011	25	19	0
Total	100	75	0
July 7, 2012	33	33	33
July 17, 2012	40	30	0
August 1, 2012	40	30	0
August 12, 2012	40	30	0
Total	153	123	33

(adjusted to 15.5% moisture content) using a plot combine. The irrigation treatments evaluated were full irrigation (FIT), which was managed to prevent crop water stress, 75% of full irrigation (75% FIT), and rainfed (i.e., no irrigation) and the N treatments were 0, 84, 140, 196, and 252 kg ha^{-1}. Irrigated treatments were planted at a population density of 74,100 and 80,000 seeds ha^{-1} in 2011 and 2012, respectively. To reflect common management practices in the region, the rainfed treatments were planted at a reduced population density of 59,300 and 56,800 seeds ha^{-1} in 2011 and 2012, respectively. The slight difference in planting densities across growing seasons was due to the change in hybrid selection as well as differences in forecasted weather conditions. Nitrogen fertilizer was side-dressed using an eight-row capstan liquid unit on June 6–7 in 2011 and May 17 in 2012. Irrigation was applied using a GPS guided variable rate linear move irrigation system (Valmont Industries, Valley, NE) with iWob sprinklers with black plates (Senninger Irrigation, Clermont, FL) installed 2.4 m above ground every 3.0 m along the lateral. The irrigation dates and amounts are presented in Table 2 and the cumulative precipitation for different growth periods is presented in Table 3. Seasonal precipitation (planting to harvest) in 2011 and 2012 was 371 and 296 mm, respectively.

2.2. Soil water measurements and evapotranspiration calculations

A field calibrated Troxler 4302 Soil Depth Moisture Gauge (Research Triangle Park, NC, USA) was used to measure weekly soil volumetric water content (θv) every 0.30 m to a depth of 1.50 m for both growing seasons (Rudnick et al., 2015). With limitation on equipment availability, one replication of neutron gauge access tubes were installed for the 84, 140, 196, and 252 kg N ha^{-1} treatments under all irrigation levels in 2011 and three replications in 2012. One replication of neutron gauge access tubes were installed for the control (0 kg ha^{-1}) N treatments in 2012; however, one replication of Watermark Granular Matrix Sensors® (Irrometer Company, Inc., Riverside, CA, USA) were also included for the control treatments. Matric potential measured from the Watermark sensors was converted to θv using a site-specific soil water retention curve for the experimental field (Rudnick et al., 2015).