CUMULATIVE DEFICIT IRRIGATION AND NITROGEN EFFECTS ON SOIL WATER TRENDS, EVAPOTRANSPIRATION, AND DRY MATTER AND GRAIN YIELD OF CORN UNDER HIGH FREQUENCY SPRINKLER IRRIGATION

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HIGHLIGHTS

- Evapotranspiration and corn grain yield under full and deficit water and nitrogen application were measured in a 3-yr study.
- Soil water trends, evapotranspiration, and dry matter and grain yields were significantly different between irrigation treatments and study year.
- Nitrogen availability did not significantly affect soil water trends or evapotranspiration within an irrigation level.
- Grain yield was not significantly different between full irrigation and 75% of full irrigation within a nitrogen level.
- Results indicate that crop evapotranspiration is independent of crop yield potential when soil water content is similar under high evaporative demand and frequent sprinkler irrigation.
- Reducing irrigation application to low-yield potential field areas will reduce yield.

ABSTRACT. *Historically feed corn has been a minor crop in south central Idaho but over the past three decades corn production in southern Idaho has increased fourfold in response to a similar increase in the local dairy industry. Corn seasonal water use and response to water deficits in the region's climate is lacking. A 3-year field study on corn (*Zea mays* L.) was conducted in 2017, 2018, and 2019 to evaluate the cumulative effects of continuous water and nitrogen (N) deficits on soil water trends, evapotranspiration, and dry matter and grain yield. Four irrigation rates, fully irrigated (FIT) and three deficit irrigation rates (75% FIT 50% FIT, and 25% FIT) combined with two N supply rates (0 and 246 kg N ha^{-1}) were investigated under lateral-move irrigation. Growing season soil water depletion in 2017 in the 25% FIT and 50% FIT irrigation treatments significantly reduced soil water availability at planting in subsequent years and resulted in reduced yields relative to 2017. Nitrogen treatments had no significant effect on soil water availability, seasonal soil water depletion, or crop evapotranspiration (ET_c) for a given irrigation treatment. Crop evapotranspiration was significantly different between irrigation treatments in each study year and decreased as irrigation amount decreased. Dry matter yield was significantly different between irrigation treatments in each study year, but there was no significant difference between the 75% FIT and FIT irrigation treatments for a given N treatment. Differences in dry matter yield decreased between N treatments as irrigation amount decreased. Grain yield was significantly reduced by deficit irrigation in each study year, but there was no significant difference between the 75% FIT and FIT irrigation treatments for a given N treatment in each study year. Grain yield was significantly different between nitrogen treatments for only the FIT irrigation treatment. The lack of significant difference in grain yield between the 75% FIT and FIT irrigation treatments resulted in a curvilinear convex downward water production function regardless of nitrogen treatment. A reduction in applied water resulted in a reduction of grain yield regardless of N availability suggesting that a reduction in irrigation application to less productive areas of a field will cause a yield reduction. The lack of significant difference in crop ET_c between N treatments for a given irrigation treatment indicates that crop ET_c is unaffected by crop yield potential when soil water contents are similar under high evaporative demand and frequent sprinkler irrigation.*

Keywords. *Corn, Deficit irrigation, Evapotranspiration, Nitrogen, Sprinkler irrigation, Water use, Water production function, Yield.*

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Historical water resources for irrigated agricultural in the western U.S. are being diverted to support growing urban populations and environmental and ecosystem restoration. Groundwater levels in many areas have steadily decreased from historic levels as urban areas and municipalities grow and ground water use is approaching an unsustainable level. Warmer winter temperatures due to climate change are predicted to reduce mountain snowpack, which is the source of early irrigation developments in much of the western U.S. The growing demand on irrigation water supplies for other societal uses combined with climate change necessitates increased crop water productivity to meet food and fiber needs of a growing population.

The dairy industry in southcentral Idaho has undergone rapid expansion in the region over the past 25 years transforming the common irrigated crop mix from sugar beet, dry bean, and cereal grains to include more forages to support the regions dairy feed needs. Consequently, the production of alfalfa and corn, both for grain and forage, has increased. Historically, corn has been a minor crop in the region and limited local information about water use and yield response to deficit irrigation are available. Advances in corn genetics over the past 30 years have increased productivity that has affected water productivity relations. Genetic improvements in corn varieties have resulted in an average 1% to 2% annual increase in yields with little or no increase in seasonal water use (Irmak and Sharma, 2015). The region's relatively short growing season (~124 days), high evaporative demand, and limited non-growing season soil water recharge prevents direct transfer of corn water use and deficit irrigation yield response measured in regions with greater seasonal precipitation, less evaporative demand, or longer growing seasons.

Grain corn is an important feed stock for both human and domestic animals worldwide and has been the focus of numerous water and nutrient production management research studies under a wide variety of climatic conditions. Doorenbos and Pruitt (1983) reported the water requirement for maximum corn grain yield ranges from 400 to 750 mm depending upon climate and length of growing season. Grain corn water use studies in the U.S. Great Plains region have reported seasonal water requirements ranging from 530 to 840 mm for maximum yield (Trout and DeJonge, 2017). Greater water requirements are associated with greater evaporative demand and longer growing season in the southern Great Plains while lesser water requirements are associated less evaporative demand and shorter growing season of the northern Great Plains. Corn grain yield response to deficit irrigation induced water stress (water production function, WPF) is often modelled as a linear function of crop evapotranspiration (ET_c) based on a seasonal soil water balance (Schneekloth et al., 1991; Schneider and Howell, 1998; Payero et al., 2008; Lamm et al., 2009; Klocke et al., 2011; Spurgeon and Yonts, 2013; Irmak, 2015). However, Trout and DeJonge (2017) reported a curvilinear (concave downward) corn grain yield response to ET_c and applied irrigation water under surface drip irrigation. The curvilinear response represents a decreasing yield response to increasing ET_c or applied irrigation or conversely a small decrease in yield with a larger decrease in ET_c or applied irrigation. The shape of a WPF is important for irrigation management decisions. If the WPF is curvilinear, the marginal productivity decreases with each additional unit of water so once sufficient water is applied to obtain yield, additional water should be spread evenly across the cropped area to generate maximum yield (Trout and DeJonge, 2017), used to expand cropped area (water spreading) to generate additional yield, or transferred (leased) to another beneficial use. However, if the WPF is linear, the marginal productivity is constant and there is no disadvantage to applying all the water required to maximize yield on a portion of the cropped area when the water supply is limited (Trout and DeJonge, 2017). Evenly spreading the limited water supply across the entire cropped area would increase production costs (increase seed, fuel, and labor costs) without increasing total crop yield.

Most studies investigating corn grain yield response to water have been conducted using non-yield limiting fertility regimes. A few studies have investigated the interaction between crop water use and nutrient availability (Carlson et al., 1959; Eck, 1984; Allen, 1990; Fernández et al., 1996; Pandey et al., 2000a, 2000b; Hati et al., 2001; Ogola et al., 2002; Lenka et al., 2009; Rudnick and Irmak, 2013; Rudnick et al., 2017; Lo et al., 2020). Nitrogen (N) fertilizer had a significant effect on ET_c in the studies of Pandey et al. (2000a, 2000b), Ogola et al. (2002), Lenka et al. (2009), Rudnick and Irmak (2013), Rudnick et al. (2017), and Lo et al. (2020). Conversely, N fertility had no significant effect on ET_c in the studies of Carlson et al. (1959) and Fernández et al. (1996), and Allen (1990) reported no significant effect of phosphate fertility on ET_c for barley but did find a reduction in soil water evaporation with phosphate application. Nitrogen supply has dramatic effects on corn growth, development, and grain yield (Eck, 1984; Pandey et al., 2000a). Leaf area index, leaf area duration, photosynthetic rate, radiation interception, and radiation efficiency are increased by N supply (Pandey et al., 2000b). Soil water evaporation is the primary component of corn ET_c at planting and decreases as the canopy develops and shades the soil surface and comprised about 25% of total seasonal ET_c for fully irrigated corn in a semi-humid climate (Kang et al., 2003). Reduced corn canopy development from N stress will likely decrease transpiration due to reduced transpiring leaf area and increase soil water evaporation due to reduced soil shading with the net effect on ET_c depending upon level of N deficiency, climatic conditions, irrigation type, and irrigation frequency. These may be the reasons why some studies have found a significant effect of N fertility on corn ET_c while other studies have not. The interaction between crop growth, soil water evaporation, and transpiration will likely be site specific due to the influence of climate, irrigation system type, and irrigation frequency on the soil water evaporation component of ET_c.

The intention of variable rate center pivot irrigation (VRI) is to increase crop water productivity by addressing spatial variation in crop water availability through spatially variable optimum water application in terms of amount and timing. There are several potential applications of VRI (O'Shaughnessy et al., 2019) to increase crop water productivity or reduce the environmental impact of irrigated agriculture. One perceived potential advantage of VRI is that less water can be applied to field areas with low productivity, without adversely affecting yield, thereby reducing water use, nutrient leaching, and pumping costs. Based on aforementioned research studies investigating the effect of nutrient availability on ET_c, low crop yield potential may or may not be accompanied by reduced ET_c, which also means the notion of reducing water application without affecting yield is questionable. Additional research is needed to fully understand if water application to low productivity areas of a field can be reduced without adversely affecting yield.

Most field research studies investigating crop yield response to water and/or fertility deficits have been conducted on research plots relocated each study year to avoid any potential spatially variable effects from previous rate studies on yield. A small number of studies have investigated multiyear cumulative effects of deficit irrigation treatments on yield (Klocke et al., 2011; Benjamin et al., 2015). Multiyear cumulative effects of deficit irrigation on soil water trends as well as yield need to be known to develop recommendations for deficit irrigation management that match local climatic conditions and crop rotations. In regions where nongrowing season precipitation is sufficient to refill the soil profile to field capacity, the cumulative effects of deficit irrigation on yield are of less importance. In regions where nongrowing season rainfall is insufficient to fully replenish the soil profile in the active crop root zone, deficit irrigation can impact water availability at planting the following year. Klocke et al. (2011) reported deficit irrigation end of growing season soil water content influenced the following year's starting soil water content and yield variability increased as irrigation decreased illustrating the increased risk to the producer when using deficit irrigation. They also found that under deficit irrigation more nongrowing season precipitation was utilized because the previous year deficit irrigated crop extracted more soil water from deeper in the soil profile than a fully irrigated crop. Benjamin et al. (2015) reported that long-term use of deficit irrigation of ~50% ET_c was detrimental to corn yield and water productivity due to the lack of soil water storage replenishment during the nongrowing season. Deficit irrigated corn is more susceptible to crop damage by mites and root insects and tends to have weaker stalks that are more susceptible to lodging, all of which will likely increase risk of unanticipated yield loss (Trout and DeJonge, 2017). While deficit irrigation will reduce seasonal water use, the effects of continual deficit irrigation on future crop growth needs to be determined before deficit irrigation can be recommended or expected to be adopted by producers.

The objectives of this study were to evaluate and quantify corn water use, dry matter and grain yield, and soil water trends to continual nitrogen and irrigation deficits in south-central Idaho. A secondary objective was to test the hypothesis that corn ET_c is independent of corn yield potential in a high evaporative demand environment with frequent irrigation. Nitrogen deficiency created by multiyear deficit N application was used to attain reduced crop yield potential needed to test the hypothesis.

Methods and Materials

Site Description

A field study was conducted in 2017, 2018, and 2019 at the USDA-ARS Northwest Irrigation and Soil Laboratory near Kimberly, Idaho. The climate is borderline arid-semi-arid where the 20-yr average annual precipitation and alfalfa-reference evapotranspiration (ET_r) are approximately 253 and 1479 mm, respectively. Approximately 45% of annual precipitation and 83% of annual ET_r occurs during April through mid-October. The soil at the study site is a Portneuf silt loam (coarse-silty mixed mesic Durixerollic Calciorthid). The soil profile is classified as very deep and well drained with weak silica cementation ranging from 30 to 45 cm deep that can restrict root growth (USDA, 1998).

Experimental Design

The field study utilized a split block experimental design to evaluate two nitrogen treatments and four irrigation treatments with four replications (fig. 1). The two N treatments were 0 and 246 kg ha^{-1} N. The latter N rate was determined based on soil sampling in the spring of 2017 and local non-yield limiting N recommendations. The four irrigation treatments applied using a lateral move irrigation system were fully irrigated (FIT), 75% FIT, 50% FIT, and 25% FIT. Irrigation treatment plots were 18.2 m wide (24 rows) × 41.1 m long, which was the length of each lateral move irrigation system span. Crop row direction was east-west. The harvest area within each plot was 3.7 m (2 rows) × 22.9 m centered in the plot to avoid the effect of sprinkler overlap from adjacent lateral move spans and non-uniform application caused by the lateral move irrigation system structural elements. The FIT represents the conditions where the crop was irrigated one to three times a week with a cumulative depth equal to weekly cumulative estimated corn evapotranspiration (ET_c). Each treatment replication was separated by a 12 m wide strip of spring barley bounded by 3 m (4 rows) corn border rows where the lateral move irrigation system was stopped, and sprinkler nozzles changed to achieve randomized irrigation treatment amounts using different sized sprinkler nozzles (fig. 1). The experimental treatments remained in the same physical location each year of the study to investigate the cumulative effects of continuous deficit N and irrigation on corn yield and develop low yielding plots across all irrigation treatments to evaluate crop yield potential effect on ET_c.

Irrigation System

The six-span lateral move irrigation system used to irrigate the experimental plots was equipped with Nelson S3000 red plate sprinklers (Nelson Irrigation Corp., Walla Walla, Wash.) attached to Nelson 138 kPa pressure regulators mounted at a height of 1.8 m. The irrigation treatments were achieved by using sprinkler nozzles with flow rates in proportion to the desired relative irrigation treatment amounts. The FIT treatment used nozzles with a flow rate of 24.7 L min^{-1} (#29) and the 75% FIT, 50% FIT, and 25% FIT treatments used nozzles with flow rates of 28.2 (#25), 12.7 (#21), and 6.5 (#15) L min^{-1}, respectively. All treatments within a given replication were irrigated at the same time with different irrigation depths corresponding to sprinkler nozzle size for each treatment. Irrigation application depth to the FIT was nominally 20 to 25 mm, which corresponds to 5 to 6 mm applied to 25% FIT and there were about 22 irrigations occurring between emergence and harvest each year. This deficit irrigation protocol was specifically chosen to reflect how variable rate center pivot irrigation would be implemented in the region. Water application to low production (assumed lower ET_c) areas of the field would be reduced but irrigation frequency would remain the same to meet ET_c of high production areas of the field. Rain gauges designed for minimum evaporation loss (All-Weather Rain Gauge, Forestry Suppliers, Jackson, Miss.) on adjustable height stands were used in each plot to verify water application and rainfall amounts to each plot.

Cultural and Harvest Practices

In each study year, tillage consisted of four tillage passes: two passes with a tandem disk, roller harrow and bedding in the spring prior to planting. Corn was planted on 19 May 2017, 22 May 2018, and 23 May 2019 (Pioneer P9188R Roundup Ready corn 2; Raxial PPST 250 seed treatment; 91 CRM) with a row spacing of 0.76 m at a rate of 86,100 plants ha^{-1}. All plots were dammer-diked after planting to prevent surface water movement within and among plots. Full emergence was achieved on 27 May 2017, 1 June 2018, and 1 June 2019. Urea nitrogen fertilizer to high N plots was surface applied within 3 weeks of emergence and immediately irrigated with a uniform irrigation amount applied to all plots to incorporate the fertilizer. Herbicide and pesticide practices followed local practices for corn production. Glyphosate and Dicamba were applied each year as a one-time application to all plots at maximum labeled rates to control weeds.

Corn grain yield samples were hand collected 5 October 2017, 18 October 2018, and 15 October 2019 from two 6.1-m row segments in the center of each plot. Grain yields were adjusted to 15.5% moisture content for statistical analysis and reporting. Corn aboveground biomass was measured 15 September 2017, 13 September 2018, and 11 September 2019, using a plot harvest system for a concurrent forage yield study. These harvest dates corresponded to the late R4 (Dough) and early R5 (Dent) growth stages. The harvest system was composed of John Deere (Moline, Ill.) 6420 tractor with a Kemper (Stadtlohn, Germany) Champion 1200 Universal Forage Harvester mounted to the front of the tractor and a Corn Harvester Haldrup (Ilshofen, Germany) M-63 unit fixed to a 3-point hitch on the back of the tractor. Cut plant material was transferred via a flexible hose to the Corn Harvester Haldrup (Ilshofen, Germany) M-63 unit. The Corn Harvester Haldrup M-63 contained a load cell platform to collect and weigh the cut plant material and an auger port allowed collection of plant subsamples. From each plot an area of 34.8 m^2 (two rows by 22.9 m) was harvested and total wet and dry biomass determined.

Irrigation Scheduling and Soil Water Measurement

Irrigation scheduling for the FIT was based on a weekly soil water balance to ensure soil water content remained above 50% available and did not appreciably increase or decrease throughout the growing season. Estimated daily corn ET_c was based on the ASCE standardized reference evapotranspiration equation (Allen et al., 2005) and daily crop coefficients (Wright, 1982) obtained from an AgriMet (U.S. Bureau of Reclamation, https://www.usbr.gov/pn/agrimet/) weather station located within 4.5 km from the study site. Daily precipitation was also obtained from the AgriMet weather station. Irrigation was applied 1 to 3 times a week depending upon weekly soil water balance. Soil water content was measured in 0.3 m depth increments from 0.3 to 2.1 m in each plot using a neutron probe calibrated to the experimental site soil using the methods of Hignett and Evett (2002). Soil water content was measured at 100% emergence, immediately before harvest and at approximately 2-week intervals between emergence and harvest. The neutron access tubes were removed prior to harvest and reinstalled after planting the following year. Thus, soil water content was not monitored in the same exact plot location in each study year.

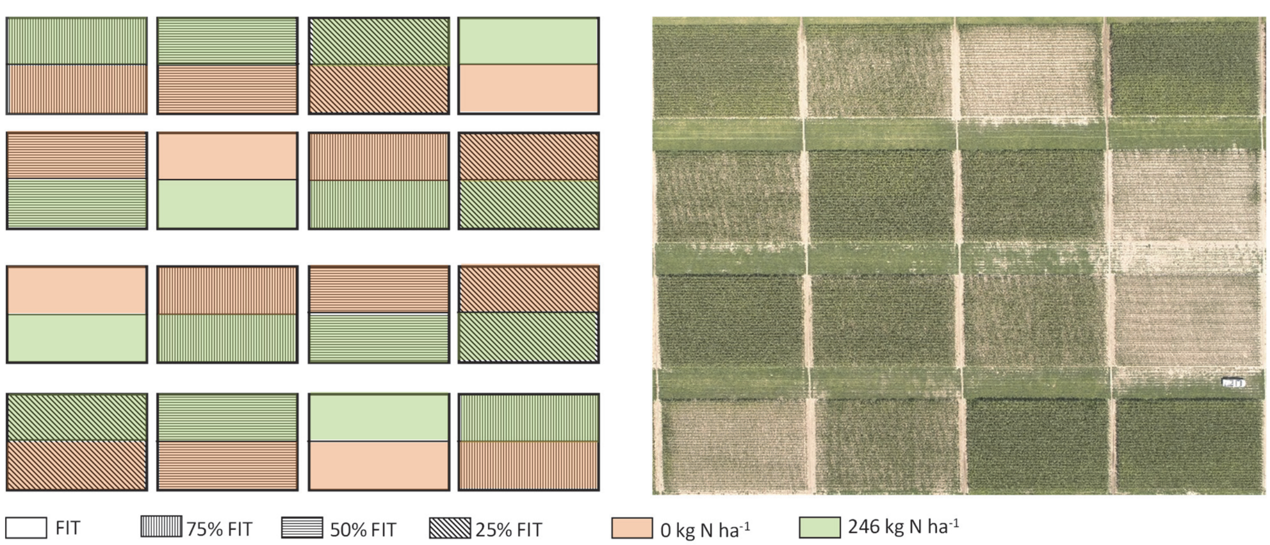

Figure 1. Experimental plot and treatment layout (left) and aerial view of field plots on 17 August 2018 (right).

SEASONAL EVAPOTRANSPIRATION

Seasonal corn ET_c (mm) was calculated using a soil water balance between emergence and harvest:

$$ET_c = \Delta S + P + I + U - DP - R \quad (1)$$

where

ΔS = the change in soil water storage in the soil profile between emergence and harvest (mm),

P = cumulative precipitation between emergence and harvest (mm),

I = cumulative irrigation applied between emergence and harvest (mm),

R = the difference between plot runoff and run-on (mm),

U = upward soil water flux (mm), and

DP = cumulative water percolating below the root depth between emergence and harvest (mm).

Deep percolation was assumed to be zero based on soil water content in the lower depths of the 2.1 m soil profile remaining less than field capacity and constant or decreasing from emergence to harvest. Runoff was assumed to be zero as all plots were dammer-diked to prevent surface water movement within and between plots and visually confirmed over the season. Upward soil water flux was assumed to be zero as the ground water table was more than 5 m below the surface.

STATISTICAL ANALYSIS

Data reduction and analysis were conducted in MS Excel spreadsheets. Statistical data analysis was conducted using PROC MIXED in SAS (SAS 9.4, SAS Institute Inc., Cary, N.C.) to test for treatment differences. Irrigation and N treatments were designated as fixed effects and replication and year as random effects. Least square means (LSMEANS) was used to differentiate significance of treatment and interaction effects. Treatment differences and interactions were considered significant at p = 0.05 unless otherwise noted. Residual diagnostics were conducted to evaluate the assumptions of ANOVA and determine the need for data transformations. Graphical presentations were generated using Sigmaplot 14 (Systat Software, San Jose, Calif.).

RESULTS

CLIMATIC CONDITIONS

May through September monthly average air temperature, solar radiation, relative humidity, wind speed, and average vapor pressure deficit (VPD) between hours of 7:00 to 19:00 MDT and monthly and growing season total rainfall and alfalfa reference evapotranspiration (ET_r) in each study year are given in table 1. Monthly and seasonal average solar radiation and wind speed were similar in all three study years. Monthly average air temperature and VPD were less in 2019 compared to 2017 and 2018. There was no rainfall after June in 2018 but rainfall was least in 2017. The combination of greater mean relative humidity, lesser mean air temperature, and lesser average vapor pressure deficit in 2019 resulted in about 100 mm less ET_r compared to 2017 and 2018.

SOIL WATER TRENDS

Soil water content profiles at emergence and prior to harvest are depicted in figures 2-4 for study years 2017, 2018, and 2019, respectively. Nominal field capacity and permanent wilting point for the Portneuf silt loam soil at the study site is 32% and 14% by volume as determined in the laboratory using a pressure plate apparatus (McDole et al., 1974). In this study, field capacity and permanent wilting point were taken as the maximum and minimum soil water contents measured by neutron probe over the 3-year study period, which generally occurred at the beginning and end of the season, respectfully (figs. 2-4). In this manner, field capacity and permanent wilting point were considered as 34% and 11%, respectively. The real behavior of crops often reveals that soil water can be extracted below the classical limit of -1.5 MPa (Cabelguenne and Debaeke, 1998). Based on observed field capacity and permanent wilting point,

Table 1. Monthly average and growing season average ($\bar{x}$) air temperature, solar radiation, relative humidity, wind speed, and vapor pressure deficit between hours of 7:00 to 19:00 MDT and monthly and growing season total (Σ) rainfall and alfalfa reference crop evapotranspiration (ET_r) in each study year.

Year	Month	Air Temperature (°C)	Solar Radiation (W m^{-2})	Relative Humidity (%)	Wind Speed (m s^{-1})	Vapor Pressure Deficit (kPa)	Rainfall (mm)	Alfalfa Reference ET_r (mm)
2017	May	15.8	522	46.5	3.3	1.1	29.2	187
	June	21.1	545	43.5	3.4	1.6	11.9	230
	July	26.9	538	37.6	2.3	2.5	3.0	254
	August	24.8	472	40.0	2.4	2.2	0.8	226
	September	18.1	370	48.2	2.6	1.4	14.7	158
	Season Summary	$\bar{x}$ = 21.4	$\bar{x}$ = 489	$\bar{x}$ = 43.1	$\bar{x}$ = 2.8	$\bar{x}$ = 1.8	Σ = 59.7	Σ = 1056
2018	May	17.0	481	57.7	2.9	1.0	51.6	172
	June	20.1	617	46.4	3.0	1.4	15.5	218
	July	26.4	625	33.1	2.6	2.6	0	276
	August	23.4	513	38.2	2.5	2.1	0	224
	September	19.2	452	33.8	2.7	1.7	0	195
	Season Summary	$\bar{x}$ = 21.2	$\bar{x}$ = 538	$\bar{x}$ = 42.1	$\bar{x}$ = 2.7	$\bar{x}$ = 1.7	Σ = 67.1	Σ = 1086
2019	May	14.4	452	58.7	3.1	0.8	59.7	151
	June	20.3	644	42.3	3.1	1.5	0	224
	July	24.3	550	45.3	2.6	1.9	2.0	228
	August	24.4	549	42.2	2.4	2.0	7.4	227
	September	18.0	412	54.1	2.7	1.2	20.3	155
	Season Summary	$\bar{x}$ = 20.3	$\bar{x}$ = 523	$\bar{x}$ = 48.5	$\bar{x}$ = 2.8	$\bar{x}$ = 1.5	Σ = 89.4	Σ = 985

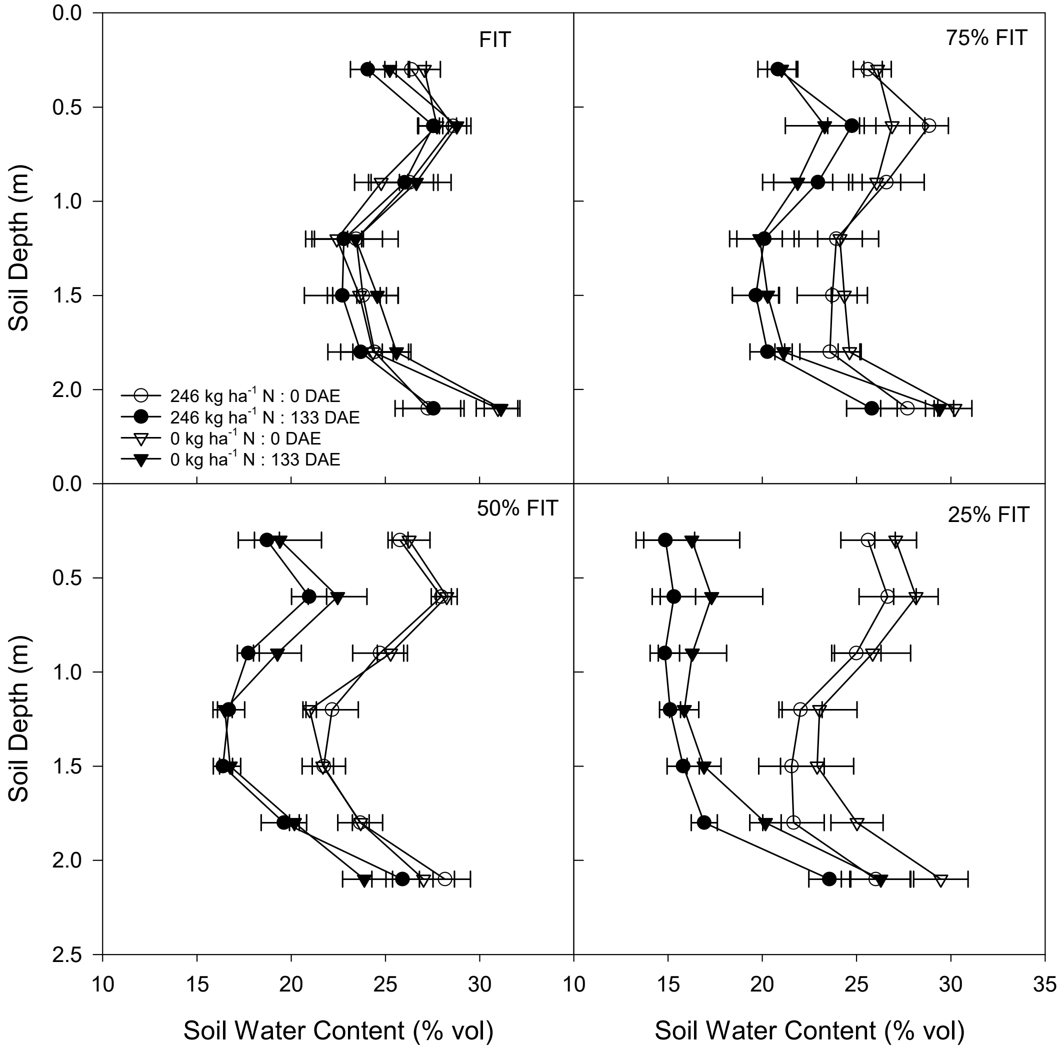

Figure 2. Soil water content profiles for two nitrogen application rates, 0 and 246 kg N ha^{-1}, and four irrigation rates, full irrigation (FIT), 75% FIT, 50% FIT, and 25% FIT, at emergence (0 DAE) and harvest (133 DAE) in study year 2017. Bars represent the standard error of the measurements.

maintaining 50% available soil water to avoid crop water stress corresponds to 22.5% soil water content. In all study years, the upper 1 m of the soil profile in FIT treatments remained greater than 22.5% soil water content at the end of the season (figs. 2-4) and throughout the season (data not shown), indicating that FIT treatment irrigation amounts adequately replaced seasonal ET_c and avoided plant water stress.

Soil water content profiles in the four irrigation treatments in 2017 (fig. 2) were very similar at emergence and soil water stored in the 2.1 m soil profile was not significantly different between irrigation or nitrogen treatments at emergence. The soil water profiles prior to harvest in 2017 differed substantially between the four irrigation treatments with seasonal soil water extraction greatest for the 25% FIT treatment. Stored soil water in the 2.1 m soil profile prior to harvest was highly significantly different ($p \leq 0.001$) between irrigation treatments but not significantly different between N treatments.

Soil water profiles at emergence in 2018 (fig. 3) were substantially different between irrigation treatments due to carryover effects from the irrigation treatments in 2017. Wright (1993) reported 1985 through 1991 nongrowing season evaporation at Kimberly, Idaho, averaged 180 mm. Nongrowing season precipitation October 2017 through May 2018 was 230 mm resulting in an average soil water recharge of 49 mm. Actual non-growing season soil water recharge is dependent on precipitation timing and amounts in relation to frozen soil conditions and snow cover duration. Stored soil water in the 2.1 m soil profile at emergence was significantly different between irrigation treatments but not significantly different between N treatments, paralleling differences present at 2017 harvest. The soil water profiles prior to 2018 harvest differed substantially between the four irrigation treatments, however, soil water profiles for the 50% FIT and 25% FIT were similar, likely due to soil water contents approaching permanent wilting point in much of the crop root zone, limiting development of soil water extraction differences between these irrigation treatments. Stored soil water in the 2.1 m soil profile prior to 2018 harvest was significantly different ($p \leq 0.001$) between irrigation treatments but not significantly different between N treatments.

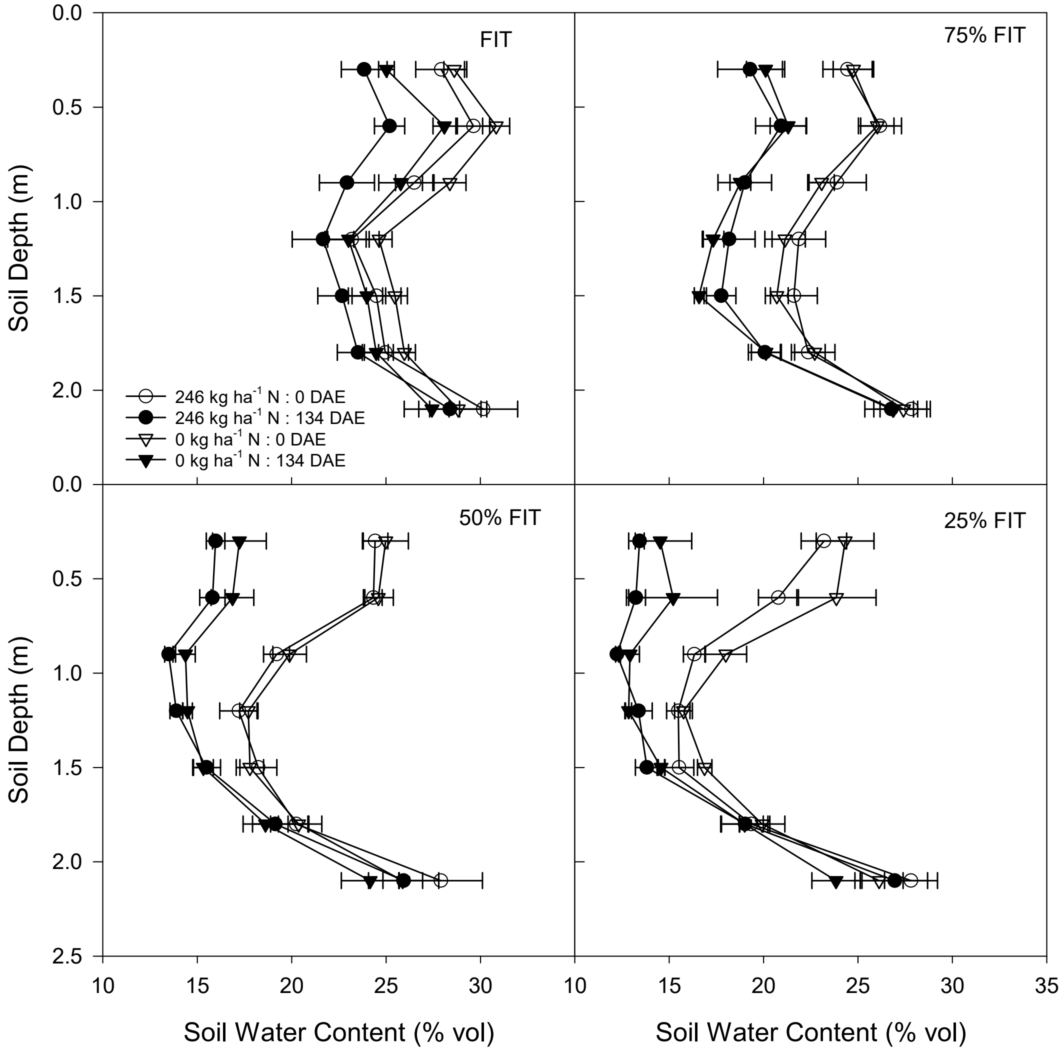

Figure 3. Soil water content profiles for two nitrogen application rates, 0 and 246 kg N ha^{-1}, and four irrigation rates, full irrigation (FIT), 75% FIT, 50% FIT, and 25% FIT, at emergence (0 DAE) and harvest (134 DAE) in study year 2018. Bars represent the standard error of the measurements.

The soil water profiles at emergence in 2019 (fig. 4) paralleled those prior to harvest in 2018 reflecting the cumulative effects of the irrigation treatments in 2017 and 2018. Non-growing season precipitation between 2018 and 2019 was 225 mm resulting in an average soil water recharge of 127 mm, which increased soil water contents for the 50% FIT and 25% FIT plots to a depth of 1 m. The soil water profiles prior to harvest in 2019 were substantially different between irrigation treatments. Soil water stored in the 2.1 m soil profile prior to harvest in 2019 was highly significantly different ($p \leq 0.001$) between irrigation treatments but not significantly different between N treatments. In each study year soil water contents prior to harvest for the FIT were numerically greater for the zero N treatment compared to the 246 kg N ha^{-1} treatment and the magnitude of the difference tended to increase with each study year. This may be due to minimal reduction in ET_c for the zero N treatment relative to the 246 kg N ha^{-1} treatment that accumulated over years. However, the magnitude of the difference in soil water contents between the N treatments was not sufficient to result in a significant difference over the three study years.

Analysis of variance results for soil water depletion between emergence and harvest are displayed in table 2. There was a highly significant ($p \leq 0.001$) interaction between irrigation treatment and study year. This significant interaction was due to differences in soil water depletion between irrigation treatments and study year. The interactions between N and irrigation treatments and N treatment and study year were not significant. The irrigation main effect was highly significant ($p \leq 0.001$) but the N main effect was not significant, consistent with the observed trends in soil water stored in the soil profile between emergence and harvest. Study year was not significant as the relative magnitude of soil water depletion between treatments was largely consistent across study years (fig. 5). In 2017 and 2019, soil water depletion was significantly less for the FIT treatment (fig. 5) compared to the other irrigation treatments and significantly less than the 50% FIT and 25% FIT treatments in 2018. In 2017, soil water depletion for the 25% FIT treatment was significantly larger than for other irrigation treatments. In 2018 and 2019, there was no significant difference in soil water depletion between the 50% FIT and 25% FIT

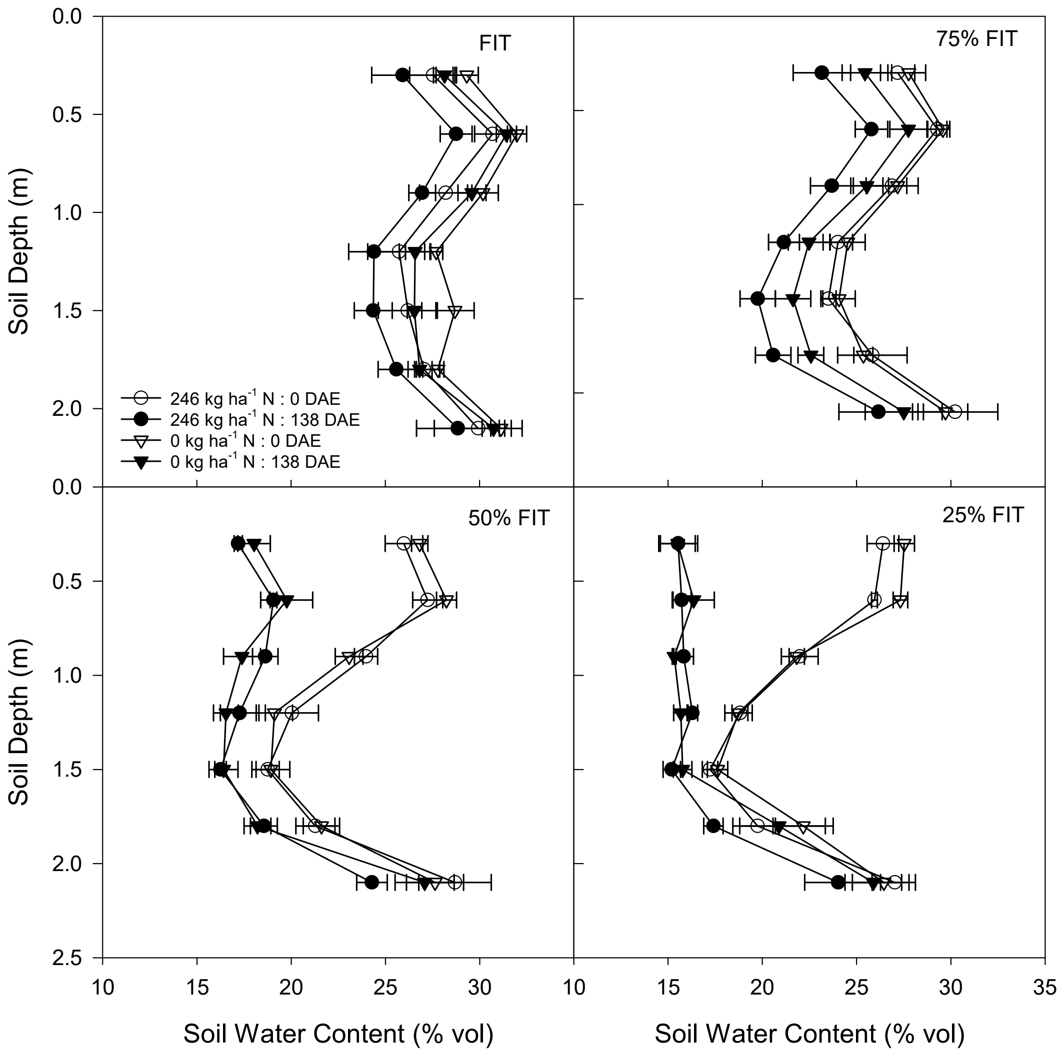

Figure 4. Soil water content profiles for two nitrogen application rates, 0 and 246 kg N ha^{-1}, and four irrigation rates, full irrigation (FIT), 75% FIT, 50% FIT, and 25% FIT, at emergence (0 DAE) and harvest (138 DAE) in study year 2019. Bars represent the standard error of the measurements.

treatments due to limited soil water recharge between study years.

The fraction of available soil water (FASW) in the 2.1 m soil profile on selected days after emergence (DAE) during each study year are displayed in table 3. Analysis of variance (not shown) found no significant effects of N treatment (N main effect, N × irrigation, N × DAE, N × irrigation × DAE) on FASW. Based on this result, FASW values shown in table 3 are averages for N treatments. In each study year, FASW in the FIT treatment was well above the threshold of 50% available soil water for well-watered corn. There was no significant difference in FASW between irrigation treatments in 2017 until 56 DAE signifying that soil water at the beginning of the 3-yr study area was relatively uniform. Beyond 56 DAE significant differences in FASW between the irrigation treatments developed over the season with the 50% FIT and 25% FIT treatments ending the season with the lowest FASW. There were significant differences in FASW between irrigation treatments at emergence in 2018 as nongrowing season precipitation minus nongrowing season evaporation was far less than available water storage for any irrigation treatment. Significant differences in FASW persisted throughout the 2018 season with FASW of the 50% FIT and 25% FIT being statistically equivalent throughout the season with about 25% available soil water in the 2.1 m soil profile at harvest. The 2019 trends in FASW were like those in 2018 as there were significant differences in FASW between the irrigation treatments at emergence that remained throughout the season and FASW of the 50% FIT and 25% FIT treatments were statistically equivalent

Table 2. Analysis of variance results for soil water depletion between emergence and harvest, evapotranspiration (ET_c), dry matter yield, and grain yield.

Source	Season Soil Water Depletion[a]	ET_c	Dry Matter Yield	Grain Yield
Nitrogen	0.088	0.088	<0.001***	0.047*
Irrigation	<0.001***	<0.001***	<0.001***	<0.001***
Nitrogen x Irrigation	0.396	0.396	<0.001***	<0.001***
Year	0.128	<0.001***	<0.001***	<0.001***
Nitrogen × Year	0.535	0.535	<0.01**	0.198
Irrigation × Year	<0.001***	<0.001***	<0.01**	0.002**
Nitrogen × Irrigation × Year	0.819	0.819	0.097	0.287

[a] *p<0.05, **p<0.01, ***p<0.001.

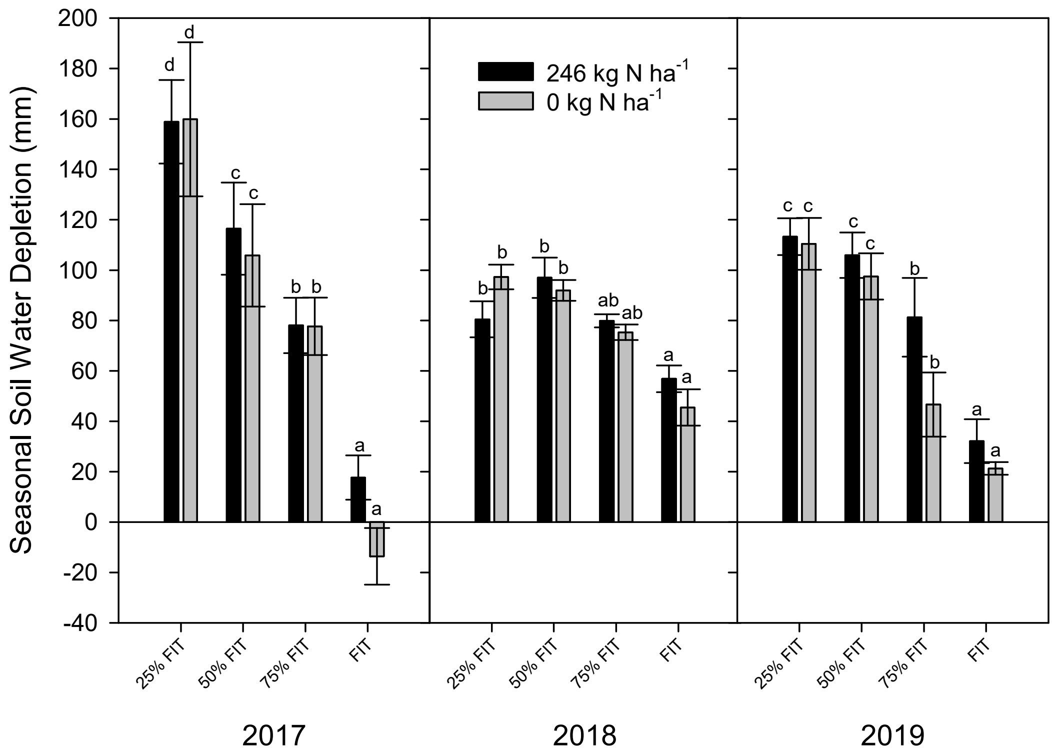

Figure 5. Mean growing season soil water depletion for each irrigation and nitrogen treatment in each study year. Bars with the same letter in a study year are not significantly different ($p \leq 0.05$). Bars represent the standard error of the measurements.

throughout the season. The main difference in FASW between 2018 and 2019 was that FASW was greater at emergence in 2019 from greater contribution of non-growing season precipitation to soil water storage in 2019.

Table 3. Effects of four irrigation treatments (FIT, 75% FIT, 50% FIT, and 25% FIT) on fraction of available soil water in the root zone on selected dates (indicated as days after emergence, DAE) during the 2017, 2018, and 2019 growing seasons.

		Fraction of Available Soil Water in the Root Zone			
	DAE	FIT	75% FIT	50% FIT	25% FIT
2017 season	0	0.64[a]	0.65[a]	0.60[a]	0.61[a]
	41	0.57[a]	0.55[a]	0.50[a]	0.48[a]
	56	0.63[a]	0.56[a]	0.50[ab]	0.44[b]
	66	0.61[a]	0.53[a]	0.46[ab]	0.38[b]
	81	0.67[a]	0.53[b]	0.43[bc]	0.34[c]
	90	0.67[a]	0.51[b]	0.41[bc]	0.31[c]
	112	0.65[a]	0.48[b]	0.38[bc]	0.27[c]
	139	0.66[a]	0.49[b]	0.37[c]	0.28[c]
2018 season	0	0.70[a]	0.56[b]	0.46[bc]	0.40[c]
	40	0.69[a]	0.56[b]	0.45[bc]	0.38[c]
	55	0.67[a]	0.52[b]	0.43[bc]	0.35[c]
	68	0.73[a]	0.53[b]	0.40[c]	0.30[c]
	82	0.75[a]	0.54[b]	0.39[c]	0.28[c]
	104	0.73[a]	0.51[b]	0.35[c]	0.29[c]
	141	0.60[a]	0.40[b]	0.27[c]	0.23[c]
2019 season	0	0.77[a]	0.69[a]	0.55[b]	0.51[b]
	39	0.71[a]	0.61[a]	0.50[ab]	0.46[b]
	49	0.77[a]	0.64[b]	0.50[bc]	0.44[c]
	60	0.75[a]	0.63[b]	0.46[c]	0.39[c]
	74	0.77[a]	0.61[b]	0.45[c]	0.35[c]
	84	0.76[a]	0.59[b]	0.38[c]	0.38[c]
	101	0.79[a]	0.59[b]	0.36[c]	0.30[c]
	140	0.71[a]	0.56[b]	0.34[c]	0.28[c]

[a] Treatment means on a given DAE and year (row) with the same letter are not significantly different ($p < 0.05$).

CORN EVAPOTRANSPIRATION

Rainfall, irrigation, and total water applied to each irrigation treatment in each study year are presented in table 4. The ANOVA results for ET_c between emergence and harvest computed using the soil water balance (eq. 1) are shown in table 2. There was a highly significant ($p \leq 0.001$) interaction between irrigation treatment and study year, however, the interaction between N treatment and study year was not significant. The irrigation main effect was highly significant ($p \leq 0.001$) but the N main effect was not significant, consistent with the observed trends in soil water stored in the soil profile at emergence and harvest. Study year was significant due to differences in ET_c across study years (fig. 6) so each year will be treated separately.

In all three study years, ET_c was significantly different between each irrigation treatment (fig. 6). In 2017 and 2018, ET_c for the FIT were similar but about 85 mm less in 2019. In 2018 and 2019, ET_c for the 25% FIT were numerically similar but

Table 4. Rainfall, irrigation, and total water applied to each irrigation treatment during each study year.

Year	Irrigation Treatment	Rainfall (mm)	Irrigation (mm)	Total (mm)
2017	FIT	39	526	565
	75% FIT	39	363	402
	50% FIT	39	243	282
	25% FIT	39	131	170
2018	FIT	47	455	503
	75% FIT	47	315	362
	50% FIT	47	209	256
	25% FIT	47	114	161
2019	FIT	27	427	454
	75% FIT	27	303	330
	50% FIT	27	207	234
	25% FIT	27	111	138

about 80 mm less than in 2017 due to less initial soil water contents at emergence limiting use of stored soil water for ET_c. In all three study years, ET_c for the two N treatments for a given irrigation treatment were numerically similar, which lead to no significant difference between N treatments.

Dry Matter Yield

The ANOVA results for dry matter yield are shown in table 2. Irrigation and N treatment main effects were highly significant ($p \leq 0.001$) and the interactions between irrigation and N, irrigation and study year, and N and study year were also significant. Study year was highly significant ($p \leq 0.001$) due to decreasing dry matter yield with study year and varying effect of zero N application on dry matter yield with study year. Since study year was significant, each year will be considered separately.

In 2017 there was no significant difference in dry matter yield between N treatments for any irrigation treatment (fig. 7). There was no significant difference in dry matter yield between the 50% FIT, 75% FIT, and FIT irrigation treatments for either N treatment. Dry matter yield for the 25% FIT treatment was significantly different from the other irrigation treatments for both N treatments.

In 2018 there were no significant differences in dry matter yield between N treatments for any irrigation treatment (fig. 7). There was no significant difference in dry matter production between the 75% FIT and FIT for the zero N treatment but there was for the 246 kg N ha^{-1} treatment. There were significant differences in dry matter yield between the 25% FIT, 50% FIT and 75% FIT irrigation treatments for both N treatments.

In 2019, there were no significant differences in dry matter yield between N treatments for 25% FIT and 50% FIT, but there were significant differences between N treatments for 75% FIT and FIT (fig. 7). There was no significant difference in dry matter yield between the 75% FIT and FIT for the 246 kg N ha^{-1} treatment or zero N treatment. In 2019, the lack of nitrogen only significantly reduced dry matter yield for the 75% and FIT irrigation treatments.

Corn Grain Yield

The ANOVA results for grain yield are shown in table 2. There were significant interactions between irrigation treatment and study year and between N treatment and study year. The irrigation treatment main effect was highly significant ($p \leq 0.001$) and the N main effect was also significant. Study year was highly significant ($p \leq 0.001$) due to decreasing yield over the 3-year study (fig. 8). Since study year was significant, each year will be considered separately.

In 2017 there were significant differences in grain yield between irrigation treatments but there was no significant grain yield difference between N treatments for a given irrigation treatment (fig. 8). There were no significant differences in grain yield between the 50% FIT, 75% FIT, and FIT for the 246 kg N ha^{-1} and no significant difference between the 75% and FIT for the zero N treatment despite significant differences in ET_c between the irrigation treatments (fig. 6). However, there was a trend for decreased grain yield with decreased ETc. Grain yield for the 25% FIT was significantly less than the other irrigation treatments.

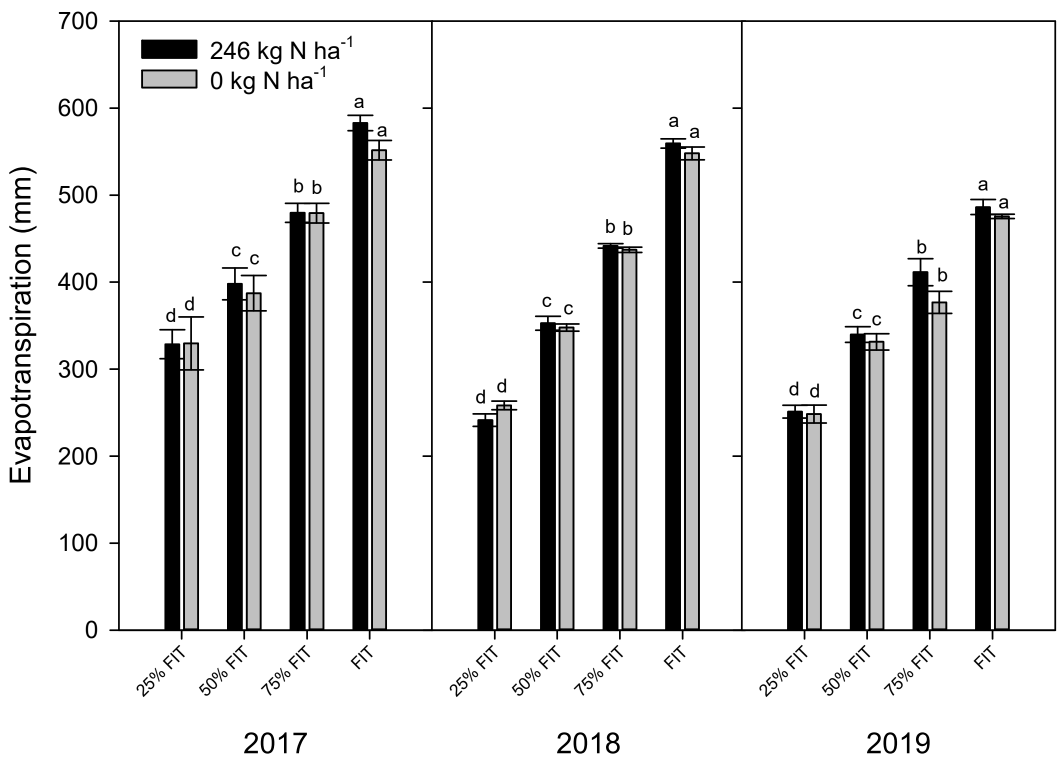

Figure 6. Mean evapotranspiration for each irrigation and nitrogen treatment in each study year. Bars with the same letter in a study year are not significantly different ($p \leq 0.05$). Bars represent the standard error of the measurements.

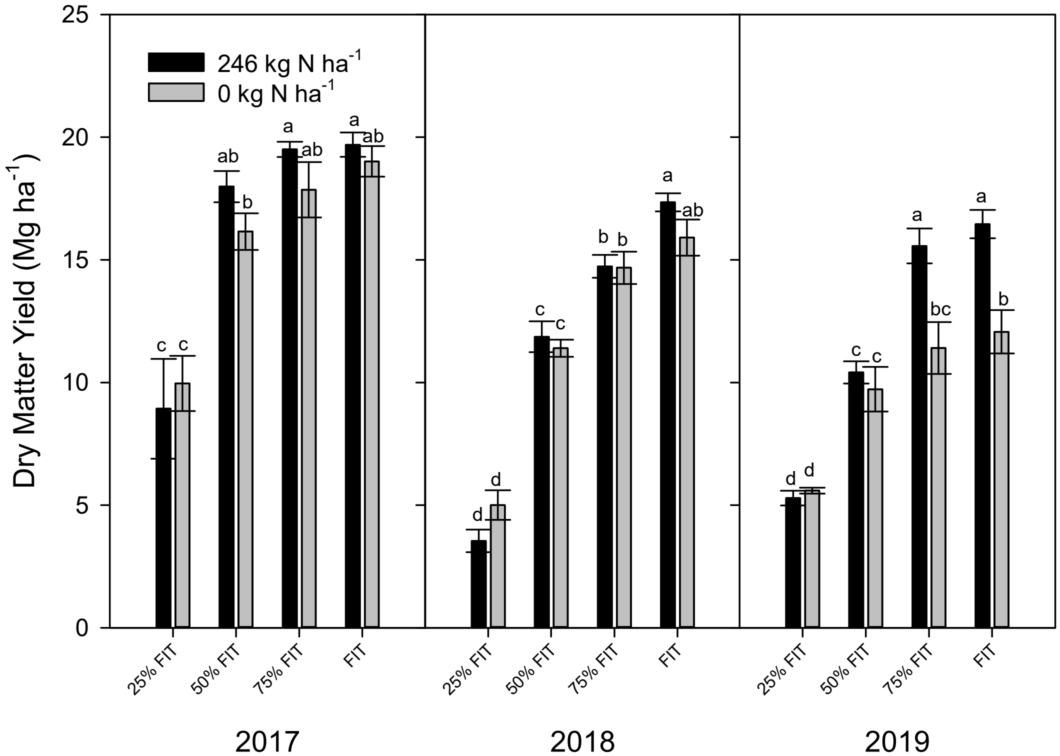

Figure 7. Mean dry matter yield for each irrigation and nitrogen treatment in each study year. Bars with the same letter in a study year are not significantly different (p ≤ 0.05). Bars represent the standard error of the measurements.

Grain yield for the 246 kg ha^{-1} N treatment was significantly greater than the zero N treatment for only the FIT treatment in 2018. Grain yields for the 75% FIT, 50% FIT, and 25% FIT irrigation treatments were significantly different for both N treatments. There were no significant

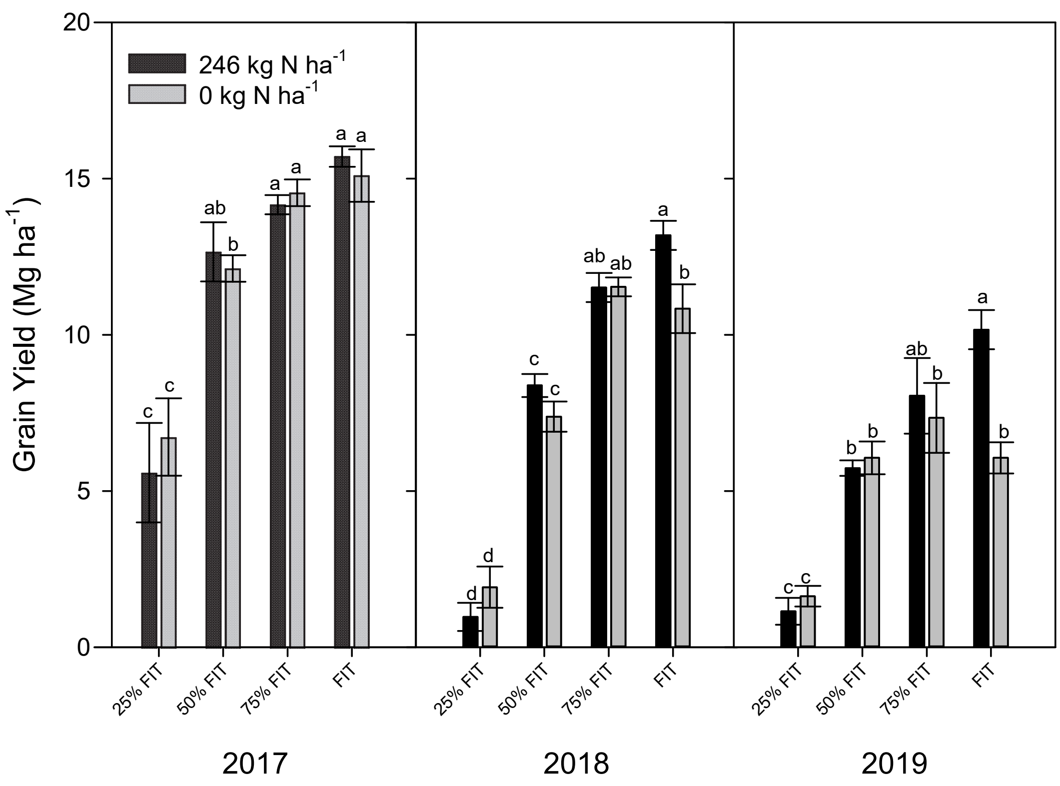

Figure 8. Mean grain yield for each irrigation and nitrogen treatment in each study year. Bars with the same letter in a study year are not significantly different (p ≤ 0.05). Bars represent the standard error of the measurements.

differences in grain yield between the 75% FIT and FIT irrigation treatments for either N treatment.

In 2019, there was a significant difference in grain yield between N treatments for only the FIT irrigation treatment, consistent with 2018 results. Grain yield for the 75% FIT, 50% FIT, and 25% FIT irrigation treatments were significantly different for both N treatments. There were no significant differences in grain yield between the 75% FIT and FIT irrigation treatments for either nitrogen treatment. The trends and differences in grain yield in 2019 were consistent with those of 2018, but yields were less.

Discussion

This study differs from most other water and N rate studies as plot treatment locations remained spatially fixed for 3 years to investigate the effect of continual deficit irrigation and N on soil water trends, dry matter yield, and grain yield. At the study site, non-growing season precipitation minus non-growing season evapotranspiration is about 50 mm on average (Wright, 1993), but varies yearly due to precipitation amount, timing relative to frozen soil conditions, and duration of snow cover. The FASW at emergence under the FIT increased during the 3-year study due to non-growing season precipitation partially replenishing soil water storage (table 3). For the 75% FIT, FASW at emergence decreased between 2017 and 2018 but increased between 2018 and 2019. This reversing trend between study years was due to seasonal soil water depletion of the 75% FIT being nearly equal to the amount of non-growing season soil water recharge and yearly variability. Since FASW of the 75% FIT remained above the allowed soil water deficit for non-water stressed corn throughout the study, a yearly seasonal 25% reduction in applied irrigation water appears to be sustainable, especially considering that there were no significant differences in grain yield between the FIT and 75% FIT treatments for either N treatment in any study year (fig. 8). However, there will likely be an increased risk of unintended yield reduction due to yearly variability in non-growing season climatic conditions and associated effect on non-growing season soil water recharge (Klocke et al., 2011). The FASW in 2018 and 2019 was not significantly different between the 50% FIT and 25% FIT irrigation treatments over the growing season due to similar available soil water at planting. The FASW of the 25% FIT and 50% FIT treatments were below the allowable soil water deficit for non-water stressed corn throughout much of the growing season in 2018 and 2019 resulting in significantly less grain yield than either the 75% or FIT irrigation treatments (fig. 8). Seasonal soil water depletion of the 25% FIT and 50% FIT treatments was substantially less in 2018 and 2019 (fig. 5) due to limited non-growing season soil water recharge. Long-term seasonal irrigation application less than 75% FIT in the study region will likely result in decreased soil water availability after the first year of deficit irrigation leading to reduced grain yield. The results of this study are consistent with those of Benjamin et al. (2015) where soil water storage at the beginning of the season was significantly less under continuous deficit irrigation of corn compared to full irrigation due to limited non-growing season precipitation. They concluded one year of deficit irrigation was viable but long-term use of deficit irrigation was detrimental to corn grain yield. Similarly, Klocke et al. (2011) found that under long-term deficit irrigation, the soil water content at the end of the previous season influenced the next year's starting soil water content due to limited non-growing season precipitation and corn grain yield was more influenced by non-growing season precipitation than growing season precipitation.

The N treatments had no significant effect on seasonal soil water depletion (fig. 5), which resulted in nitrogen treatments having no significant effect on soil water balance based ET_c (fig. 6). Conventional thinking assumes that reduced crop growth results in reduced ET_c as there is less leaf area for transpiration (Lo et al., 2020). Results from other studies have been mixed as to the effect of fertility on ET_c. Pandey et al. (2000a), Ogola et al. (2002), Lenka et al. (2009), Rudnick et al. (2017), and Lo et al. (2020) reported a significant decrease in corn ET_c as nitrogen availability decreased. Conversely, Carlson et al. (1959), Allen (1990), and Fernández et al. (1996) reported no effect of nutrient availability on ET_c. Irrigation method, frequency, seasonal amounts, and climate varied between the studies, likely influencing the effect of fertility on ET_c. Only the studies of Rudnick et al. (2017) and Lo et al. (2020) used sprinkler irrigation, but their study sites had substantial growing season precipitation and less evaporative demand requiring only four irrigations in the study of Rudnick et al. (2017) and ten on average in the study of Lo et al. (2020). The study reported here had high evaporative demand and growing season precipitation $\leq$ 10% of irrigation applied (table 3). Rudnick et al. (2017) found a significant difference in corn ET_c due to N availability only occurred during the corn reproductive growth stage and not the vegetative stage. They attributed the lack of ET_c response during the vegetative growth state to soil water evaporation, which can dominate ET_c when canopy cover is sparse. Allen (1990) reported that soil water evaporation encompassed 77% of ET_c for rainfed sparse barley. The canopy of the 25% FIT and 50% FIT treatments were quite sparse when viewed from above (fig. 1) suggesting that soil water evaporation was likely a major component of ET_c in these treatments. More than 20 irrigation applications were applied to each irrigation treatment over the growing season in this study, with up to 3 irrigations per week during the peak water use period. This frequent wetting of the crop canopy and soil surface provided maximum opportunity for evaporation from both, which is largely independent of crop N availability. It is possible that soil water evaporation was largely limited by energy availability rather than soil hydraulic conductivity as readily evaporable water is in the range of 8 to 10 mm (Allen et al., 1998) for the silt loam soil. The reduction in application depth between irrigation treatments rather than reduced irrigation frequency used in this study mimics VRI where application depths are reduced to areas of a field having less irrigation need. Trout and DeJonge (2017) reported ground cover for corn decreasing from 90% to 65% as dry matter yield decreased from 22 to 10 Mg ha^{-1}. Dry matter yields of the 25% FIT and 50% FIT treatments of this study (fig. 7) were equal or below the minimum reported by Trout and

DeJonge (2017) suggesting that ground cover was less than 65% in these treatments, consistent with figure 1 aerial view. The results of this study suggest that ET_c is independent of crop yield potential under high frequency irrigation in a high evaporative demand environment and the same everywhere in a field when soil water availability is similar.

In two of three years, dry matter yield was not significantly different between the 75% FIT and FIT irrigation treatments (fig. 7) for either N treatment. Trout and DeJonge (2017) also reported no significant difference in dry matter yield between 75% FIT and FIT in four of five years. This lack of statistical significance results in a concave downward curvilinear dry matter water production function. In contrast, Nilahyane et al. (2018) reported a significant difference in dry matter yield between 80% FIT and FIT resulting in a linear dry matter water production function over a limited water deficit range, 60% FIT to FIT. In this study, there was no significant difference in dry matter yield between N treatments except for the 75% FIT and FIT treatments in 2019. Pandey et al. (2000b) reported dry matter yield differences due to N availability decreased with increasing irrigation deficit, consistent with the results of this study. In this study, plot treatment locations were spatially static over the study duration and minimal (if any) nitrogen leaching occurred as soil water contents were below field capacity throughout the study period due to limited non-growing season precipitation, proper irrigation management, and end of season soil water deficits even in the FIT treatment. The lack of N leaching combined with N mineralization and N deposition (Fenn et al., 2003) could have reduced the effect of the nitrogen treatments on dry matter yield until the third year of the study. Prior N research studies at the general location of this study and on similar soil types have shown that there are high N mineralization rates that can often lead to crops not responding to N inputs (Stanford and Smith, 1972; Carter et al., 1976; Tarkalson et al., 2016). For example, in N rate studies in sugar beet in southern Idaho, 8 of 14 research sites showed no sucrose yield response to N inputs (Tarkalson et al., 2016). An unpublished data set from research conducted from 2010 to 2017 in southern Idaho assessing corn grain yield response to N supplies showed that only 7 out of 15 sites had significant corn grain yield responses to added N (Tarkalson, personal communication).

Consistent with dry matter yield, grain yield was not significantly different between the 75% FIT and FIT irrigation treatments (fig. 8) for either N treatment in any study year. Trout and DeJonge (2017) also reported no significant difference in grain yield between 75% FIT and FIT in 4 of 5 years. The grain yield WPF in this study was concave downward, consistent with the results reported by Trout and DeJonge (2017). There were no significant differences in grain yield between the N treatments for the 25% FIT, 50% FIT, and 75% FIT irrigation treatments in any study year. The zero N treatment significantly reduced grain yield for only the FIT in study years 2018 and 2019. Grain yield differences between irrigation and nitrogen treatments generally followed the same trend as dry matter yield. Grain yields of the 246 kg N ha^{-1} and FIT combination in 2017 and 2018 are consistent with yields reported in irrigation studies in the Great Plains of the U.S. (Trout and DeJonge, 2017). Yields in this study significantly decreased with study year. Fernández et al. (1996) also reported a similar decrease in corn yield in their 3-year study. This outcome is attributed to the continuous corn rotation used in this study, which is commonly referred to as the continuous corn yield penalty (CCYP) (Gentry et al., 2013; Seifert et al., 2017). The cause of the CCYP is not fully understood but is likely due to increased disease and pest pressure, allelopathy between corn residue, and crop and a decrease in nitrogen availability (Seifert et al., 2017). Under rainfed conditions the CCYP has been reported in the range of 9% to 25% (Seifert et al., 2017). The yield difference for the 246 kg N ha^{-1} and FIT combination between 2017 and 2019 in this study was 32%, greater than that expected for rainfed conditions but plausible for a single experimental study not designed to evaluate the CCYP.

Assuming the range in corn yields measured in this study due to nitrogen deficiency are representative of corn productivity differences caused by factors other than excess or deficit soil water across a center pivot irrigated landscape, the results of this study indicates that a reduction of water application to low productivity areas will further reduce yield. This inference is based on the decrease in corn yield when irrigation amount was decreased regardless of nitrogen availability and the lack of significant difference in ET_c between nitrogen treatments in this study. The results of this study do not support the precision irrigation hypothesis that reduced yield potential equates to reduced ET_c. Thus, VRI does not provide the opportunity to reduce water use and pumping costs by reducing water application to low production field areas. Reducing application rates in low production areas will further reduce crop yield. The results of this study conducted under high evaporative demand and high frequency sprinkler irrigation may not apply to other climatic conditions, irrigation systems, irrigation frequencies, and crops.

Summary and Conclusions

The effects of two N application rates (0 and 246 kg N ha^{-1}) and four irrigation rates, fully irrigated (FIT) and three deficit irrigation rates of 75% FIT, 50% FIT, and 25% FIT, on soil water trends, ET_c, and dry matter and grain yield of corn were evaluated in a 3-year field study at the Northwest Irrigation and Soils Research Laboratory near Kimberly, Idaho, in 2017, 2018, and 2019. The experimental plots remained spatially fixed for the 3-year study to quantify the cumulative effects of water and N deficits.

Depletion of soil water during the 2017 growing season in the 25% FIT and 50% FIT irrigation treatments significantly reduced available soil water at planting in following years due to limited non-growing season precipitation. Less available soil water at planting in 2018 and 2019 reduced the amount of soil water available for crop growth in the 25% FIT and 50% FIT treatments and reduced dry matter and grain yields relative to 2017. Corn ET_c was significantly different between irrigation treatments in each study year and decreased as irrigation water applied decreased. The N treatments had no significant effect on seasonal soil water depletion or ET_c for any irrigation treatment in any year of the study. The effect of the zero N treatment on grain yield of the FIT treatment increased each year of the study, culminating in a 40% decrease in 2019, with an associated decrease of only 2.4% in ET_c. The absence of reduced ET_c with a 40% decrease in grain yield suggests that under high evaporative demand and high frequency sprinkler irrigation, crop ET_c is independent of crop yield potential when soil water contents are similar.

Dry matter yield was significantly different between irrigation treatments in each study year, however there was no significant difference in dry matter yield between the 75% FIT and FIT treatments for a given N treatment in any study year. Differences in dry matter yield between N treatments decreased as the amount of irrigation applied decreased.

Grain yield was significantly reduced by deficit irrigation in each study year, however there was no significant difference in grain yield between the 75% FIT and FIT irrigation treatments for a given N treatment in any study year. Grain yield was significantly different between N treatments for only the FIT irrigation treatment in 2018 and 2019. The lack of a significant difference in grain yield between the 75% FIT and FIT irrigation treatments in any study year results in a curvilinear convex downward water production function regardless of N treatment. The 25% FIT and 50% FIT treatments resulted in a similar reduction in grain yield regardless of N treatment i.e. crop yield potential. This result indicates that reduction of water application to less productive areas of a field will result in a yield reduction.

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