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NITRATE LEACHING UNDER VARYING IRRIGATION TREATMENTS IN CORN PRODUCTION

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ABSTRACT

Ineffective irrigation management can either limit the optimum crop N uptake (under-irrigation) or cause nutrient leaching below the crop root zone (over-irrigation), making nutrients largely unavailable for plant uptake and, in turn, reduce crop productivity and cause environmental contamination. A study was initiated in 2018 to evaluate response of corn yield, water use efficiency, and nitrate leaching to irrigation and nitrogen rates at western Nebraska. Results have indicated that under-irrigation treatments resulted significantly higher water use efficiency. However, higher nitrate-N concentration was also observed in under-irrigation treatments, primarily due to heavy rainfall received during the growing season.

INTRODUCTION

Corn is widely grown in Nebraska with 2.14 million hectares of irrigated harvested cropland (USDA-NASS 2012). In panhandle Nebraska, over 182,111 hectares were planted to corn in 2012, which accounts for 50 percent of irrigated acreage in the area. The Panhandle District is different from any other in the state, primarily due to its high elevation, limited water supply, low precipitation, and unique cropping systems. Water resource is key to the region's agricultural productivity. However, irrigators in the district are subjected to water allocations posed by Natural Resource District (NRD), and must rely on water supplies that are less than optimum. Therefore, it is essential for them to develop a strategy for timely irrigations while maximizing water use efficiency during the growing season. Other than water quantity issues, western Nebraska irrigators also face water quality issues. Numerous studies have documented the presence of nitrate in ground water in western Nebraska along with increasing use of commercial fertilizer. It was reported by Böhlke et al. (2007) that in ground water along the North Platte River in western Nebraska, NO_3^- concentrations exceed acceptable contaminant levels (10 mg/L) set by the Environment Protection Agency (EPA). Furthermore, the North Platte NRD (NPNRD) has approved forming of a nitrogen management advisory group recently for the purpose of reviewing and possibly change regulations in its district, which could contain nitrogen management controls. Therefore, it is essential for farmers to optimum water and nitrogen use to produce profitable yields while conserving environmental resources. Extensive studies have been done in the past in central and eastern Nebraska on economic return of corn (Rudnick et al. 2016) and ways to minimize nitrate leaching (Ferguson et al. 2013) subject to different water and N regimes, yield and fertilizer use efficiency for corn (Russelle et al. 1981, Wortmann et al. 2011), as well as nitrate leaching under different irrigation systems (Spalding et al. 2001) and crop rotation systems (Klocke et al. 1999). Wells et al. (2018) evaluated variables related to groundwater recharge, nitrate concentrations, and irrigation methods in western Nebraska. However, to author's best knowledge, there has been no study to quantify response of crop production and nitrate leaching to combination of irrigation and nitrogen management. Therefore, the goals of this study are to: 1) quantify corn yield and water production functions to various irrigation and nitrogen levels; 2) quantify nitrate leaching, especially concentration under various irrigation and nitrogen levels. This is a three-year study and the first year (2018) results are presented here.

MATERIAL AND METHODS

Field experiment was conducted at the Panhandle Research and Extension Center (PHREC) of University Nebraska-Lincoln in Scottsbluff, Nebraska (41.89° N, 103.68° W, elevation: 3899 ft). The soil at PREC is a Tripp very fine sandy loam (Coarse-silty, mixed, superactive, mesic Aridc Haplustolls) at pH=8.2 with an organic matter content of 1.5%. Field capacity ranges from 0.23 to 0.28 m^3 m^{-3}, while permanent wilting point is 0.11 m^3 m^{-3}. Slope at Scottsbluff site ranges from 0.5% to 1% (Hergert et al., 2016). Climate at the experimental site is classified as semi-arid with annual precipitation of 15.4 inches, average temperature of 65.3 °F, and average relative humidity of 55.7% (Irmak and Sharma, 2015). An automated weather station from the High Plains Reginal Climate Center (HPRCC) Automated Weather Data Network (AWDN) located at the research center record daily minimum and maximum air temperature, relative humidity, precipitation, solar radiation, and wind speed at a 2 m height.

The experimental design is split-plot randomized complete block with three replications. The main plot factor is irrigation at 0%, 33%, 66%, 100%, and 133% of fully-irrigated treatment (100%). The fully-irrigated treatment represents the conditions in which the crop was irrigated to meet its full evapotranspiration (ET) demand, to avoid any potential water stress impact on crop yield. Irrigation was applied using a variable rate linear sprinkler irrigation system (Lindsay Corporation, Omaha, NE). The sub-plot factor is N treatment that includes N1- N5 (0, 50, 75, 100, and 125 % of recommended N rate 185 lbs N/ac based on spring soil test) applied around emergence. There was additional N treatment plots; N6 (30% of recommended N rate at emergence, and 70% at V6-V8), N7 (all N at V6-V8), N8 (30% of recommended N rate at emergence, and supplemental N based on crop sensing at V6-V8), and N9 (50% of recommended N rate at emergence, and supplemental N based on crop sensing at V10-12). A summary of treatments is presented in Table 1. Corn variety Pioneer P0157 was planted on May 11th and harvested on October 31st. The experimental plots were previously planted with dry edible beans in 2017 growing season.

Table 1. Summary of nitrogen treatments and irrigation treatments

Treatments	Irrigation	Treatments	Nitrogen
	(main plot)		*(split plot)*
1	0%	1	0%, control
2	50%	2	50% of recommended N
3	100%	3	75% of recommended N
4	133%	4	100% of recommended N
-		5	125% of recommended N
-		6	30% of N rate at emergence, rest at V6-V8
-		7	all N at V6-V8
-		8	30% of N rate at emergence, supplemental N based on crop sensing at V6-V8
-		9	50% of N rate at emergence, supplemental N based on crop sensing at V10-V12

After planting, suction cup lysimeters (Irrometer Soil Solution Access Tubes, Irrometer, Riverside, CA) were installed at 5 ft depth in crop rows of N4 treatment plots at all irrigation levels. Lysimeters were left under vacuum in the field and water samples in lysimeters, if present, were collected periodically. Attempts for water sample collection was made once a week and after irrigation and rain events as water collection depends on its availability in lysimeter. Then water samples were sent to lab for nitrate-N concentration analysis. A handheld crop sensor RapidSCAN CS-45 (Holland Scientific, Lincoln, NE) was also used to collect crop reflectance at various growth stages during the season. Soil samples at depths 0-8, 8-24, and 24-48 inches were collected after harvest to determine residual nitrate-N in all treatment plots. Yield and water use efficiency (WUE) were evaluated for different irrigation and nitrogen management scenarios. Water use efficiency was calculated as:

$$\mathrm{WUE} = \frac{Yield}{Irrigation + Precipitation}$$

Access tubes were installed in the center of each plot for nitrogen treatments N1 (0% N) and N4 (100% N) at all irrigation treatments. Soil water profile was monitored down to 4 ft depth at 1 ft interval using a Campbell Pacific Nuclear 503 DR neutron probe (InstroTek, Inc., Raleigh, NC).

RESULTS AND DISCUSSION

Weather, Irrigation, and soil water profile

From planting to harvesting, a total rain of 12.6 inches was received, which is higher than the region's average. As shown in Figure 1, several intense rainfalls also occurred during the growing season on May 19th (3.21 inches), May 27th (1.83 inches), and July 16th (1.73 inches). Reference ET (ET_o) ranged from 0.013 to 0.4 inches per day with average of 0.2 inches per day. Wind was stronger at beginning of the season and gradually weakened towards end of the season. Hottest temperature was observed in end of June with 103.7 °F. There were 10 irrigation events during the growing season. Irrigation applied for 0%, 50%, 100%, and 133% treatments were 0.3 inches, 5.5 inches, 10.7 inches, and 14.1 inches, respectively.

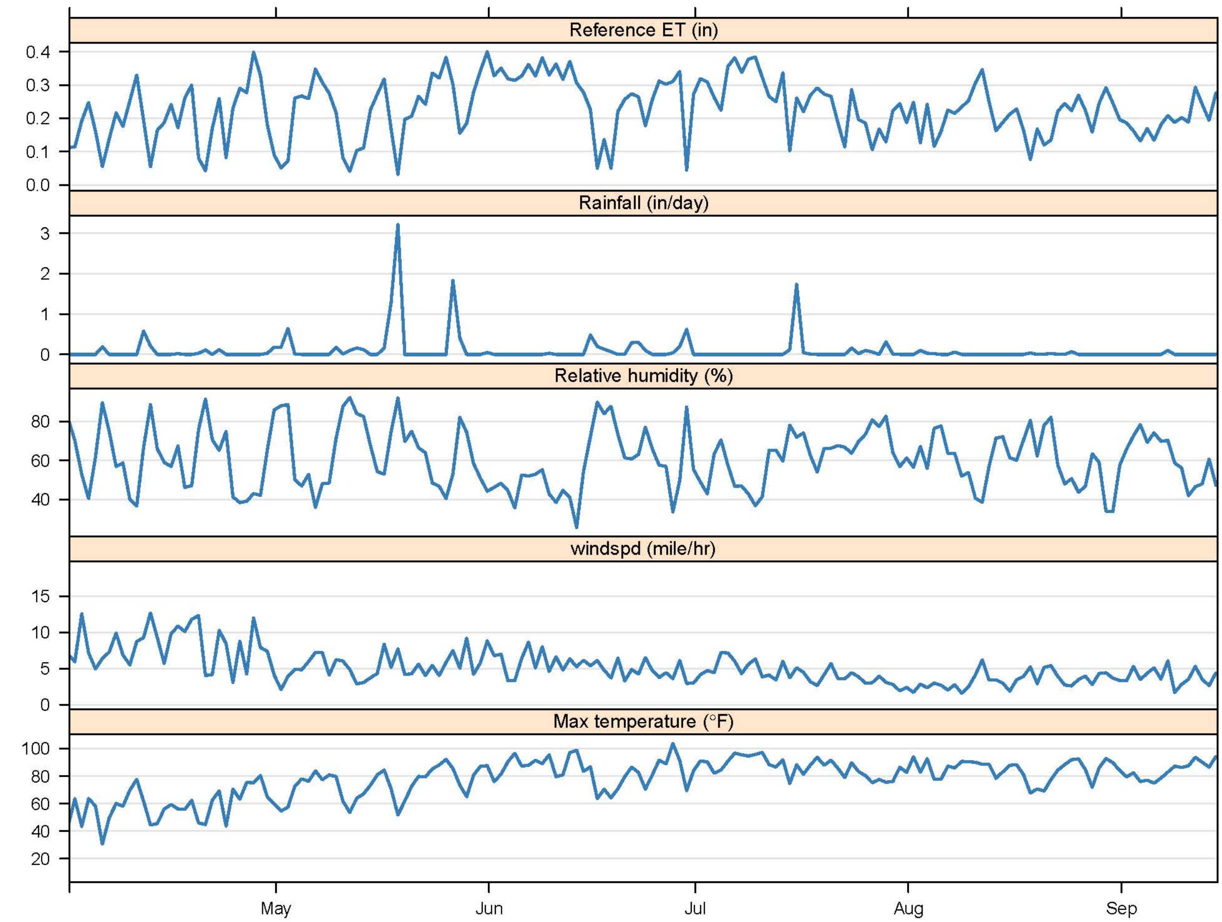

Figure 1. Weather data during 2018 growing season at Scottsbluff, NE.

Soil moisture content were measured by neutron probe at 0% N and 100% N levels of all irrigation treatments (Figure 2). Due to breakdown of the neutron probe, measurements were only available on three dates. Soil water profile patterns were similar for 0% and 100% N treatments at all depths. At 1 ft depth, soil water content did increase with amount of irrigation.

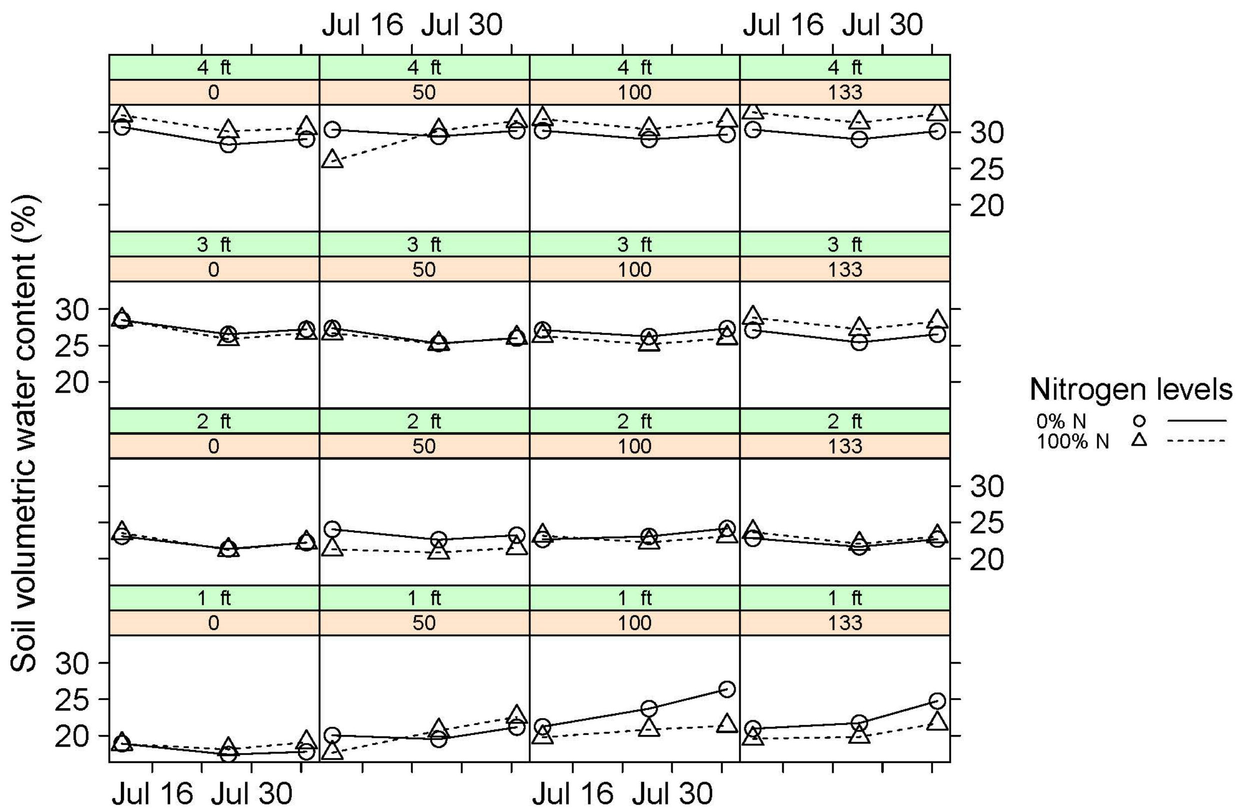

Figure 2. Soil water content measured at 0% N and 100% N treatments of all irrigation levels. Panels from bottom to top are soil water content measured at 1, 2, 3, 4 ft depths. Panels from left to right are soil water content measured at 0%, 50%, 100%, and 133% irrigation treatments.

Yield and WUE response to irrigation and nitrogen

Average corn yield was 169 bu/acre across all plots. At southern end of the experimental plots, heavy rainfall flooded the plots and therefore lowered the overall average plot yield. In the meantime, one strip of 100% irrigation treatment plots were located in the flooded zone and therefore yield of 100% irrigation plots were lower than the rest three (Figure 3). Although visual water stress difference was observed in field among treatments, irrigation treatments had no significant on corn yield ($P = 0.12$). Corn yield was significantly affected by nitrogen treatments ($P = 0.0159$), in which pairwise comparisons show corn yield of N2-8 were significantly higher than N1 (0% N, control). Unlike findings in Rudnick et al (2016), in which significant interaction effect of irrigation and nitrogen was observed on corn yield. There was no significant interaction effect of irrigation and nitrogen on corn yield based on data collected in 2018 ($P = 0.7987$).

Water use efficiency (WUE) of corn in 2018 ranged from 3.47 to 14.4 bu/(ac*in), and was significantly affected by irrigation ($P < 0.001$) and nitrogen treatments ($P <0.001$). All treatments showed significantly different WUE except for 100% and 133% irrigation treatments (Figure 4). For instance, WUE of 0% was the highest and WUE of 50% was significantly higher than 100% or 133% treatments (Figure 4). Water use efficiency of N2-9 were significantly higher than N1. In another word, compared to no nitrogen fertilizer applied (N1), any rate of nitrogen fertilizer (N2-9) increased water use efficiency significantly. No interaction effect of irrigation and nitrogen management on WUE was observed.

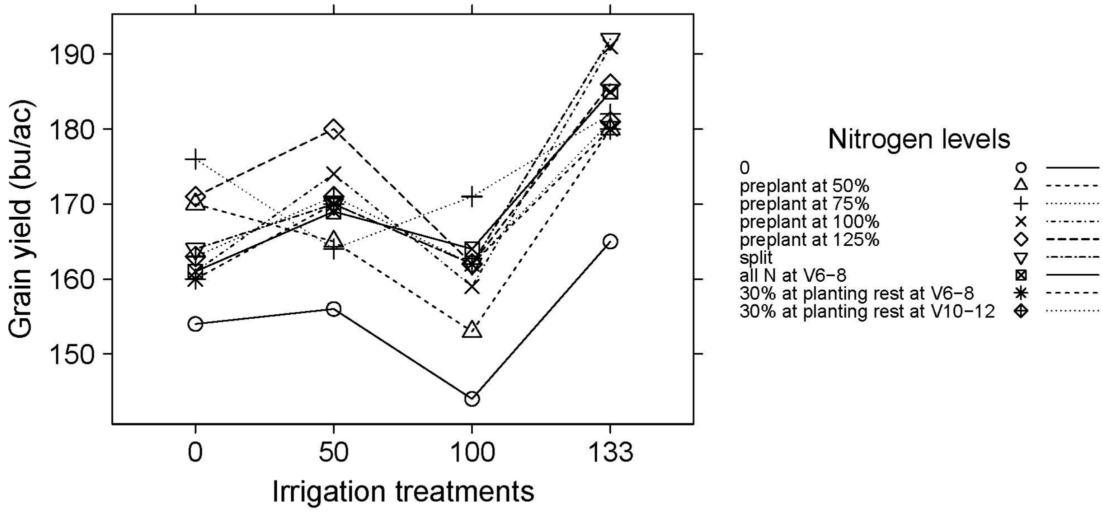

Figure 3. Average corn yield response to irrigation and nitrogen treatments.

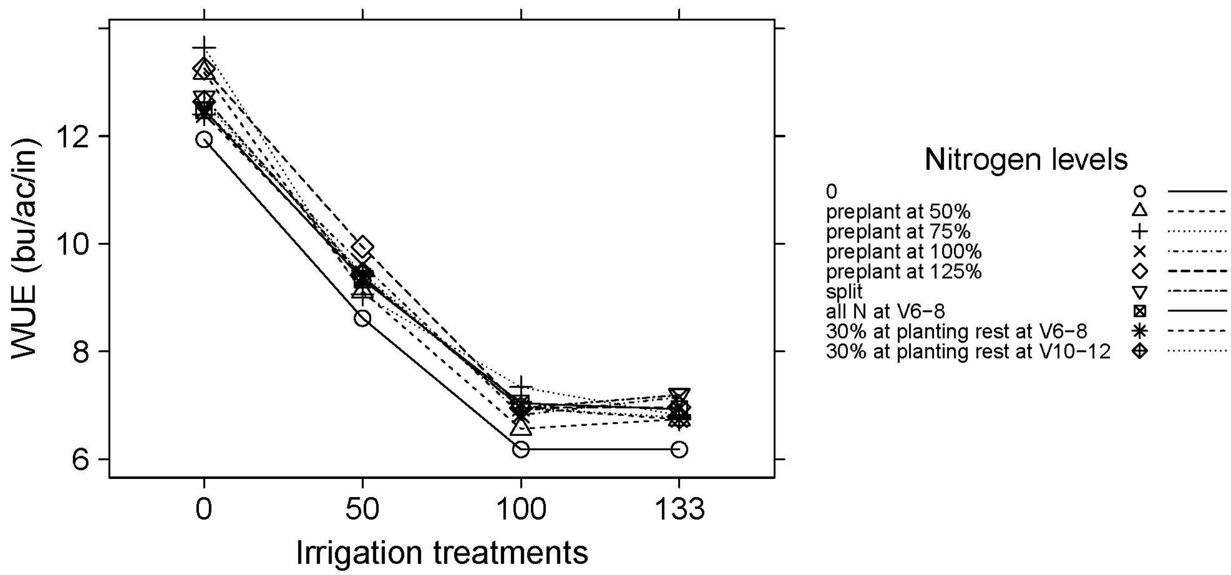

Figure 4. Corn WUE response to irrigation and nitrogen treatments.

Nitrate leaching and residue nitrate-N in soil

Similar to findings by Klocke et al (1999), during 2018 growing season, all irrigation treatments have resulted much higher nitrate-N concentration than the EPA safe line (10 ppm) at different parts of the field (Figure 5). This is attributed to the high intensity rainfall received at the experiment fields in the early growing season. It is also noted that the concentrations of nitrate leachate were decreasing along with the growing season, possibly due to crop uptake of N or the fertilizer was driven into even deeper soil than the measurement depth. In addition, 0% and 50% irrigation treatments generally showed very high nitrate-N concentrations (Figure 5), which corresponds to the high residue nitrate-N in the soil at 4 ft depth of N4 at same irrigation treatments (Figure 6).

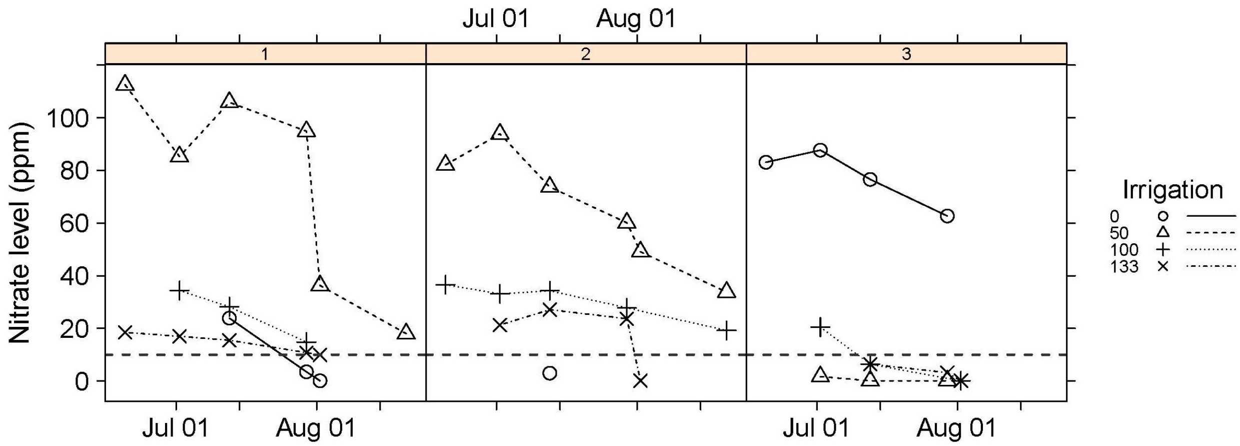

Figure 5. Nitrate-N concentration in the leachate collected from the four irrigation treatments on different dates. The dashed line shows EPA safe nitrate-N levels at 10 ppm. The three panels are experiment blocks from north (1) to south (3), in which north block is the highest and the south block is the lowest and flooded during the season.

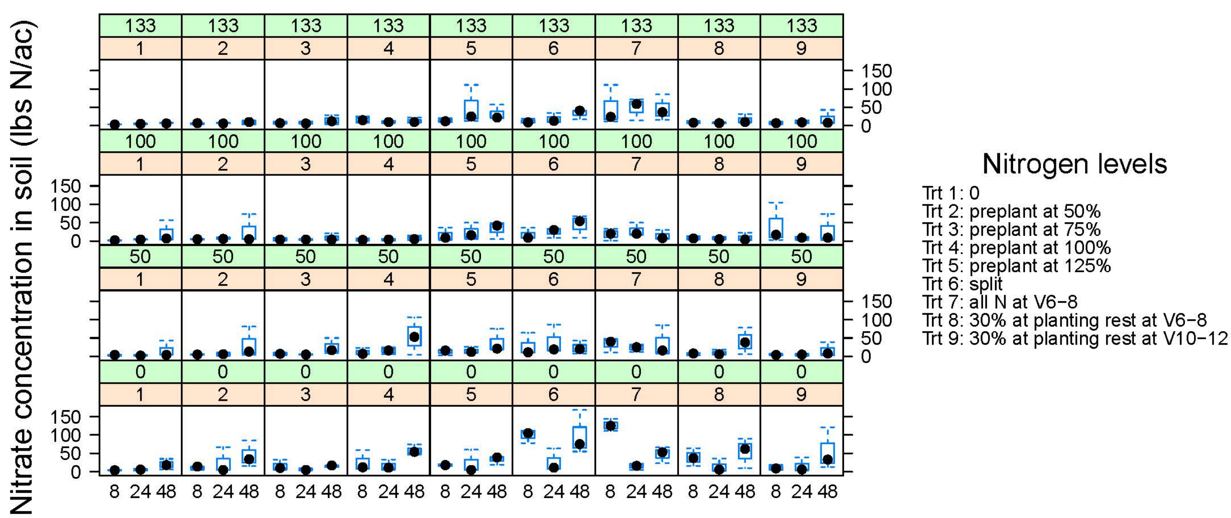

Figure 6. Residue nitrate-N in soil depths of 8 inches, 24 inches, and 48 inches of all irrigation and nitrogen treatments. Panels from left to right are the nine nitrogen treatments. Panels from bottom to top are the four irrigation treatments (0, 50%, 100%, and 133%).

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