IMPROVING NITROGEN USE-EFFICIENCY IN SUBSURFACE DRIP-IRRIGATED-COTTON

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Abstract

Irrigation in arid lands is crucial for cotton production. Declining water availability in the American West continues to generate interest in subsurface drip irrigation (SDI). Fertigation of liquid urea ammonium nitrate is an important advantage of SDI. However, Nitrogen (N) fertilizer guidelines, specific to SDI cotton are few. The objectives of this study on a Casa Grande sandy/sandy clay loam soil in Maricopa, AZ were to develop a pre-plant soil profile NO_3 test algorithm and a canopy reflectance approach to managing in-season N fertilizer for SDI cotton in AZ. Treatments included soil test-based N management, reflectance-based N management, and zero-N at 100 % ET irrigation replacement with 30 % soil water depletion. A second irrigation level of 70 % ET replacement, included soil test-based N and zero-N treatments. Plots were 8, 40-inch rows wide and 330 feet long. The five treatments were replicates three times. In 2016, the N fertilizer treatments were 156 and 141 lb N/ac for soil test and reflectance, respectively. In 2017, the N fertilizer treatments were 154 and 112 lb N/ac for soil test and reflectance, respectively. Nitrogen recovery efficiency of N was high with 24 fertigations between first square and mid bloom, ranging from 59 to 81 % in 2016 and from 60 to 93% in 2017. Lint and seed yields were reduced with the 70 % irrigation treatment compared to 100%. On the other hand, cotton yields with reflectance-based N management saved 15 to 42 lb N/ac without hurting yields, compared to the soil test-based N treatment.

Introduction

Declining water availability in the lower Colorado River basin has been a fact of life in the American Southwest since 2000 (Scanlon, 2016). Following water, N fertilizer is the main constraint to cotton production in the western USA (Morrow and Krieg, 1990). Canal infrastructure of irrigation water in Arizona means basin, flood, and furrow irrigation are still the pre-dominant choices of irrigation methods. Navarro et al. (1997) in Arizona, and Booker et al. (2007) and Bronson et al. (2007; Bronson, 2008) in Texas reported that recovery efficiency ground-based N applications in furrow-irrigated cotton ranged from only 15 to 34 %. With declining water resources and competition from growing urban areas there is renewed interested in subsurface drip irrigation (SDI) systems. However, N management research and recommendations in the far western US are lacking for SDI cotton. In the western US, weekly petiole NO_3 sampling and analysis is the recommended approach to monitor in-season cotton plant N status. However, petiole sampling is laborious and laboratory turn-around is time-consuming. Additionally, petiole NO_3 analysis can be highly variable (Bronson et al. 2001). Canopy reflectance, on the other hand is a rapid, non-destructive method to assess in-season cotton N status (Chua et al., 2003; Bronson et al, 2003). Canopy reflectance-based N management in subsurface drip systems in Texas resulted in reduced N fertilizer use, without hurting lint yields (Yabaji et al., 2009). In that research, N fertilizer was initially applied at half the rate of a regional soil test based recommendation. When normalized difference vegetative index (NDVI, a common remote sensing vegetative index) in the reflectance treatment fell below NDVI of the soil test/adequately fertilized plot, N fertigation was increased. This simple "sufficiency index" approach has not been tested in the western US in SDI cotton.

Nitrous oxide is a potent greenhouse gas with a heat-trapping potential 300 X that of CO_2 (USEPA, 2015). Agricultural, particularly N fertilizers make up 74 % of the N_2O emissions in the USA (USEPA, 2015). Nitrous oxide is produced in cropped soils primarily during the anaerobic reduction of NO_3 to N_2. A secondary pathway of N_2O production is during the oxidation of NH_4 to NO_3. Relatively few studies have been conducted on cotton that measure N_2O emissions (Scheer et al., 2008; Liu et al., 2010, Wang et al., 2013).

We propose an improved and updated N fertilizer management recommendation for 4-bale/acre cotton based on a 36-inch NO_3-N soil test. Additionally, we will compare soil test-based N management for full and deficit irrigation, and measure N_2O emissions. The study was conducted in Maricopa, AZ on a Casa Grande sandy loam.

Objectives:

1. Compare lint yields and NUE with soil test-based N fertilizer management with canopy reflectance-based UAN-N management approach in subsurface drip irrigated cotton.
2. Compare lint yields and NUE for full and deficit irrigation in subsurface drip irrigated cotton.
3. Construct N balances for subsurface drip irrigated cotton, i.e. quantify total N uptake, recovery N use efficiency, NO_3 leaching, and N_2O losses.

Methods

In March, 2017, pre-plant soil sampling to 180 cm (70-inch) for NO_3 was done on four samples per plot. Total number of DGPS-referenced soil sampling points was 60. Cotton cultivar 'DP1549 B2XF' was planted on 11 April, 2017 in plots that were 8, 1-m (40 inch) rows wide by 330 feet. Harvest was in October. Nitrogen and irrigation treatments included:

Nitrogen treatment	Irrigation level (% ET)
1. Soil test-based N†	100
2. Reflectance-based N‡	100
3. Zero-N	100
4. Soil test-based N†	75
5. Zero-N	75

† Based on lint yield goal of 4.0 bale/ac, and a 225 lb N/ac N requirement, minus 0 - 36 in. soil NO_3-N and estimated irrigation input of 20 lb N/ac (estimated 40 inch irrigation of 2 ppm NO_3-N water).

‡ Applications start out at 50 % treatment no. 1, subsequent applications based on NDRE relative to treatment no. 1.

Nitrogen fertilizer as UAN was fertigated in 24 doses between first square and mid bloom with a diaphragm pump. The experimental design was a completely randomized block, with three replicates. Canopy reflectance was measured weekly from first square to first open boll using two Crop Circle ACS-470 active sensors. Several vegetative indices were calculated including NDVI, CCCI, and NDRE. NDRE was used for reflectance-based N treatments.

Surface flux of N_2O was measured weekly for 16 weeks during the seasons using 4-qt vented and insulated chambers (Yabaji et al., 2009). Two chambers per plot were be placed on the side of the bed facing a traffic and non-traffic furrows, respectively for 24-minute periods. Fifty-mL samples were taken at 0, 12, and 24 minutes. Nitrous oxide analysis was performed on a Shimadzu 2014 gas chromatograph fitted with a ^{63}Ni electron capture detector (Mosier and Mack, 1980). Nitrous oxide fluxes were calculated according to the logarithmic equation of Hutchinson and Mosier (1981). If the increase in N_2O concentration in the chamber headspace in the 12-24 minute period was not equal to the 0-12 minute increase in concentration, then a linear increase in N_2O was estimated as suggested by Venterea and Baker (2008).

Biomass and total N uptake were determined for plant sampled from 1 m (36 inches) of row at first open boll. Nitrogen recovery efficiency, physiological N use efficiency and agronomic use efficiency were calculated. Lint and mature seed yields were measured by two-row picker harvesters for both yield mapped-entire plot and 20-foot long sections centered on the DGPS points. Mature cotton seed N was determined from grab samples at the four DGPS points per plot and the percentage of seed N to total N uptake calculated. Micronaire and other fiber quality attributes will be determined on lint and the relationships of these to N fertilizer rate estimated (data not available at report time). Soil sampling for extractable NO_3-N from 0 to 180 cm was done after harvest to assess residual NO_3 on four samples per plot to assess the spatial variation of residual NO_3 across the plot, and effect of treatments (data not available at time of this report).

Soil moisture to 72 inches was determined every week with a neutron probe and the water balance was calculated with irrigation amounts, rain and estimated ET (Maharjan et al., 2014). Pre-plant and harvest soil profile NO_3, N_2O emissions, NDVI, plant biomass, plant N uptake, lint, and seed yield were analyzed with a mixed model using SAS. Replicate was considered random, and N treatment was considered fixed. Since N_2O data often has a log-normal distribution, the statistical analysis was also conducted using PROC GLIMMIX with a log distribution (SAS, 2013).

Results and Discussion

Pre-plant soil profile (0-36 inch) soil NO_3-N in the soil test – 100 % ET plots average 51 lb N/ac. Our soil test based N rate was therefore 154 lb N/ac (225 target – 24 – 20 estimated from irrigation water). We used the same soil test N rate for both the 100 and 75 % ET irrigation level, in order to make these treatment comparisons strictly for water level.

Nitrogen deficiency in this study appeared rapidly in several vegetation indices as significant differences in N-fertilized plots vs. zero-N, on day 150, 15 days after the start of fertigation. Several vegetation indices for the reflectance-based N treatment fell significantly below soil test N plots, 29 days after fertigation commenced (N rates for reflectance were initially 50 % of soil test target of 154 lb N/ac). Amber NDVI during the growing season is shown in Fig. 1. The last two weeks of the fertigation period, UAN injection rates were the same between the two treatments (Fig. 2). Final reflectance-based N rate was 112 lb N/ac, a significant 42 lb N/ac less than the soil test treatment.

Petiole-NO_3-N levels quickly dropped in the zero-N plots for both irrigation levels and remained low (Fig. 3). Initial values for all plots at first square were similar to last year's study and again markedly below the critical petiole-NO_3-N value of 15,000 ppm (Silvertooth et al., 2011). At squaring (between day 151 and 158), soil test and reflectance N at 100 % irrigation were at adequate levels. Reflectance-based N petiole-NO_3 was initially significantly lower than soil test, and then caught up by day 172. At first bloom (day 166), the N-fertilized plots were well below the critical of 12,000.

In early August, first open boll biomass samples were taken. Biomass was high at 12,000 lb/ac for soil test N and 100% irrigation, and 9,200 lb/ac for soil test N, 70 % water (Table 1). Nitrogen and water effects on canopy height related very well to NDVI (Fig. 4). We find that the Honeywell height sensor was very rapid response and is accurate.

Lint yields are shown in Table 1. There was no yield reduction with reflectance-based management compared to soil test N, although biomass was less in the former. A significant savings of 42 lb N/ac less N fertilizer was achieved with reflectance-based N management (Table 1). However, the lint yields of 1,600 lb/ac were lower than the target of 2,000 lb/ac (Table 1). It is not clear why under SDI we are not obtaining the 1,800 lb/ac lint yields we observed with furrow irrigation (FI) and overhead sprinkler (OSI) (Bronson et al., 2017). We are using a different cultivar. We did not observed massive fruit loss in the 6- 9 node positions we observed last year. The DP 1549 we have used in the SDI study the last two years does not appear to branch as much as DP 1044 did under FI and OSI. We observed no leaf wilting in 2017. Canopy temperature data shows that only the zero-N plots exhibited plant leaf temperatures above air (Fig. 5). Interestingly, the soil test N rate at 75 % irrigation had canopy temperatures less than air, similar to the soil test and reflectance-based N at 100 % water. The relatively high "canopy" temperatures observed at day 152 were due to the high, hot exposed soil background 42 days after emergence.

The high recovery efficiency of added/fertigated N of 90-92 % in the soil test, 100 % irrigation was not unexpected, but is a significant result that solidifies the hypothesis that NUE is high in fertigated drip systems (Table 1).

Deep percolation estimates from the water balances were a high of 2.0 % of rain and irrigation in reflectance N – 100% irrigation (Table 2). There was no deep percolation in the zero-N plots. We did not notice surface water in the beds of the zero-N plots or low water plots as we did in 2016.

Nitrous oxide emissions were low and not different between N-fertilized and zero-N plots (Table 3, Fig. 6). There is a great deal of interest in calculating "emission factors" with N_2O flux field data from N fertilizer treatments. This is especially true given the growing emphasis on low greenhouse gas production/footprint in agriculture and industrial production today. The emission factor is simply the percentage of applied N fertilizer emitted as N_2O, with the fluxes from zero-N plots subtracted out. The IPCC makes the assumption that an average, single emission factor of 1.0 % can be used for N-fertilized field crops (IPCC, 2006), but emission factors are often lower or higher than 1.0 % (Lesschen et al., 2011). Nitrous oxide emissions, rarely reach economically significant levels. In the 2012-2015 data, the N_2O emission factors were measured were ocassionaly in line with the IPCC factor, but were more often much less than 1.0 %. Two recent studies on N_2O emissions with irrigated cotton in China reporte emission factors of 1.0 % (Liu et al., 2010; Wang et al., 2013), and a study in Uzbekistan measured an emission factor 1.5 % (Scheer et al., 2008). Published studies with Agrotain Plus in corn, often show strong mitigation of N_2O emissions (Halvorson et al, 2014; Thapa et al., 2016). It is notable that in our study and in a similar study with SDI in Texas (Yabaji et al., 2009), there was a zero emission factor. This is likely due to the fact that drip irrigation is a highly efficient irrigation system with little leaching or evaporative losses of irrigation water. Additionally, fertigating in 24 doses in SDI amounts to "spoon feeding" N to the crop.

In summary, the 2017 field season with SDI cotton was successful. High biomass, N uptake and recovery efficiency of fertigated N were the highlights. Also notable was the relatively low deep percolation, and the very low N_2O emissions. Lint yields were improved compared to 2016, despite greater level 3 heat stress days. The study will be repeated in 2018.

Table 1. Lint yield, seed yield, N uptake and N use efficiencies as affected by N management and irrigation level in subsurface drip-irrigated 'DP 1549 B2XF' cotton, Maricopa, AZ 2017

Nitrogen treatment	Irrigation level	Fertilizer rate	Biomass yield	Lint yield	Total N uptake	Recovery efficiency-diff method	Recovery efficiency-^{15}N method	Agron. N use efficiency	Internal N use efficiency
	mm	lb N/ac	lb/ac	lb/ac	lb N/ac	%	%	lb lint/lb N fert.	lb N/bale
Soil test-based N	851	154	12,024 a	1,589 a	198 a	92 a	90 a	6.5 b	61 ab
Reflectance-based N	851	112	11,024 ab	1,656 a	160 b	93 a	88 a	9.5 a	47 b
Zero-N	851	0	4,127 c	593 c	56 c	-	-	-	46 b
Soil test-based N	608	154	9,182 b	1,014 b	160 b	60 a	73 a	2.4 c	78 a
Zero-N	608	0	5,320 c	642 c	68 c	-	-	-	51 b

Table 2. Water balances as affected by N management and irrigation level in subsurface drip-irrigated ‘DP 1549 B2XF’ cotton, Maricopa, AZ 2017.

N treat.	Irrigation level	Root zone (cm)	ET	Rain	Irrigation	Change soil storage (0-1.7m)	Deep perc	Deep perc (% of irrigation+rain)
			------------------------ cm --------------------------					
Soil test-based N	851	180	-101	5.1	85.1	-11.7	1.1	1.2
Reflectance-based N	851	180	-101	5.1	85.1	-12.4	1.8	2.0
Zero-N	851	180	-101	5.1	85.1	-9.9	0	0
Soil test-based N	608	180	-69.1	5.1	60.8	-15.9	0	0
Zero-N	608	180	-69.1	5.1	60.8	-10.7	0	0

Table 3. Seasonal nitrous oxide emissions as affected by N management and irrigation level in subsurface drip-irrigated ‘DP 1549 B2XF’ cotton, Maricopa, AZ 2017.

Nitrogen treatment	Irrigation level	Fertilizer rate	N_2O Emissions
	mm	lb N/ac	g N/ac/117 d
Soil test-based N	851	154	78 a
Reflectance-based N	851	112	54 a
Zero-N	851	0	24 b
Soil test-based N	608	154	87 a
Zero-N	608	0	2.4 b

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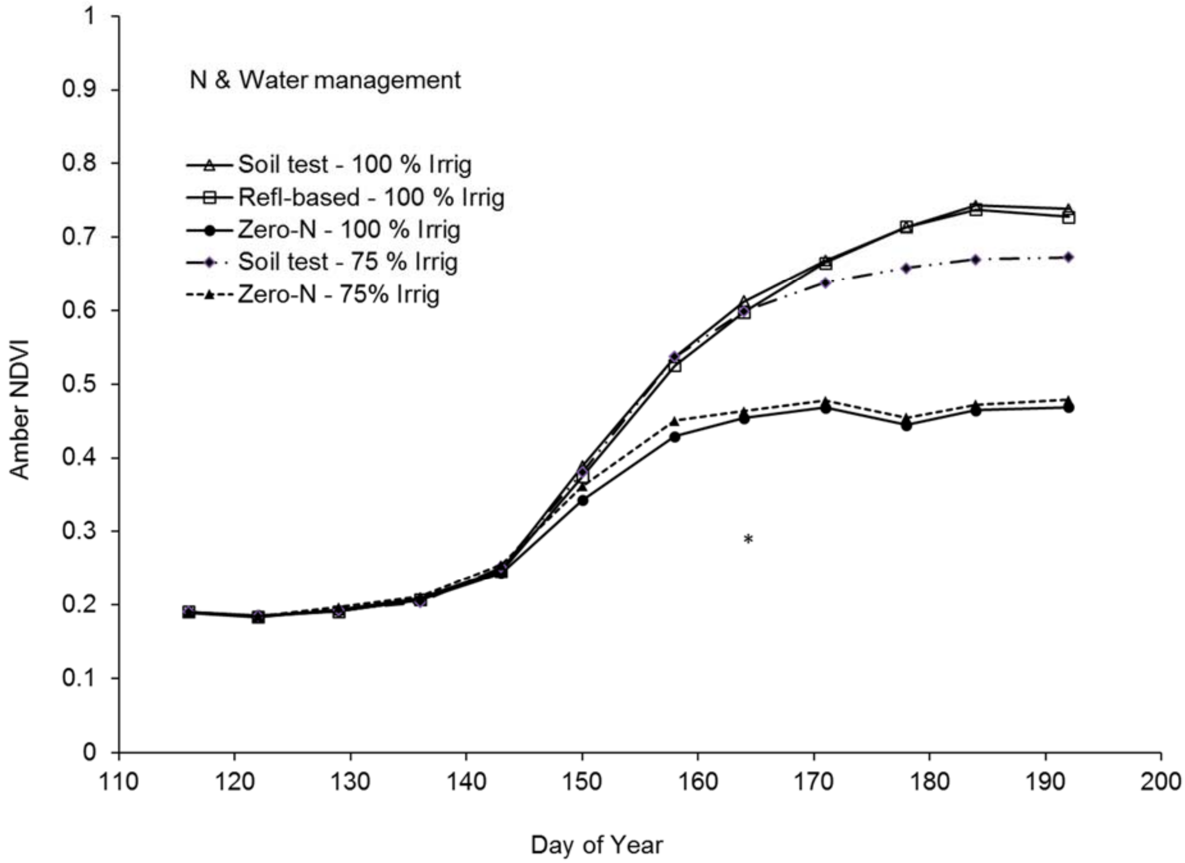

Fig. 1. Amber NDVI as affected by N management and irrigation level in SDI cotton, Maricopa, AZ, 2017.

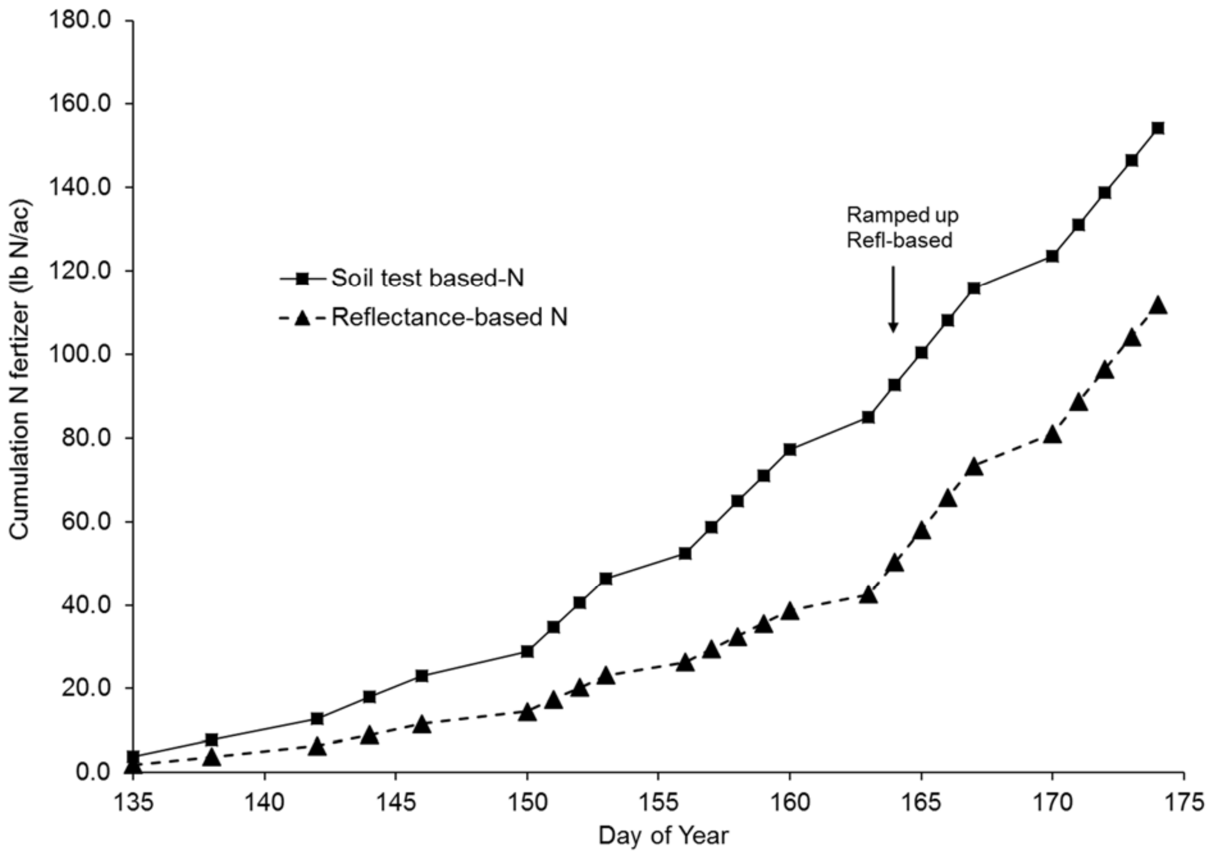

Fig. 2. Nitrogen (urea ammonium nitrate) fertigations as affected by N management in SDI cotton, Maricopa, AZ, 2017.

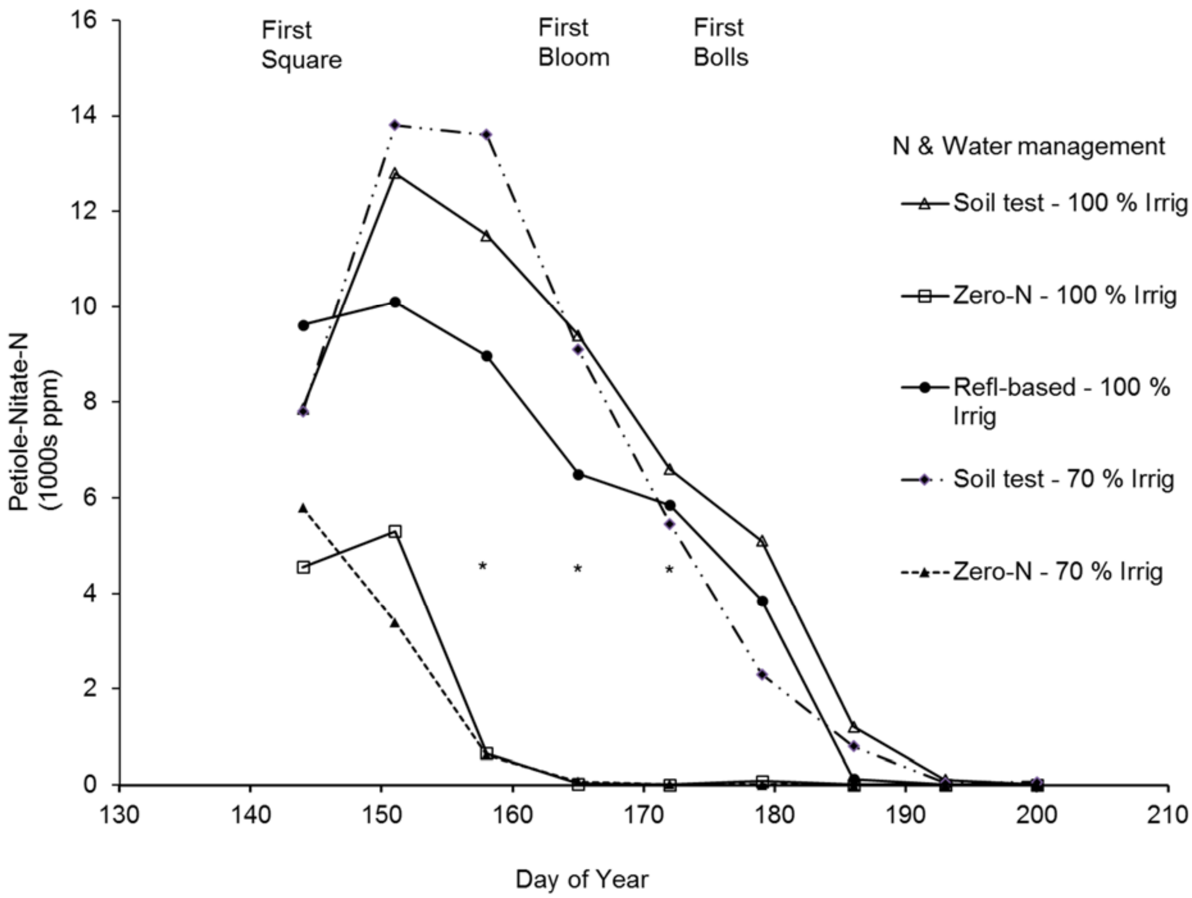

Fig. 3. Petiole-nitrate-N as affected by N management and irrigation level in SDI cotton, Maricopa, AZ, 2017.

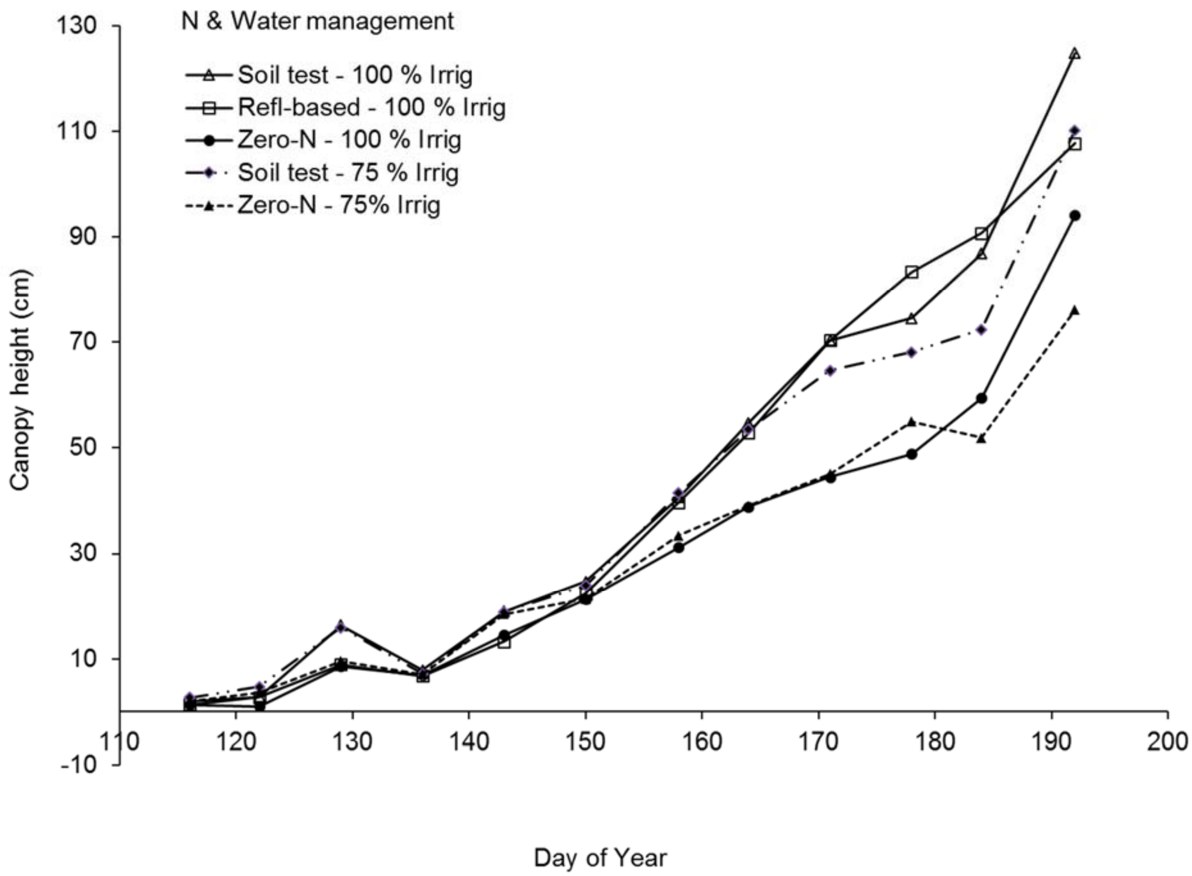

Fig. 4. Canopy height measured by ultrasonic sensor as affected by N management and irrigation level in SDI cotton, Maricopa, AZ, 2017.

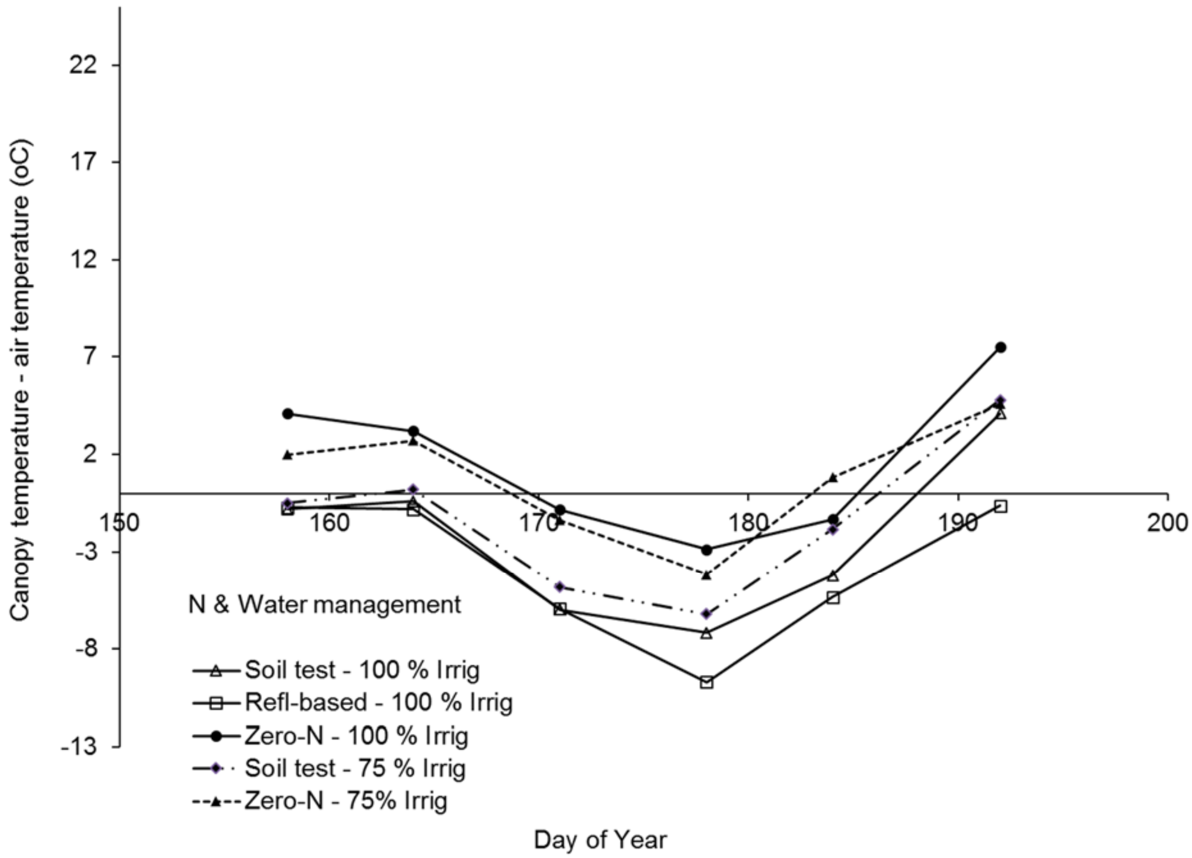

Fig. 5. Canopy temperature minus air temperature as affected by N management and irrigation level in SDI cotton, Maricopa, AZ, 2017.

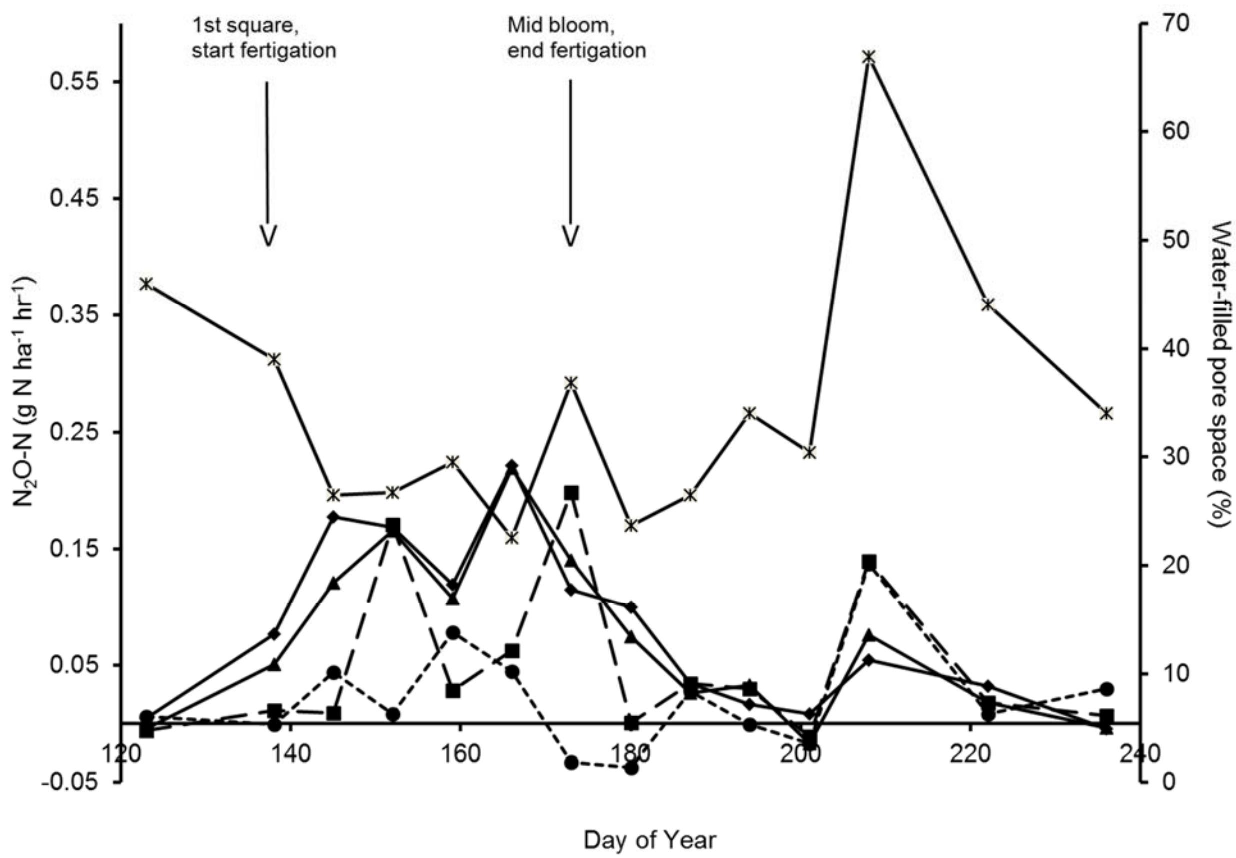

Fig. 6. Nitrous oxide emissions as affected by N management and irrigation level in SDI cotton, Maricopa, AZ, 2017.