Improving Nitrogen Fertilizer Management in Sprinkler-Irrigated Cotton.

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Background:
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;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 center-pivot or linear-move overhead sprinkler irrigation systems. However, N management research and recommendations in the far western US are lacking for sprinkler irrigation. 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 vegetation index (NDVI, a common remote sensing vegetation 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 sprinkler-irrigated cotton.

Enhanced-efficiency N fertilizers like Agrotain Plus have been shown to reduce N_2O emissions in corn (Halvorson et al., 2014), but have not been widely tested in cotton (Watts et al., 2014).

We propose and improved and updated N fertilizer management recommendation for 4-bale/acre cotton based on a 36-inch NO_3-N soil test. We will also compare UAN with UAN plus the N loss inhibitor Agrotain Plus. Additionally, we will compare reflectance-based N fertilizer management with soil test-based management. The study we be conducted in Maricopa, AZ on a Casa Grande sandy loam.

Objectives:
1. Compare soil test-based N fertilizer management with two canopy reflectance-based UAN-N management approaches in sprinkler-irrigated cotton.
2. Compare urea ammonium nitrate (UAN) and UAN with Agrotain Plus in sprinkler-irrigated cotton.
3. Construct N balances for sprinkler-irrigated cotton, i.e. quantify total N uptake, recovery N use efficiency, NO_3 leaching, and denitrification losses.

Methods:
In March, 2014, pre-plant soil sampling to 180 cm for NO_3 was done on three samples per plot. Cotton

'DP1044B2R2F' was planted in April, 2014 in plots that were 6, 1-m (40 inch) rows wide by 45 m (150 feet). At harvest, soil sampling to 180 cm for nitrate will on three samples per plot. Total number of DGPS-referenced soil sampling points was 84. Nitrogen treatments will include:

Nitrogen treatment	Fertilizer source	Notes
1. Zero-N		
2. Soil test-based N†	Urea amm. nitrate	In three splits, first square and first bloom and mid bloom†
3. 1.3*Soil test-based N†	Urea amm. nitrate	In three splits, first square and first bloom and mid bloom†
4. Soil test-based N†	Urea amm. nitrate + Agrotain Plus	In three splits, first square and first bloom and mid bloom†
5. Reflectance-based N-1‡	Urea amm. nitrate	In three splits, first square and first bloom and mid bloom‡
6. Reflectance-based N-2§	Urea amm. nitrate	In three splits, first square and first bloom and mid bloom§
7. Reflectance-based N-1‡	Urea amm. nitrate + Agrotain Plus	In three splits, first square and first bloom and mid bloom‡
8. Reflectance-based N-2§	Urea amm. nitrate + Agrotain Plus	In three splits, first square and first bloom and mid bloom‡

† Based on lint yield goal of 4.0 bale/ac, and a 200 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).
‡ First split equals 50 % treatment no. 2, second and third splits based on NDVI relative to treatment no. 2.
§ First split equals 50 % treatment no. 2, second and third splits based on NDVI relative to treatment no. 3.

Nitrogen was applied with a high clearance tractor by spraying into the furrow with fertilizer nozzles just prior to an irrigation. Irrigation was applied 2-4 times a week with spoke-wheel applicators on the side of the bed, just prior to an irrigation. Irrigation was applied 2-4 times a week with FAO crop coefficients and 85 % ET replacement (Allen et al., 2014).

The experimental design is a completely randomized block, with four replicates.

Canopy reflectance was measured weekly from first square to first open boll using Crop Circle ACS-470 active sensor. Several vegetation indices were calculated including NDVI, CCCI, and NDRE. Amber NDVI was used for reflectance-based N treatments.

Surface flux of N_2O was measured weekly for 10 weeks during the season using vented chambers and gas chromatography. Biomass and total N uptake was determined plants on 2 m of row at first open boll. Nitrogen recovery efficiency, physiological N use efficiency and agronomic use efficiency was calculated. Lint and mature seed yields was machine harvested. Mature cotton seed N was determined from grab samples at the three 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. Soil sampling for extractable NO_3-N from 0 to 180 cm was one after harvest to assess residual and NO_3 and leached NO_3 (90 – 180 cm profile NO_3). Post-harvest soil sampling will on four samples per plot to assess the spatial variation of leached NO_3 across the plot.

Pre-plant and harvest soil profile NO_3, N_2O emission, NDVI, plant biomass, plant N uptake, lint, and seed yield was analyzed with a mixed model using SAS. Replicate was considered random, and N treatment was considered fixed. The four subsamples per plot were averaged by plot in the mixed analysis to produce least square means.

Results and Discussion

We decided to increase our yield goal from the previous surface-irrigation N fertilizer studies of 3.5 lb lint/ac to 4.0 lb lint/ac. We therefore increased our N requirement in our soil test-based N fertilizer algorithm from 175 lb N/ac to 200 lb N/ac, ie the same N use efficiency of 50 lb N/bale. Pre-plant (late March) soil profile NO_3 (0 – 36 in.) was 18 lb NO_3-N/ac. Rounding this number up to 20 and crediting 20 lb NO_3-N/ac in the estimated seasonal irrigation of 40 inches of 2 ppm NO_3-N irrigation water, we calculated our soil test-based N treatment N rate at 160 lb N/ac (Table 1). Reflectance strategy-1 N rates were set at 50 % of this, or 80 lb N/ac. The 1.3 x soil test N rate was 208 lb N/ac, and the reflectance strategy-2 was 50 % of this or, 104 lb N/ac (Table 1). Nitrogen fertilizer as UAN was applied in three equal splits on 27 May (pinhead square), 17 June (3-5 squares, or one week before first bloom), and 7 July (mid bloom).

Soil samples to 12 inches were taken from all plots two weeks after the N fertilization events. Table 1 show the results for the first fertilization event. Nitrification of NH_4 was very rapid. There were some significant effects of Agrotain Plus in maintaining NH_4 levels, but they were still low, and the Agrotain effects were not consistent for all Agrotain treatments. Extractable NH_4 and NO_3 trends were similar for the second and third N applications (data not shown).

The amber NDVI in the two reflectance-based treatments never fell below their respective references during the growing season (Fig. 1). Therefore the two NDVI-based N treatments were not adjusted upwards. In fact, amber NDVI did not drop significantly below the N-fertilized treatments until the 217th day of the year (3 August) or peak bloom. This was one month after the third split of N fertilizer. In contrast to NDVI, the NDRE index showed zero-N plot deficiency on DOY 196 (mid bloom) and petiole NO_3 samples showed the same on DOY 175 (first bloom).

First open boll biomass averaged 8074 lb/ac, with no effect of N treatment. This was similar to the 8173 lb biomass in 2013 surface-irrigation N study. However, total N uptake at first open boll averaged 173 lb N/ac, which was significantly greater than the 130 lb N/ac with zero-N (Table 2). These are higher values than the 143 and 108 lb N/ac, for N fertilized, and zero-N, with surface irrigation in 2013. Recovery efficiency (RE) of added N fertilizer was much greater than in 2012 surface irrigation study, but was similar to that of the 2013 surface irrigation study. It should be emphasized that the 2013 study had much lower N fertilizer application rates than in 2014, i.e high RE would be expected. The greatest RE this year in 2014 was with the low N rate of 80 lb N/ac where RE was 50-55% (Table2). The lowest RE of 24 % was with the 1.3 x Soil test rate (208 lb N/ac), and surprisingly, with soil test rate (160 lb N/ac) + Agrotain Plus (Table 2). Internal N use efficiency in 2014 for N-fertilized plots averaged 49 lb N/ac uptake per bale of cotton lint produced, with no effect of N treatment (Table 3). This is greater than the 43 to 44 lb N/bale for soil test treatments in 2012 and 2013, and reflects higher than needed N content of cotton plants at first open boll.

Final lint yields showed significantly lower lint yields for zero-N plots (1462 lb lint/ac) vs. the average of the N-fertilized plots (1627 lb lint/ac, or 3.5 bale/ac, Table 3). These yield levels were lower than the 4 bale/ac yield goals.

There was no effect of Agrotain Plus in biomass, N uptake, RE, AE or lint yields (Table 2 and 3). Nitrogen uptake was greater than in previous surface irrigation studies, but biomass levels were similar.

Similar to soil NH_4, Agrotain Plus did mitigate N_2O emissions (Table 2, Fig. 2). However these effects were only statistically significant with the high, soil test-based treatment of 160 lb N/ac, and for the average of UAN with Agrotain Plus and UAN alone. Nitrous oxide emissions in this sprinkler-irrigated study were surprisingly similar to the losses in surface irrigation. Emissions were highest early in the season before plant uptake of N accelerated. As a percentage of N applied (adjusted for zero-N emissions), N_2O emissions ranged from 0.1 % of soil test-based N with Agrotain Plus to 1.0% with soil-test-based N alone.

Table 4 shows the water balance for 0- 170 cm during the season, estimated from ET, irrigation, and rain inputs, and changes in soil water as measured by neutron probes. Deep percolation for sprinkler irrigation in this study was estimated to be negligible at 0.6 %. This compares to 14 to 23 % for the previous two years study with surface irrigation.

The Nitrogen balance for 2014 is shown in Table 5. The sums ranged from 5 to 32 lb N/ac. Net mineralization estimated from zero-N plot N uptake was 97 lb N/ac, higher rates than under surface irrigation. Soil profile NO_3 between 36 and 72 inches was treated as leached and made up the largest N loss pathway. Significant positive N balances should have been due to significant NO_3 leached, but this was not consistent. Leached N among N-fertilized treatments was greater than zero-N in 2014. Although the deep percolation was negligible in 2014, NO_3 leached was fairly significant (Table 5). Agrotain Plus showed effects for mitigating N_2O emissions and NO_3 leaching, but these treatments were not as consistent as expected.

Table 1. Extractable soil NH_4 and NO_3, (0-12 inches), at pinhead early squaring, as affected by N management in sprinkler-irrigated cotton, Maricopa, AZ 2014

Nitrogen treatment	Fertilizer source	Fertilizer rate	NH_4	NO_3
		lb N/ac	------ ppm N ------	
Zero-N		0	1.2 b	10 b
Soil test-based N†	UAN	160	2.6 b	23 ab
1.3*Soil test-based N†	UAN	208	2.8 b	30 a
Soil test-based N†	UAN + Agrotain Plus	160	5.5 a	20 ab
Reflectance-based N-1‡	UAN	80	1.2 b	16 b
Reflectance-based N-2§	UAN	104	2.2 b	22 ab
Reflectance-based N-1‡	UAN + Agrotain	80	3.6 ab	21 ab
Reflectance-based N-2§	UAN + Agrotain Plus	104	5.6 a	28 a

Table 2. First open boll biomass, N uptake and recovery efficiency, as affected by N management in sprinkler-irrigated "DP 1044 B2RF" cotton, Maricopa, AZ 2014

Nitrogen treatment	Fertilizer source	Fertilizer rate	Biomass	N uptake	Recovery efficiency	Seasonal N_2O flux
		lb N/ac	lb/ac	lb N/ac	%	g N_2O-N/ac/91 d
Zero-N		0	7494 a	130 b	-	30 b
Soil test-based N†	UAN	160	8310 a	184 a	34 ab	449 a
1.3*Soil test-based N†	UAN	208	8015 a	180 a	24 b	496 a
Soil test-based N†	UAN + Agrotain Plus	160	7887 a	169 a	24 b	107 b
Reflectance-based N-1‡	UAN	80	8497 a	174 a	55 a	405 ab
Reflectance-based N-2§	UAN	104	8076 a	172 a	40 ab	282 ab
Reflectance-based N-1‡	UAN + Agrotain Plus	80	8553 a	170 a	50 ab	259 ab
Reflectance-based N-2§	UAN + Agrotain Plus	104	7757 a	163 a	32 ab	213 b

Table 3. Lint yield, seed yield, agronomic and internal N use efficiency, as affected by N management in sprinkler-irrigated "DP 1044 B2RF" cotton, Maricopa, AZ 2014

Nitrogen treatment	Fertilizer source	Fertilizer rate	Lint yield	Agron. N use efficiency	Internal N use efficiency
		lb N/ac	lb/ac	lb lint/lb N fert.	lb N/bale
Zero-N		0	1462 b	-	40.7 b
Soil test-based N†	UAN	160	1605 a	0.9 a	54.0 a
1.3*Soil test-based N†	UAN	208	1715 a	1.2 a	50.1 a
Soil test-based N†	UAN + Agrotain Plus	160	1745 a	1.8 a	46.4 a
Reflectance-based N-1‡	UAN	80	1704 a	3.0 a	48.5 a
Reflectance-based N-2§	UAN	104	1658 a	1.9 a	49.4 a
Reflectance-based N-1‡	UAN + Agrotain	80	1672 a	2.6 a	48.4 a
Reflectance-based N-2§	UAN + Agrotain Plus	104	1620 a	1.5 a	48.0 a

Table 4. Water balances for N management studies in surface and in sprinkler-irrigated "DP 1044 B2RF" cotton, Maricopa, AZ 2012-2014

Irrigation	Year	Root zone (cm)	ET	Rain	Irrigation	Change soil storage (0-1.7m)	Deep perc	Deep perc (% of irrigation)
			------------------------ cm -------------------------------					
Surface irrigation	2012	180	-82.3	9.5	83.4	-8.6	19.2	23
Surface irrigation	2013	180	-76.0	1.3	80.8	-5.0	11.1	13.7
Sprinkler	2014	180	-86.7	8.5	72.0	-6.6	0.1	0.6

Table 5. Nitrogen balances of plant and soil as affected by N management in sprinkler-irrigated cotton, Maricopa, AZ 2014

Nitrogen treatment	Fertilization source	Fertilizer rate	Pre-plant soil NO_3 (0-36 in)	Irrigation N input	N minerali-zation	Plant N uptake	Post-plant soil NO_3 (0-36 in)	N Balance	Post-plant soil NO_3 (36-72 in)
		---------- lb N/ac ----------							
Zero-N		0	20	13	97	130	22		8.4
Soil test-based N	UAN	160	17	13	97	184	71	32	33
1.3*Soil test-based N	UAN	208	15	13	97	180	148	5	39
Soil test-based N	UAN + Agrotain Plus	160	17	13	97	169	95	23	33
Reflectance-based N-1	UAN	80	15	13	97	174	25	7	16
Reflectance-based N-2	UAN	104	20.5	13	97	172	49	14	28
Reflectance-based N-1	UAN + Agrotain Plus	80	20.5	13	97	170	31	10	16
Reflectance-based N-2	UAN + Agrotain Plus	104	17	13	97	163	34	34	21

Fig. 1. Amber NDVI as affected by N management in sprinkler-irrigated cotton, Maricopa, AZ, 2014.

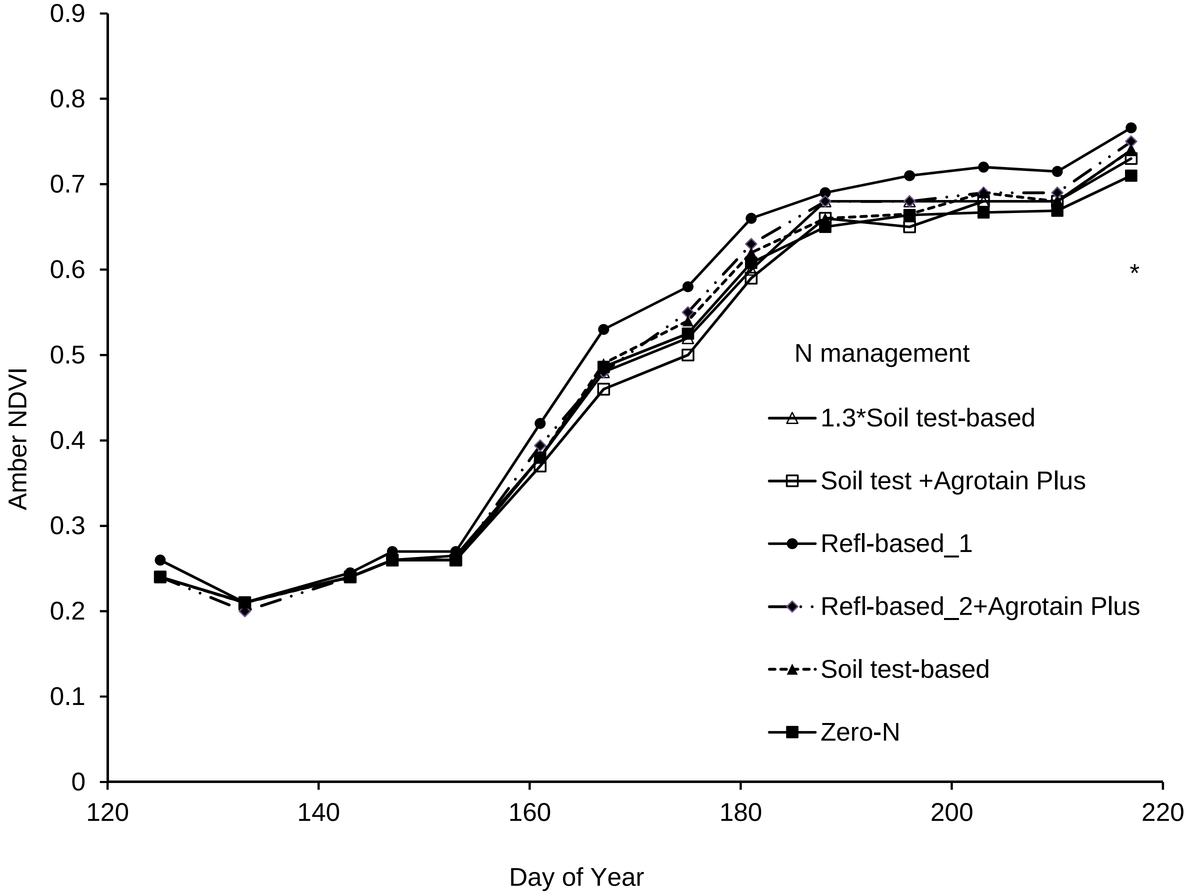
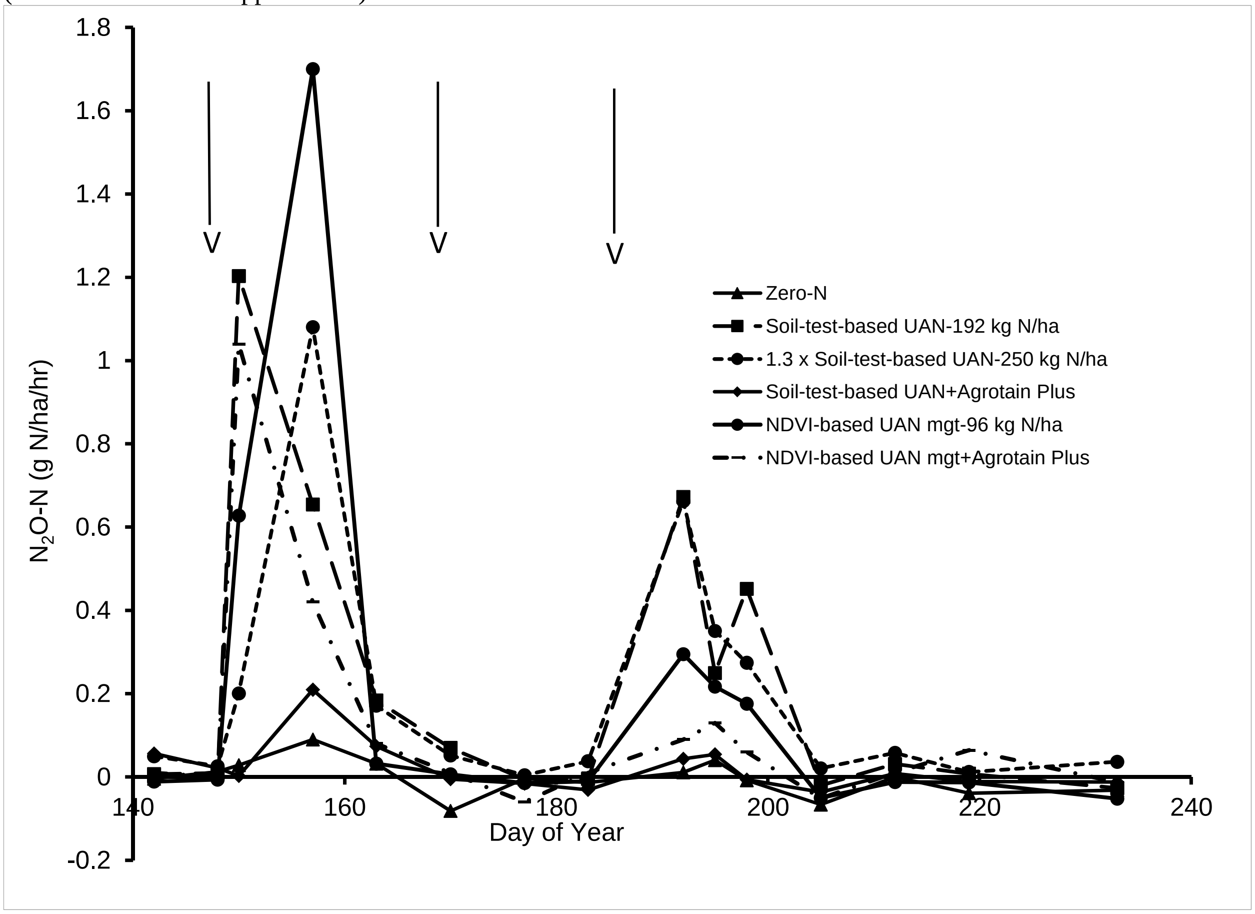


Fig. 2. Nitrous oxide emissions as affected by N management in sprinkler-irrigated cotton, Maricopa, AZ, 2014 (arrows are fertilizer applications)



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