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Nitrogen Accumulation in Cotton Grown Continuously or in Rotation with Peanut Using Subsurface Microirrigation and GOSSYM/COMAX Management

P. G. Hunt,* P. J. Bauer, C. R. Camp, and T. A. Matheny

ABSTRACT

Excessive N application to cotton (*Gossypium hirsutum* L.) is an unnecessary cost and a potential cause of elevated groundwater N. The objectives of this study were to determine if seed yields or excess N were affected by timing of N application via buried microirrigation tubing, tubing spacing, or peanut (*Arachis hypogaea* L.) rotation. The experimental design was a randomized complete block in split-plot arrangement with four replications. The main plots (continuous cotton and peanut-cotton rotation) were planted with cotton cultivar PD 3 in May of 1991 through 1994 on an Eunola loamy sand (fine-loamy, siliceous, thermic Aquic Hapludult). Water and N were applied through microirrigation tubing that was buried 0.30 m directly under each row (IR) or under alternate row middles (AM). Sidedress-N was applied in one 112-kg ha^{-1} application (STD); five, 22-kg ha^{-1} increments (INC); or 11- to 22-kg ha^{-1} increments when required by GOSSYM/COMAX (GC) [a cotton growth model/expert system]. Rotation did not significantly affect any of the measured parameters. Cotton managed with the IR-STD treatment had the highest seed yield, 2.02 Mg ha^{-1} yr^{-1}. The GC management did not improve seed yield, but it did reduce excess N (fertilizer N − seed N) to <20 kg ha^{-1} yr^{-1}. The best overall treatment was AM-GC. It had 1.87 Mg ha^{-1} yr^{-1} seed yield, 8 kg ha^{-1} yr^{-1} excess N, 45 kg less N applied, and 50% less tubing installed. Cotton managed by AM-GC also had a low (9.2) ratio of accumulated shoot N per 100 kg of lint.

BOLL WEEVIL (*Anthonomus grandis* Boheman) eradication in the eastern Coastal Plain has allowed cotton production to become more extensive during the past 10 yr. In addition to the improved management of insects, there is great interest in improved management of N in cotton crops for both production and environmental reasons. Insufficient N can limit fruiting sites (Joham, 1986) but excess N can cause unnecessary cost, excessive vegetative growth, and N leaching into shallow groundwater. Nitrogen management for cotton has been based on profitable lint production because lint is the most economically important component of cotton. However, cotton seed is also an important commodity, and N is accumulated and removed from the field in cotton seed. Thus, the accumulation of seed N must be understood and controlled in order to manage the net excess N.

Both the quantity and timing of N and water applications have an influence on the ability of the cotton plant to utilize N for seed and lint production (Guinn and Mauney, 1984; Mullins and Burmester, 1990). One of the most effective methods of water and N application is microirrigation (Lamm, 1995). By this method, water and nutrients can be provided as needed (Phene and Beale, 1979; Camp et al., 1997). Compared with standard (overhead) irrigation (e.g., center pivots, towed irrigation guns, and solid set irrigation), microirrigation has particular usefulness in the southeastern USA where potential leaching, oxygen stress, and ethylene damage from excessive rainfall can be diminished by small incremental irrigations that maintain soil water content at less than saturation (Campbell and Phene, 1977; Hunt et al., 1982). In addition to the normal benefits of surface microirrigation, buried microirrigation offers the advantages of long-term use and minimal cultural interference (Camp et al , 1989). In either surface or buried microirrigation, capital cost of installing tubing in every row can be reduced significantly if tubing is placed in alternate row middles (Camp et al., 1989, 1997). Further refinements in water and N management may be obtained by the use of GOSSYM/COMAX, a cotton growth model coupled with an expert system (Baker et al., 1983; Lemmon, 1986). The objectives of this study were to determine if seed yields or excess N were affected by timing of N application via buried microirrigation tubing, tubing spacing, or peanut rotation.

METHODS

Site, Soil, and Treatments

The experimental site was 1.2 ha of Eunola loamy sand (fine-loamy, siliceous, thermic Aquic Hapludult), which is typical of the eastern Coastal Plain. It was located on the Pee Dee Research and Education Center near Florence, SC, at latitude 34° 18′, longitude 79° 44′, and an elevation 37 m above mean sea level. The site was subsoiled in perpendicular directions prior to installation of irrigation laterals in 1991, and the seedbed was prepared each year by disking to a depth of about 0.20 m. The nonirrigated (NI) treatments were subsoiled each year. In all years, surface soil samples were taken for analysis; and P, K, Mn, and lime were applied based on soil test results.

The experimental design was a randomized complete block in split-plot arrangement with four replications. The main plots were continuous cotton and peanut-cotton rotation treatments. Sub-plots had eight sidedress-N and water treatments. The water and N application treatments are described in Table 1. Irrigation water was applied via microirrigation laterals (Geoflow, Sausalito, CA)[1] buried 0.30 m below the soil surface. Microirrigation tubing was either directly under each row (IR) or under the alternate row middles (AM). All sidedress-N (30% urea ammonium nitrate solution) and water were applied via the irrigation system; N applications were in additions of 1 mm of water. Sidedress-N for the NI treatments was applied via the same type lateral as used for the irrigation

[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

USDA-ARS, Coastal Plains Soil, Water, and Plant Research Center, 2611 W. Lucas St., Florence, SC 29501-1241. Received 16 April 1997. *Corresponding author (Hunt@florence. ars.usda.gov).

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Abbreviations: AM, alternate middle microirrigation; GC, GOSSYM/COMAX application of N; INC, incremental application of N; IR, in-row microirrigation; LSD, least significant difference; NI, nonirrigated; SDFC, single degrees of freedom contrast; STD, standard application of N

Table 1. Microirrigation tubing placement and N application treatments.

Treatment name	Treatment description
IR-STD	In-row irrigation with one 112 kg N ha^{-1} application
IR-INC	In-row irrigation with five, weekly 22-kg N ha^{-1} increments
IR-GC	In-row irrigation with 11- to 22-kg N ha^{-1} increments as recommended by GOSSYM/COMAX
AM-STD	Alternate middle irrigation with one 112 kg N ha^{-1} application
AM-INC	Alternate middle irrigation with five, weekly 22 kg N ha^{-1} increments
AM-GC	Alternate middle irrigation with 11- to 22-kg N ha^{-1} increments as recommended by GOSSYM/COMAX
NI-STD	Nonirrigated with one 112 kg N ha^{-1} application
NI-GC	Nonirrigated with 11- to 22-kg N ha^{-1} increments as recommended by GOSSYM/COMAX

treatments, but laterals were located on the soil surface adjacent to the cotton in each row. The sidedress-N was applied in one application (STD), five equal increments (INC), or when recommended by GOSSYM/COMAX (GC). The experimental site was not large enough for the inclusion of a balanced 3 × 3 experiment with all nine water by N treatments, so the NI-INC treatment was not included. Nitrogen application dates and amounts for all years are included in Table 2.

Rainfall and irrigation amounts for each year are presented in Fig. 1. Irrigation applications were managed using the GC model and tensiometers. The GC computes a water stress index and an N stress index, but it is not specifically designed for scheduling N and water applications via subsurface microirrigation. Therefore, model information was supplemented with tensiometer data. Gauge-type tensiometers were installed in the row area at depths of 0.3, 0.6, and 0.9 m in the IR-GC and AM-GC treatments only. Tensiometers were serviced as required, and readings were recorded three times each week. Irrigation was applied when the GC indicated water stress and tensiometers indicated soil water potential at the 0.3-m depth was <-35 kPa. The model was operated three times each week to determine the need for irrigation and N. Irrigation applications were normally 6 mm d^{-1}. Sidedress-N applications for the GC treatments were normally 11 kg ha^{-1} each week. Water, but no N, was added as needed to peanuts. A detailed discussion of the GC operation and the water management impacts on yields can be found in Camp et al. (1997).

Planting and Harvesting

Each plot was 15 m long and 8 m wide, which provided eight rows spaced 0.96 m apart. Each cotton plot received 12 kg N ha^{-1} prior to planting. The cotton cultivar PD 3 was planted on 22 May 1991, 14 May 1992, 12 May 1993, and 19 May 1994. All treatments were hand-thinned to a population of 85 000 plants ha^{-1}. The peanut cultivar 'NC 10' was planted on 29 May 1991 and 23 May 1993. Pesticides were applied at recommended rates to control weeds, insects, and diseases; land plaster (finely ground gypsum) was applied to the peanut at recommended rates.

One meter of peanut row was harvested from each plot in September for shoot dry matter. Fifty meters of rows were dug and harvested for peanut pod yields. Two interior cotton rows (30 m^2) of each eight-row plot were harvested with a spindle picker on 17 Oct. 1991, 12 Nov. 1992, 4 Oct. 1993, and 9 Nov. 1994. Cotton lint yields were calculated from lint percentages determined in the laboratory on a saw gin from subsamples collected from each plot at harvest.

Depleted ^{15}N Studies

We did not have sufficient depleted ^{15}N to allow investigation of all treatments, and we were most interested in the comparison of IR-STD vs. IR-GC, IR-GC vs. AM-GC, and IR-STD vs. NI-STD. Therefore, depleted ^{15}N in the form of ammonium nitrate was applied to one row of each plot for the IR-STD, IR-GC, AM-GC, and NI-STD treatments. A different row was used each year to prevent interaction with residual depleted ^{15}N. The irrigation lateral for each row had a valve at each end and a port that allowed connection to a tractor-mounted pump for depleted ^{15}N applications. Cotton shoot samples were obtained from one meter of row in each depleted ^{15}N plot on three dates. The date with maximum dry matter production was used for calculations. The shoots were air-dried, weighed, and ground. After ginning, the seeds were acid-delinted, dried, weighed, and ground. Ground plant and seed samples were analyzed for total N and atom percent of ^{15}N with a Carlo-Erba model NA 1500 automatic N analyzer interfaced with an Europa Scientific Ltd. (Crewe, Cheshire, UK) Tracermass stable isotope mass spectrometer in the laboratory of Dr. James Schepers, USDA-ARS, Lincoln, NE, (Schepers et al., 1989). Samples were also analyzed with a

Table 2. Sidedress fertilizer N applications to cotton grown on a southeastern Coastal Plain soil.

Year	N treatment†	Weeks after planting											Total N†
		5	6	7	8	9	10	11	12	13	14	15	
		kg/ha											
1991	GC‡	–	11	11	11	23	11	–	–	–	–	–	79
	INC	–	22	22	23	22	23	–	–	–	–	–	124
	STD	–	56	56	–	–	–	–	–	–	–	–	124
1992	GC	–	–	–	11	23	11	11	11	–	–	–	79
	INC	–	–	22	–	23	22	22	23	–	–	–	124
	STD	–	–	56	56	–	–	–	–	–	–	–	124
1993	GC	11	–	–	11	–	–	23	–	–	11	11	79
	INC	22	22	–	23	22	23	–	–	–	–	–	124
	STD	112	–	–	–	–	–	–	–	–	–	–	124
1994	GC	–	–	–	11	–	11	–	11	23	11	–	79
	INC	–	–	22	22	23	22	23	–	–	–	–	124
	STD	–	–	112	–	–	–	–	–	–	–	–	124

† All treatments received 12 kg ha^{-1} N before planting.
‡ Treatment codes for N sidedress treatments are GC = when required by GOSSYM/COMAX, INC. = 112 kg ha^{-1} in five equal increments, and STD = 112 kg ha^{-1} application.

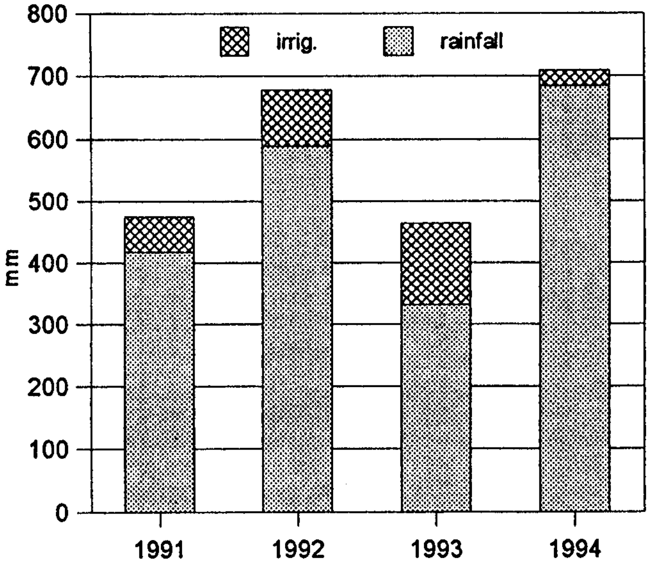

Fig. 1. Seasonal irrigation and rainfall amounts.

TRAACS 800 Auto-Analyzer (Brant Luebbe, Buffalo Grove, IL) for total Kjeldahl N.

Soil samples were collected in 15-cm intervals to a depth of 90 cm. After drying and grinding, samples were digested with sulfuric acid and analyzed for Kjeldahl N. At the conclusion of the 1991- and 1992-crop seasons, soil samples were analyzed for atom percent ^{15}N (Schepers et al., 1989). However, soil dilution prevented the detection of changes in atom percentage, and the soil was not analyzed in 1993 and 1994.

Statistical Analyses

Data were subjected to analysis of variance (ANOVA) (SAS, 1990). Neither rotation nor treatment × rotation terms from the ANOVA were significant, so rotational cotton was pooled into the analyses with the continuous cotton in 1992 and 1994. Differences among means were determined by the LSD test. The LSD values are different for the two rotational years because of the doubled number of experimental units. Comparisons between the following treatments were made with single-degree-of-freedom contrasts (SDFC) (SAS, 1990): GC vs. STD, GC vs. INC (irrigated only), INC vs. STD (irrigated only), lateral spacing (IR vs. AM), and irrigated vs. NI.

RESULTS AND DISCUSSION

Nitrogen from Peanut and Cotton Response to Rotation

Peanut pod yields were low for the eastern Coastal Plain, 2.99 and 2.36 Mg ha^{-1} for 1991 and 1993, respectively; and yields were not significantly different for the water treatments even though peanuts were grown in the two drier years. Water treatments did not significantly affect shoot dry matter accumulations, which were about 2.2 times greater than pod yields. The shoot dry matter weight relative to pod weight was within the range reported by Hunt et al. (1993) for peanut grown under varying water table depths in the Coastal Plain of North Carolina. Vegetative N accumulations were about 96 and 76 kg ha^{-1} yr^{-1} in 1991 and 1993, respectively.

The potential net accumulation of N to the soil system was dependent on the amount of dinitrogen fixation as well as the total accumulation of N in the shoots and pods. A dinitrogen fixation percentage of 65% is a reasonable assumption for unfertilized peanut (Selamat and Gardner, 1985). By Eq. [1], and assuming 65% dinitrogen fixation, the potential net N additions to the soil system in 1991 and 1993 were estimated to be 21 and 17 kg ha^{-1} yr^{-1}, respectively (Hunt et al., 1993).

$$\text{Net N} = [(\text{vegetative N} + \text{pod yield N})(\%\ \text{dinitrogen fixation}) - \text{pod yield N}] \quad [1]$$

Assumptions:

(i) pod yield = 0.72 seed + 0.28 pod wall.
(ii) [seed N] = 0.05, [pod wall N] = 0.014.
(iii) pod yield N = 0.0399 pod yield.

If the fixation percentage had been as low as 50%, there would have been no net addition of N to the soil system. These small potential N additions to the soil system were consistent with the lack of cotton response to the peanut rotation.

Cotton Seed and Lint Yield

Mean cotton seed yields for the eight water and N treatments ranged from 2.02 to 1.64 Mg ha^{-1} (Table 3). The GC-managed cotton yield was not significantly different from either the STD- or INC-managed cotton for production of seed ($P \leq 0.76$ vs. STD and $P \leq 0.46$ vs. INC by SDFC). The INC management of N did not improve seed yield over the STD ($P \leq 0.66$). Nor were the IR and AM treatments significantly different ($P \leq 0.89$ by SDFC). However, the IR-STD treatment had the highest yield ($P \leq 0.01$). There was a significant year × treatment interaction ($P \leq 0.01$), and the interaction was primarily caused by the differences in perfor-

Table 3. Cotton seed and N yield as influenced by irrigation and N application.

	1991		1992		1993		1994		Mean	
Treatment†	**Seed**	**Lint‡**	**Seed**	**Lint**	**Seed**	**Lint**	**Seed**	**Lint**	**Seed**	**Lint**
					Mg ha^{-1}					
IR-STD‡	2.63	1.81	1.06	0.72	2.08	1.34	2.29	1.57	2.02	1.36
IR-GC	2.22	1.61	1.10	0.72	1.74	1.14	2.06	1.44	1.78	1.23
IR-INC	2.62	1.80	0.99	0.65	1.88	1.18	2.05	1.41	1.89	1.26
AM-STD	2.35	1.60	0.91	0.59	1.83	1.15	2.01	1.40	1.78	1.19
AM-GC	2.53	1.73	1.04	0.67	1.81	1.15	2.08	1.47	1.87	1.26
AM-INC	2.60	1.75	0.98	0.63	2.11	1.30	1.86	1.58	1.89	1.32
NI-STD	2.41	1.57	0.96	0.62	1.07	0.68	2.12	1.45	1.64	1.08
NI-GC	2.68	1.91	0.90	0.59	1.28	0.82	2.11	1.43	1.74	1.19
$LSD_{0.05}$	0.39	0.25	0.27	0.18	0.39	0.25	0.27	0.18	0.16	0.07

† IR, AM, and NI represent in-row irrigation, alternate middle irrigation, and no irrigation, respectively. STD, INC, and GC represent single N application, incremental application, and GOSSYM/COMAX application, respectively.
‡ The lint yields for 1991 and 1993 are also reported in (Camp et al., 1997).

Table 4. Cotton seed N content, seed N accumulation, and net excess N addition as influenced by irrigation and N application.

	1991			1992			1993			1994			Mean		
Treatment†	Content	Accumulation	Net	Content	Accumulation	Net	Content	Accumulation	Net	Content	Accumulation	Net	Content	Accumulation	Net
	g kg^{-1}	—— kg ha^{-1} ——		g kg^{-1}	—— kg ha^{-1} ——		g kg^{-1}	—— kg ha^{-1} ——		g kg^{-1}	—— kg ha^{-1} ——		g kg^{-1}	—— kg ha^{-1} ——	
IR-STD	46.4	123	0	49.9	53	70	45.5	95	28	41.3	94	29	45.8	91	32
IR-GC	29.5	67	12	44.4	49	29	40.7	70	8	37.8	78	0	38.1	66	12
IR-INC	31.7	82	41	32.5	32	91	47.4	89	34	34.9	72	51	36.6	69	54
AM-STD	31.9	75	48	33.9	31	92	43.3	80	43	33.5	67	56	35.7	63	60
AM-GC	31.8	81	−3	41.2	43	36	45.5	83	−5	34.9	74	5	38.4	70	8
AM-INC	33.2	87	36	33.2	33	90	41.7	88	35	35.8	78	46	36.0	72	52
NI-STD	30.3	73	50	38.1	36	87	44.0	47	76	37.7	80	43	37.5	59	64
NI-GC	28.8	77	1	29.6	27	51	45.3	58	20	34.4	72	6	34.5	59	20
$LSD_{0.05}$	6.3	18	18	4.5	12	12	6.3	18	18	4.5	12	12	2.6	7	7

† IR, AM, and NI represent in-row irrigation, alternative middle irrigation, and no irrigation, respectively. STD, INC, and GC represent single N application, incremental application, and GOSSYM/COMAX application, respectively.

mance of the NI treatments in the wet and dry years. When the ANOVA was done on only irrigated treatments, the year × treatment interaction was not significant ($P \leq 0.55$). More irrigation was required in 1992 and 1993, and the NI cotton yielded low in those years (Fig. 1 and Table 3). Lint and seed yields were highly correlated ($r = 0.93$, $P \leq 0.01$). A detailed discussion of the rainfall, water management, and lint yields for the experiment is presented in Camp et al. (1997). In addition, they described the high correlation of the early season (first 50 d) degree days heat units and lint yields for this experiment; and the seed yield is similarly correlated to degree days heat units for the first 50 d after planting ($r^2 = 0.72$, $P \leq 0.01$). The early-season-temperature ranking from coldest to warmest was 1992, 1993, 1994, and 1991. Therefore, we conclude that the yearly seed yield differences were associated with early season temperatures, and the year × treatment differences were due to irrigation and rainfall differences among the years.

Cotton Seed N Content, Seed N Accumulation, and Net Excess N

Seed N contents were significantly affected by treatments, years, and treatment × year interactions ($P \leq 0.01$). Only the IR-STD gave consistently high seed N contents. In three of the 4 yr, cotton seed from the IR-STD treatment had the highest N contents, which were always >41 g N kg^{-1} seed (Table 4). The 4-yr mean for the IR-STD was significantly higher ($P \leq 0.01$) than for any other treatment (45.8 vs. < 39 g N kg^{-1} seed). The more favorable N uptake by the seed in the IR treatments may have been because of the large amount of N directly under the plant. In the best year for seed and lint yields, 1991 seed N was distributed in a large seed mass, and only the IR-STD had contents ≥33.2 g N kg^{-1} seed. In contrast, all treatments had seed N contents ≥40.7 g N kg^{-1} in 1993, the year with lowest seed and lint yields. These high N contents were likely related to low rainfall and leaching of N in 1993. Seed N contents were not related to temperature of the seasons as were seed and lint yields. Heat units were not highly correlated to seed N content during either the first 50 d after planting or the whole season, $r = 0.17$ and 0.41, respectively. Rainfall and irrigation differences affected the relative seed N contents from year to year, but there was no dominant treatment impact from rainfall and irrigation on the year × treatment interactions as there were for the seed and lint yields. These data show the ability of cotton seed to differentially accumulate N, and this is a very important characteristic for lowering the net N lost to the soil system.

Seed N accumulation values were significantly different for treatment, year, and treatment × year ($P \leq 0.01$). Cotton managed with the IR-STD was consistently higher than any other treatment for seed N accumulations (Table 4), and the 4-yr mean was significantly higher than any other treatment (91 vs. ≤72 kg ha^{-1}, $P \leq 0.05$). Under AM and NI treatments, the GC-managed cotton accumulated as much seed N as cotton in the STD and INC treatments. In 1991 and 1994, years with lower irrigation, the NI treatments had seed N accumulations equal to the irrigated treatments; but in the other 2 yr, the seed N accumulations in the NI treatments were lower than the irrigated treatments.

The differences in accumulation of seed N and the application rates of fertilizer N produced substantial and significant differences in the net excess N. Treatments, years, and treatment × year interactions were significant by the ANOVA ($P \leq 0.01$). The IR-STD treatment had less net excess N in all years than did the AM-STD treatment (Table 4), and their 4-yr means (32 vs. 60 kg ha^{-1}) were significantly different ($P \leq 0.05$). The net excess N for the NI-STD was 64 kg ha^{-1}, but it had a higher than recommended level of N fertilizer for nonirrigated cotton. The NI-GC excess of 20 kg ha^{-1} was a more realistic estimation of likely excess in nonirrigated cotton. The GC treatments had lower amounts of excess N under all water management systems: 12, 8, and 20 kg ha^{-1} for IR, AM, and NI water management, respectively. The INC treatments had no advantage over the STD treatments in reduction of net N. The STD vs. INC sidedress-N treatments had excess net N applications of 32 vs. 54 kg ha^{-1} and 60 vs. 52 kg ha^{-1} under IR and AM water treatments, respectively. All treatments had high excesses in 1992 (>29 kg ha^{-1}) because of the low seed N that resulted from early cold, early drought, and late excess water. Net excess N for the IR-STD varied from 0 to 70 kg ha^{-1} from 1991 to 1992. These data indicate that the water and N treatments had a greater effect upon seed N accumulation and net excess N than upon the seed or lint yield. AM-GC was the best overall treatment. It had only 8 kg ha^{-1} excess N application, yielded 1.87 Mg ha^{-1} seed, used 50% less

Table 5. Cotton shoot dry matter, shoot N accumulation, and ratio of shoot N to lint yield as influenced by irrigation and depleted ^{15}N nitrogen application.

Treatment†	1991			1992			1993			1994			Mean		
	DM‡	N	N:L§	DM	N	N:L	DM	N	N:L	DM	N	N:L	DM	N	N:L
	Mg ha^{-1}	kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	
IR-STD	6.37	138	7.6	5.14	88	11.0	5.33	125	9.4	3.82	68	4.3	5.17	105	8.1
IR-GC	5.99	114	7.1	4.31	73	10.4	3.40	71	6.3	2.78	46	3.2	4.12	76	6.8
AM-GC	6.13	191	10.9	4.64	76	9.7	5.33	125	12.0	3.35	59	4.0	4.88	113	9.2
NI-STD	6.49	227	14.6	4.33	91	12.9	3.05	77	11.4	4.42	87	5.9	4.57	121	11.2
$LSD_{0.05}$	2.04	64	4.1	1.10	19	2.2	1.60	29	4.1	1.18	21	2.2	0.57	13	2.4

† IR, AM, and NI represent in-row irrigation, alternate middle irrigation, and no irrigation, respectively. STD and GC represent single N application and GOSSYM/COMAX application, respectively.
‡ DM = Dry matter (does not include lint).
§ N:L = kg shoot N per 100 kg lint.

tubing than the IR treatment, and required 36% less N than the STD or INC treatments.

Shoot N and Depleted ^{15}N Accumulations

The four treatments that received depleted ^{15}N during sidedress application of N (IR-STD, IR-GC, AM-GC, and NI-STD) were significantly different for dry matter accumulations ($P \leq 0.01$, Table 5). In each of the 4 yr, cotton dry matter accumulation was numerically lower for the IR-GC treatment than the other two irrigated treatments, and the 4-yr mean was significantly different ($P \leq 0.05$). The lower accumulation of dry matter in cotton managed by IR-GC relative to IR-STD was expected because the STD had more N fertilization, but the lower accumulation relative to the AM-GC was unexpected because the GC treatments had equal amounts of fertilizer. It appears that rather than enhancing the leaching of N, the AM-STD promoted a growth pattern that favored uptake of N. The possibilities of larger root systems and capture of water and N by the AM-GC are supported by the fact that the AM-GC shoots were larger, and they had greater concentrations of N than the IR-GC (22.0 vs. 18.4 g kg^{-1}). Not withstanding this consistently low response to the IR-GC treatment, the year × treatment interaction was significant ($P \leq 0.01$). As with seed yield, dry matter accumulation was greatest in 1991, but the other years did not follow the ranking for seed yield. The irrigated treatments had their lowest dry matter accumulations in 1994, but 1994 was a relatively good year for the NI-STD treatment.

The treatment, year, and treatment × year terms from ANOVA for cotton shoot accumulation of N were significant ($P \leq 0.01$, Table 5). However, the IR-GC-treated cotton consistently accumulated less N than any of the other treatments, and the 4-yr mean was significantly lower than any other treatments (76 vs. ≥105 kg ha^{-1}, $P \leq 0.01$). Based on shoot N accumulations and lint yields, 8.1, 6.8, 9.2, and 11.2 kg N in the cotton shoot were needed to produce 100 kg of cotton lint for the IR-STD, IR-GC, AM-GC, and NI-ST treatments, respectively. The values are in general agreement with Bassett et al. (1970) and Halevy (1976) who found 10 to 13 kg of shoot N needed to produce 100 kg lint in irrigated cotton. Our values were lower than the 19.9 kg of cotton shoot N per 100 kg of cotton lint reported by Mullins and Burmester for dry land cotton (1990), but we used larger (1.0 vs. ≥0.3 m of row) samples, and smaller samples (≤0.3 m of row) may be upwardly biased. Hunt et al. (1987) found that samples of soybean shoots were upwardly biased if they were <1 m in length.

The treatment ranking according to the amount of shoot N that came from fertilizer was about the same as the ranking according to total shoot N (Table 6). Fertilizer N was placed on the surface of the NI-STD treatment and at the 30-cm depth of the IR-STD treatment. The deeper placement of fertilizer N did not decrease the mean amount of fertilizer N uptake, but N uptake by the IR-STD cotton in 1994 may have been decreased by potential leaching from the high rainfall (708 mm). The IR-GC was significantly lower in the amount of fertilizer N uptake than any of the other treatments (18 vs. >26 kg ha^{-1}); percentage uptake relative to the amount applied was also lower (27 vs. >32%). This result was unexpected and contrary to the hypothesis of better N efficiency with the IR-GC treatment, which hypothesized that the IR placement would be the best for capture of water and N before they passed from the root zone. It was thought that the GC management

Table 6. Fertilizer applied N in cotton shoot and seed as influenced by irrigation and depleted ^{15}N nitrogen application.

Treatment†	1991		1992		1993		1994		Mean	
	Shoot	Seed	Shoot	Seed	Shoot	Seed	Shoot	Seed	Shoot	Seed
	kg ha^{-1}									
IR-STD	55 (49)‡	50 (44)	35 (31)	17 (15)	37 (33)	28 (25)	16 (14)	17 (15)	36 (32)	28 (25)
IR-GC	37 (55)	19 (29)	19 (28)	14 (21)	12 (18)	14 (21)	4 (5)	7 (10)	18 (27)	14 (20)
AM-GC	46 (69)	26 (39)	19 (28)	12 (17)	37 (55)	24 (36)	3 (4)	7 (10)	26 (39)	17 (26)
NI-STD	77 (68)	22 (20)	30 (27)	12 (11)	22 (20)	12 (11)	23 (21)	23 (20)	38 (34)	17 (16)
$LSD_{0.05}$	14 (17)	8 (10)	10 (12)	6 (7)	14 (17)	8 (10)	10 (12)	6 (7)	6 (7)	3 (4)

† IR, AM, and NI represent in-row irrigation, alternate middle irrigation, and no irrigation, respectively. STD and GC represent single N application and GOSSYM/COMAX application, respectively.
‡ Numbers in parentheses indicate percentage of sidedress-N fertilizer (67 and 112 kg ha^{-1} N applied for GC and STD, respectively).

would allow the N to be applied more closely to the needs of the plant, thereby dramatically increasing the efficiency of fertilizer uptake. In general, the AM-GC treatment met the expectations of good lint yield and good accumulation of fertilizer in the plant shoot. However, in 1994, neither the cotton in the IR-GC treatment nor that in the AM-GC treatment accumulated >5% of the applied fertilizer N. This may have resulted from rapid initial growth and subsequently slow growth. In any case, the data show dramatic contrast among years. In 1994, the fertilizer uptake was <22%; but in 1991, shoot N in all of the treatments was >49% from fertilizer uptake. The lower ^{15}N uptake data are in agreement with that found by Karlen et al. (1996) for cotton grown on a Norfolk loamy sand in a contiguous experiment; shoot and seed each contained about 15% of the applied N fertilizer in double-cropped cotton that yielded about 0.7 Mg ha^{-1}.

Seed N obtained from fertilizer was affected by water and N treatments ($P \leq 0.01$). Values ranged from 50 to 7 kg ha^{-1} yr^{-1}, but none of the treatments had >44% seed N obtained from fertilizer in any year (Table 6). As expected, the conversion of shoot N to seed N was increased by irrigation. The NI-STD-managed cotton had the lowest percentage seed N obtained from fertilizer (16%). In 1991, the NI-STD-managed cotton had 68% uptake of fertilizer-applied N in the shoot but only 20% uptake in the seed. The IR-STD in 1991 had 49% of the applied N in the shoot and 44% present in seed. This difference was caused by the large difference in seed N concentration because the lint and seed yields varied by <15%. The IR-GC-managed cotton was lowest in amount of N uptake from fertilizer-applied N. The AM-GC-managed cotton had a higher percentage of N obtained from fertilizer than did cotton managed by IR-GC [26 vs. 20%, LSD(0.05)]. In general, the depleted ^{15}N uptake data agree with and support the conclusion of the overall data that the AM-GC was the best treatment for the combinations of seed yield, cost, and N conservation.

CONCLUSIONS

1. Seed yield was affected by the timing of N application, spacing of microirrigation tubing, and irrigation. It was not affected by peanut rotation. Cotton managed by IR-STD had the highest yield.
2. The GC management did not improve seed yield relative to STD or INC management, but it did reduce excess N to <12 and 20 kg ha^{-1} yr^{-1} for irrigated and nonirrigated treatments, respectively.
3. Management by AM-GC was the best for yield and N conservation. It had 1.87 Mg ha^{-1} yr^{-1} seed yield, only 8 kg ha^{-1} yr^{-1} excess N, 45 kg less applied N, and 50% less installed tubing.
4. Cotton managed by AM-GC also had a low (9.2) ratio of accumulated shoot N per 100 kg of lint.

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