Sub-surface drip irrigation fertigation for site-specific, precision management of cotton

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Abstract. *A subsurface drip irrigation study was installed at the Tennessee Valley Research and Extension Center in 2006 to evaluate the effect of four precision fertigation management scenarios and a non-fertigated control on cotton yield, nutrient uptake and lint quality. Approximately 7,500 feet of SDI tape and four positive displacement liquid fertilizer injectors were used to evaluate five nutrient timing treatments with four replications in a randomized complete block design. Each of the twenty treatment plots was made up of eight, 345-foot rows of cotton on 40-inch row spacing, with drip tape between every other row of cotton.*

In 2006, fertigated cotton yields were significantly higher than the surface-applied control. In 2007 and 2008, however, yield in surface-applied control was significantly higher than the fertigated treatments. The better non-fertigated control yield in 2007 and 2008 was possibly due to beneficial downward movement of surface-applied fertilizer as a result of early season rainfall in 2007 and possibly the leaching of fertigated nutrients beyond roots zone as a result of heavy seasonal rainfall in 2008.

Fertigated cotton yields averaged 3.0, 2.9 and 3.5 and the control yields averaged 2.7, 3.1 and 3.9 bales/acre in 2006, 2007 and 2008, respectively.

Generally, surface sidedressing enhanced nutrients uptake better than fertigation but none of them had a direct effect on cotton fiber qualities.

These results show that surface sidedressing and fertigation are not mutually exclusive under rainfed cotton production and the observed responses to SDI fertigation were directly related to the amount and distribution of rainfall during the seasons.

Keywords. Subsurface drip irrigation, fertigation, fertilizer sidedressing, rainfall, cotton yield

Introduction

While the southeastern U.S. has plenty of water available on an average annual rainfall basis, large inter-annual variability in rainfall and frequent dry periods during the growing season make purely rain-fed agriculture a poor competitor to the efficiency of irrigated agriculture (Dougherty et al., 2007). The research presented in this paper is located in northern Alabama in the Tennessee Valley, an area of widespread cotton production. Average annual rainfall in Alabama, is about 55 inches per year (AWIS, 2008). However, because of poor distribution, less than 40% of this amount typically falls during the April to August cotton growing seasons. Under recurring periods of water deficit, irrigation to meet crop water requirements prevents potential yield loss.

Prior studies have shown that drip or sprinkler irrigation increased seed cotton yield compared to rainfed cotton yield (Camp et al., 1994; Camp et al., 1997; Bronson et al., 2001; Pringle and Martin 2003; Sorensen et al., 2004; Kalfountzos et al., 2007). However, Camp et al., (1997) and Bauer et al. (1997) in a four-year study found that cotton did not respond to drip irrigation in two seasons presumably as a result of insufficient amount of irrigation water applied. Similarly, Camp et al. (1999) found that subsurface drip irrigation (SDI) did not increase cotton yield because of root growth was restricted above the SDI line by a soil hard pan.

In addition to water application, sprinkler or SDI systems can be used to precisely apply soluble pesticides and fertilizers to minimize environmental impact due to leaching and runoff. Application of fertilizer nutrients through irrigation systems (fertigation) increases seed cotton yield, water use efficiency and nutrient uptake (Janat and Somi 2001a, b; Janat, 2004; Enciso-Medina et al., 2007; Thind et al. 2008). Drip and other irrigation systems permit multiple injections of small doses of fertilizers at different intervals, reducing the risk of leaching compared to fertilizers applied in a single application. Notwithstanding, Hunt et al. (1998) found that sidedressing of N using drip irrigation in a single application produced the highest seed cotton yield compared with five split drip-applications. Similar results have been reported by Hou et al. (2007) for N applied at the beginning of the irrigation cycle rather than N applied in more frequent, smaller doses throughout the irrigation cycle. Bauer et al. (1997) found that N application method (single versus five split drip-applications) through SDI had no effect on cotton yield.

Therefore, objective of this study was to evaluate the effect of four precision fertigation management scenarios and a non-fertigated control on cotton yield, nutrients uptake and lint quality.

Materials and Methods

A subsurface drip irrigation (SDI) and fertigation study was initiated in 2006 at the Auburn University Tennessee Valley Research and Extension Center (TVREC), in Belle Mina, Alabama. The study was designed to evaluate four precision fertigation management scenarios and a non-fertigated control on cotton (*Gossypium hirsutum* L.). Individual fertigation treatments were described in Table 1. Approximately 7,500 feet of SDI tape and four positive displacement fertilizer injectors were being used to evaluate four replications of five nutrient timing treatments. Each of the resulting twenty treatment plots was made up of eight 345-foot rows of cotton on 40-inch row spacing, with drip tape between every other row of cotton (Figure 1).

Table 1. Treatment description in fertigation management trials, 2006-2008.

Treatment	Description
1. Control - drip irrigated, but all fertilizers are surface applied.	Preplant - N and K @ 60 pounds per acre. Post-Plant N (75lb/A) sidedressed at early square.
2. Drip timing 1 – with surface preplant	Preplant - 20 pounds of N and K (surface). Drip 40 pounds N, K –square to bloom (25 days) Drip 75 pounds N, K – bloom to 25 days
3. Drip timing 1 – no preplant	Planting Drip - 20 pounds N, K Drip 40 pounds N, K–square to bloom (25 days) Drip 75 pounds N, K – bloom to 25 days
4. Drip timing 2 – no preplant "spoon-fed"	Planting Drip - 20 pounds N, K Drip 40 pounds N, K square to bloom (25 days) Drip 75 pounds N, K – bloom to 40 days
5. Drip timing 2 – with surface preplant	Preplant - 40 pounds of N and K (surface). Drip 95 pounds N, K–square through bloom (50 days)

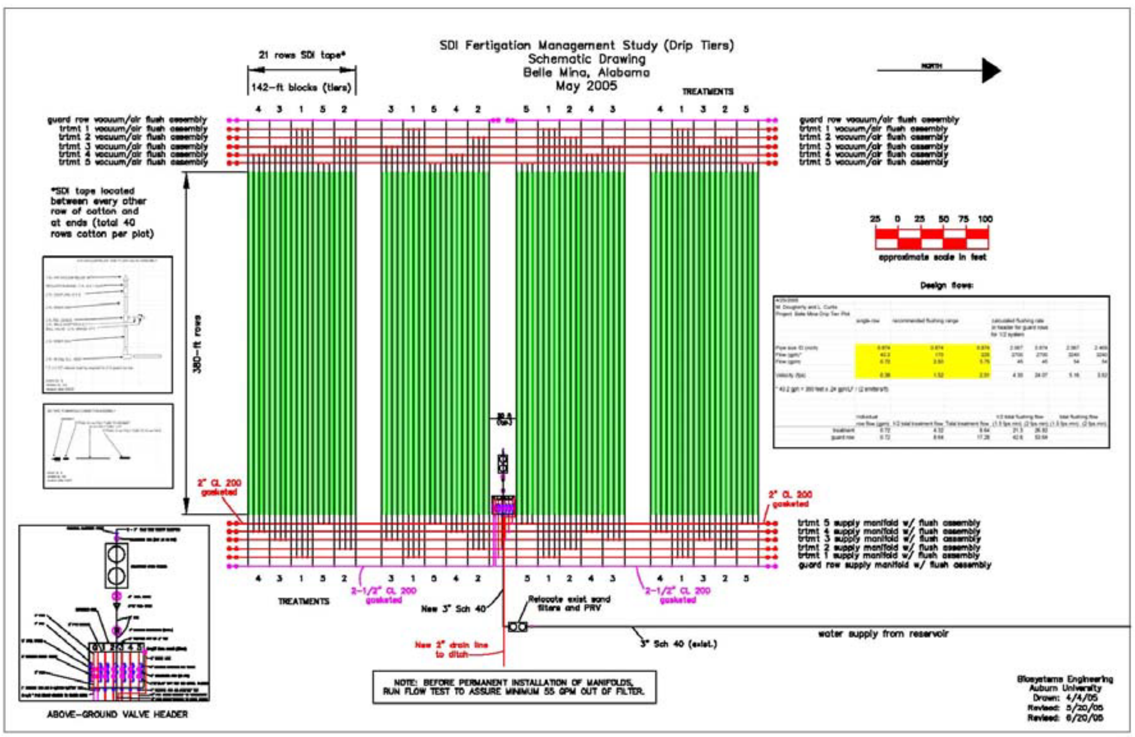

Figure 1. Design layout for drip tier fertigation management study, Belle Mina, AL, 2006-2008.

Emitters were located 24 inches along the tape with tape buried approximately 12-15 inches between every other two rows, providing four harvested rows per treatment for yield comparisons. Spacing between drip tape and two rows was 20 inches, similar to an agricultural field using an alternate row drip tape spacing of 80 inches. Rows 345 feet in length were used to better approximate field operational conditions (Figure 1).

A NETAFIM SDI tape was used in this study with the following specifications: 0.874" internal diameter, 15 mil wall thickness, 24" emitter spacing, 0.24 gph emitter flow rate, and 10 psi operating pressure.

The flow rate of the SDI tape was evaluated at least twice per season typically at the beginning and end of the growing season, after system flushing and cleaning. Flushing and cleaning operations were conducted using both chlorine and hydrochloric acid solutions.

Fertilizer was applied using two methods; 1) surface via conventional sidedress and 2) subsurface via fertigation. Sidedressing and fertigation treatments were applied as described in Table 1. All other farm cultural management practices were carried out according to standard agronomic recommendations from Auburn University.

All treatments received 135 pounds per acre of nitrogen (N) and potassium (K_2O), 20 pounds per acre of sulfur, and l.0 pound per acre of boron. Phosphorus fertilizer was surface-applied to maintain P at high soil test levels. Drip fertilizer, 8-0-8-1.2S-0.06B, was made using 32% liquid N, potassium thiosulfate, fertilizer grade KCL, solubor, and water.

Cotton variety, DPL 445 BR, was planted in each year. Planting was carried out in April each season by row unit planters in rows at 40" and 4" as inter-row and inter-plant spacing, respectively.

Leaf sampling was carried out by taking 4th or 5th fully-expanded leaf from the growing apices of plants in the middle of the plots for all treatments during middle-bloom stage. About 30-40 leaves per treatment were collected while walking directly above an SDI drip line. Leaf nutrient analysis was carried out according to the methods of Auburn University Soil-Plant Testing Laboratory.

Since each treatment was applied to eight rows of cotton, two rows of cotton on each side of the plot were treated as an unharvested border or guard row. The four middle yield rows were harvested by a cotton picker after removing 3 feet from both ends of each row and weighed using a boll buggy equipped with electronic load cells to measure accumulated seed cotton yield per plot. Average post-harvest turnout from the gin was used to determine lint yield and subsequent lint quality analysis was determined in normal ginned cotton samples by USDA, AMS Cotton and Tobacco Programs, Birmingham Classing Office.

The experimental layout was a randomized complete block design with 5 treatments and 4 replications (Figure 1). Yield data for each season was analyzed statistically using a Statistix 8 (Analytical Software, 2003) and Tukey's method at $\alpha = 0.10$ for treatments comparison.

Results and Discussion

2006 season results: Cotton was harvested on October 10 and on October 24, 2006 and evaluated for yield, quality, and leaf nutrients. Results (Figure 2 and Tables 2) indicate differences in cotton yield, quality, and leaf nutrients by treatment. Fertigated cotton yields were significantly higher ($\alpha = 0.1$) than the non-fertigated control (treatment 1). In 2006, higher yields were observed where all fertigated nutrients were applied within 50 days of square. Fertigation treatments 2 and 5, the two highest yielding treatments, received 20 and 40 pounds, respectively, of preplant surface nitrogen and potassium (K_2O). The "spoon-fed" treatment 4 that received no preplant nitrogen and potassium produced the lowest but statistically ($\alpha = 0.1$) comparable yield to treatment 3 and 5. Plant uptakes for N and P for all treatments were statistically ($\alpha = 0.1$) the same. Magnesium uptake was significantly ($\alpha = 0.1$) higher in non-fertigated control than fertigated treatments. No consistent uptake pattern was observed for K and Ca uptake. No statistical differences ($\alpha = 0.1$) were observed among treatments on lint qualities except for the highest micronaire value in the non-fertigated control. Fertigated cotton yields averaged 3.0 bales in 2006.

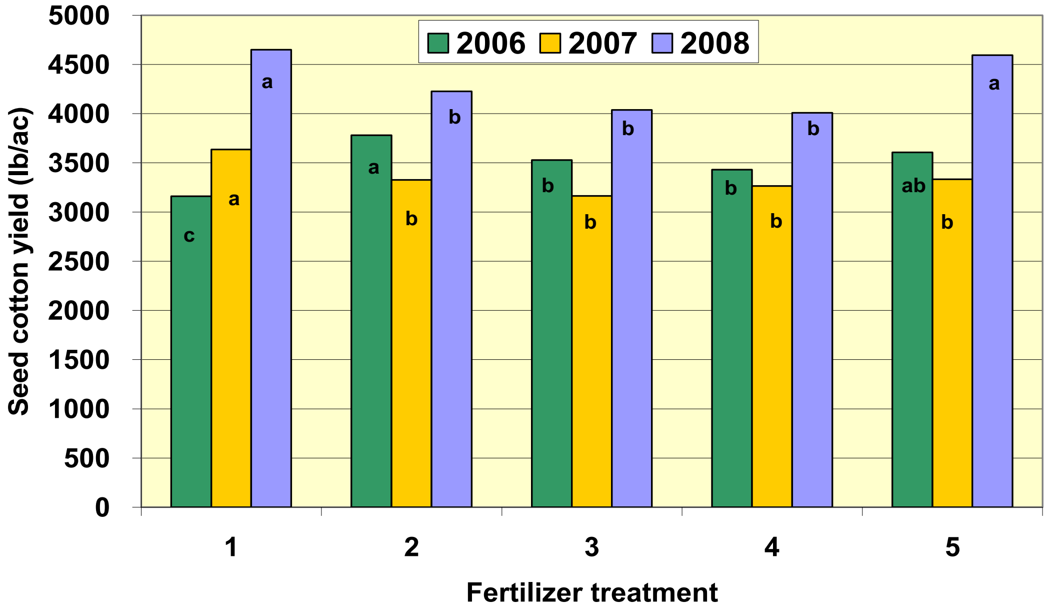

Figure 2. Seed cotton yield in drip tier fertigation management study, Belle Mina, AL, 2006-2008. Different subscripts within a year denote statistical difference ($\alpha = 0.10$).

Table 2. Lint yield and quality analysis in cotton fertigation management trials, 2006.

Trt*	Bales/ac	Micro-naire	Length (in)	Strength (g/tex)	Uniformity (%)	N%	P%	K%	Ca%	Mg%
1	2.7c	4.83a	1.13a	31.1a	84.3a	3.88a	0.28a	1.48a	2.06a	0.35a
2	3.2a	4.63b	1.15a	30.8a	84.4a	3.92a	0.29a	1.46a	2.01a	0.31b
3	3.0b	4.60b	1.12a	30.6a	84.2a	3.62a	0.24a	1.28b	1.87b	0.32b
4	2.9b	4.65b	1.13a	30.1a	83.8a	3.59a	0.30a	1.44a	2.07a	0.31b
5	3.1ab	4.58b	1.13a	30.2a	83.9a	3.80a	0.26a	1.32b	1.87b	0.32b

*1. Surface applied N-P-K with drip irrigation (control). 2. Preplant 20# N-K surface with 2 N-K drip timings. 3. 20# N-K drip at planting with 2 N-K drip timings (to 25 days after bloom). 4. 20# N-K at planting with 2 N-K drip timings (to 40 days after bloom). 5. Preplant 40# N-K surface with 1 N-K drip timing (square through bloom). Different subscripts denote statistical difference ($\alpha = 0.10$). Turnout = 41%.

2007 season results: Cotton was harvested on October 2, 2007 and evaluated for yield, quality, and leaf nutrients. Results in Figure 2 and Table 3 indicate differences in cotton yield, quality, and leaf nutrients by treatment. The non-fertigated control (treatment 1) was the highest yielding treatment in 2007 and was significantly different ($\alpha = 0.1$) from all fertigated treatments. All fertigated treatments gave statistically ($\alpha = 0.1$) similar yields. Except for P, the plants from this highest yielding treatment had significantly ($\alpha = 0.1$) higher levels of uptake for N, K, Ca, and Mg than fertigated treatments (treatments 3 and 4). Fertigated treatments (treatments 2 and 5), received 20 and 40 pounds of preplant surface nitrogen and potassium (K_2O), showed higher N and K uptake than the two treatments receiving no preplant nitrogen and potassium (treatments 3 and 4). No statistical ($\alpha = 0.1$) effect was noted for all treatments on lint qualities (Table 3). Fertigated cotton yields averaged 2.9 bales in 2007.

Table 3. Lint yield and quality analysis in cotton fertigation management trials, 2007.

Trt*	Bales/ac	Micro-naire	Length (in)	Strength (g/tex)	Uniformity (%)	N%	P%	K%	Ca%	Mg%
1	3.1a	4.40a	1.11a	31.12a	83.98a	4.64a	0.44c	1.74a	3.30a	0.57a
2	2.8b	4.52a	1.11a	30.72a	84.22a	4.12b	0.54a	1.58ab	3.09ab	0.42bc
3	2.7b	4.48a	1.10a	29.62a	83.85a	3.95b	0.47bc	1.47b	2.84c	0.39c
4	2.8b	4.45a	1.09a	30.80a	83.92a	3.49c	0.49b	1.48b	2.99bc	0.41bc
5	2.8b	4.40a	1.12a	30.88a	84.35a	4.14b	0.47bc	1.57ab	3.08ab	0.44b

*1. Surface applied N-P-K with drip irrigation (control). 2. Preplant 20# N-K surface with 2 N-K drip timings. 3. 20# N-K drip at planting with 2 N-K drip timings (to 25 days after bloom). 4. 20# N-K at planting with 2 N-K drip timings (to 40 days after bloom). 5. Preplant 40# N-K surface with 1 N-K drip timing (square through bloom). Different subscripts denote statistical difference ($\alpha = 0.10$). Turnout = 41%.

For 2006 and 2007, two of the driest consecutive years on record at TVREC, fertigated yields were lower in 2007 than in 2006 (Figure 2). In 2007, plant tissue nutrients were generally higher in the highest yielding treatments (Table 3). In 2006, the surface-applied control had levels of plant tissue N, P, and K comparable to the highest yielding fertigated treatment (Table 2). Chemical movement of surface applied fertilizer early in the season was enhanced in 2007 due to 7 storms averaging 0.65" from May through July. Comparable storm events in 2006 delivered 0.41" per event. In spite of comparable seasonal rainfall for 2007 and 2006 (Figure 3) early season rainfall in 2007 assisted delivery of surface-applied nutrients. In addition, several large convectional storms later in the 2007 moved surface-applied nutrients lower into the horizon, potentially leaching fertigated nutrients out of reach of roots.

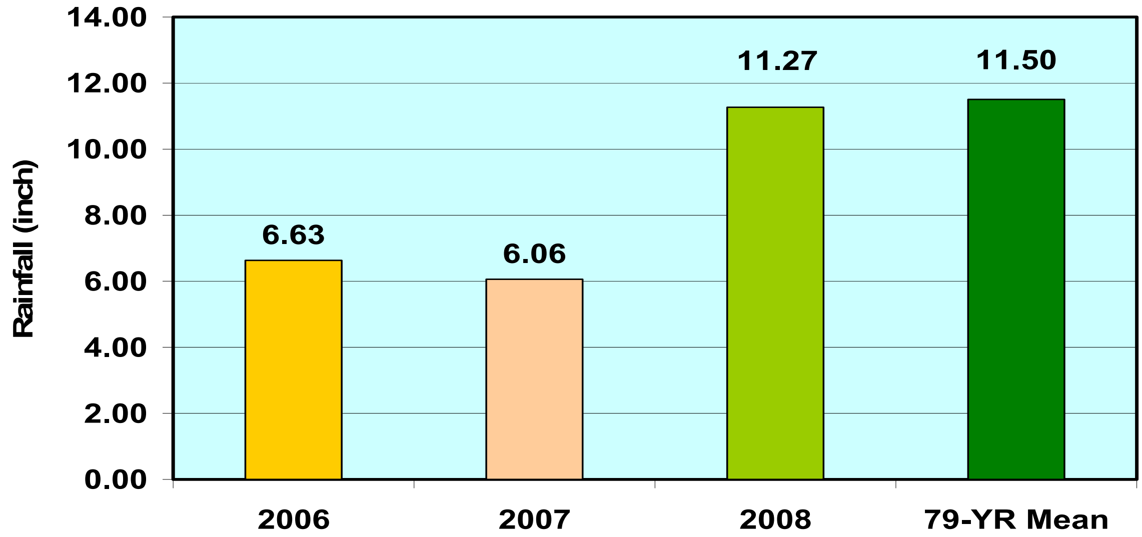

Figure 3. Total seasonal rainfall during June, July, and August period vs. 79-year average.

2008 season results: Cotton was harvested on October 13, 2008 and results are shown in Figure 2 and Table 4. Total seasonal rainfall at TVREC (Figure 3) during June-August period for 2008 was 11.27", which was near normal average (11.50"), and thus seed cotton yields for this season were exceptionally higher than in 2006 and 2007. However, the pattern of response to fertilizer treatments in 2008 is similar to 2007 (Figure 2). In this season, the 100% fertigated treatments (treatment 3 & 4) produced significantly ($\alpha = 0.1$) lower yields than treatment 1 (100% surface-applied) and treatment 5 (30% surface + 70% drip) and they gave comparatively lower yield (Figure 2) than treatment 2 (15% surface + 85% drip). The non-fertigated control treatment and the fertigated treatments that received surface-applied, preplant nitrogen and potassium (K_2O) responded much better in 2008, possibly due to sufficient rainfall and better downward movement of surface-applied fertilizer. However, higher rains may have also resulted in leaching fertigated nutrients farther out of the root zone. This may also explain the plant yellowing and the less vegetative growth observed in treatments 3 and 4 during the season. Soil compaction impeding root growth towards fertigated nutrients cannot be ruled out since the experiment is conducted in a no-till field. Statistically, treatment 1 was the best yielding treatment in 2007 and 2008 whereas treatment 3 and 4 were the least yielding.

Cotton lint yield (bales/acre), lint quality parameters, and leaf nutrient analyses for 2008 are presented in Tables 4. None of the quality parameter was significantly ($\alpha = 0.1$) affected by different fertilizer treatments except for lint length. Lint length in the 100% fertigated treatments (treatment 4) was significantly ($\alpha = 0.1$) higher than the fertigated treatments that received surface-applied, preplant nitrogen (N) and potassium (K_2O). Plant uptake for N and K was significantly ($\alpha = 0.1$) higher in the surface-applied control treatment (treatment 1) than the fertigated treatments with or without surface application. Higher seasonal rainfall in 2008 may have assisted delivery of surface-applied, preplant N and K. Phosphorus, Ca, and Mg contents were not significantly affected by any treatment.

Table 4. Lint yield and quality analysis in cotton fertigation management trials, 2008.

Trt*	Bales/ac	Micro-naire	Length (in)	Strength (g/tex)	Uniformity (%)	N%	P%	K%	Ca%	Mg%
1	3.9a	4.62a	1.10b	27.2a	84.2a	4.32a	0.28a	1.20a	2.27a	0.26a
2	3.5b	4.78a	1.07c	27.2a	83.2a	3.36c	0.27a	1.09b	2.22a	0.26a
3	3.4b	4.75a	1.11ab	28.5a	84.1a	3.24c	0.28a	1.13b	2.26a	0.25a
4	3.3b	4.58a	1.13a	28.4a	84.5a	3.35c	0.30a	1.14b	2.36a	0.26a
5	3.8a	4.65a	1.09bc	28.9a	84.0a	3.57b	0.28a	1.13b	2.28a	0.26a

*1. Surface applied N-P-K with drip irrigation (control). 2. Preplant 20# N-K surface with 2 N-K drip timings. 3. 20# N-K drip at planting with 2 N-K drip timings (to 25 days after bloom). 4. 20# N-K at planting with 2 N-K drip timings (to 40 days after bloom). 5. Preplant 40# N-K surface with 1 N-K drip timing (square through bloom). Different subscripts denote statistical difference ($\alpha = 0.1$). Turnout = 40%.

Although this study did not include a rainfed control, the high yield obtained is likely due to supplemental irrigation provided by SDI system. The beneficial cotton yield response to irrigation during insufficient growing season rainfall has been reported by several researchers (Camp et al., 1994; Bronson et al., 2001; Pringle and Martin 2003; Sorensen et al., 2004; Kalfountzos et al., 2007; Dougherty, et al., 2010).

Surprisingly, during this first period of the study, surface-sidedressing of fertilizer out yielded all fertigated treatments in two seasons (2007, 2008). Only in the first year (2006), a dry season, did fertigated treatments significantly increase cotton yield over surface-applied fertilizer. Since this study was conducted under rainfed conditions and as outlined earlier, the amount and distribution of rainfall are likely to have contributed largely to the lack of response to fertigation (Dougherty, et al., 2010). Delivering of surface-applied nutrients to the roots or leaching of fertigated nutrients away from the roots by rains or irrigations are possible too. The inability of roots to reach the fertigated nutrients at the drip line depth due to a soil hard pan could also be another reason. Comparing these results with previous and current research in this area, it is noted that the lack of response to fertigation observed herein contradicts the results of Janat and Somi (2001a, b), Janat (2004), Enciso-Medina et al. (2007) and Thind et al. (2008) who found that fertigation increased seed cotton yield. However, the results of increased seed cotton yield due to surface-applied sidedress with irrigation are in line with Hunt et al. (1998) and Hou et al. (2007) who found that sidedressing of N using drip irrigation in a single application increased cotton yield compared with multiple split applications.

In two seasons, surface-sidedressing coupled with supplementary SDI and rains resulted in generally better nutrient uptake than fertigation, particularly with N and K and indirectly to some extent with Ca and Mg but not P. However, this nutrient enhancement had no clear bearing effect on cotton lint qualities. Coker et al. (2009) reported that cotton lint yield responded 40% of the time to soil-applied K for irrigated cotton rather than for rainfed cotton. Girma et al. (2007) reported that application of N, P and K had some effects on cotton lint yield due to largely N and P whereas N and K were likely to affect lint qualities. The enhanced N and K uptake by sidedressing observed in this study increased lint yield without clear consistent effect on fiber qualities.

Conclusions

Under conditions of this study, conventional fertilizer surface sidedressing under SDI system out performed fertigation in two seasons out of three. Fertigation significantly increased cotton yield over conventional fertilizer sidedressing in the first season. Surface sidedressing enhanced nutrients uptake better than fertigation. Neither surface sidedressing nor fertigation had direct effect on cotton lint qualities. The observed responses to SDI fertigation were directly related to the amount and distribution of rainfall during the seasons. This is a long-term study in which cotton response to these treatments will continue to be evaluated under a wide range of climatic conditions.

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