Published March 6, 2014

Enhanced-Efficiency Fertilizer Effects on Cotton Yield and Quality in the Coastal Plains

Dexter B. Watts,* G. Brett Runion, Katy W. Smith Nannenga, and H. Allen Torbert

ABSTRACT

Interest in the use of enhanced-efficiency nitrogen fertilizer (EENFs) sources has increased in recent years due to the potential of these new EENF sources to increase crop yield, while at the same time decreasing N loss from agricultural fields. The efficacy of these fertilizer sources on cotton (*Gossypium hirsutum* L.) production in southeastern U.S. upland soils has not been well documented. Thus, a field study was conducted on a Coastal Plain soil (Marvyn loamy sand; fine-loamy, kaolinitic, thermic Typic Kanhapludult) in Central Alabama from 2009 to 2011 to compare EENFs to traditional N sources in a high-residue conservation cotton production system. Nitrogen fertilizer sources evaluated included urea (U), ammonium sulfate (AS), urea-ammonium sulfate (UAS), Environmentally Smart Nitrogen (ESN) (Agrium Advanced Technologies, Loveland, CO), stabilized urea (SuperU [SU] [Agrotain International, St. Louis, MO]), poultry litter (PL), poultry litter + AgrotainPlus (PLA) (KOCH Agronomic Services LLC, Wichita, KS), and an unfertilized control (C). Generally, no significant differences in cotton lint yield were observed between the traditional sources and EENFs. Nitrogen source affected fiber quality; however, effects varied among years and generally would not have impacted discount/premium values. In the present study, EENFs produced cotton lint yields similar to conventional fertilizers, suggesting their higher cost may render them uncompetitive at present. However, if EENFs reduce N loss through leaching, runoff and N_2O flux from agricultural fields they could become viable alternative fertilizer sources. More research is needed on the benefits of enhanced-efficiency fertilizer use as a tool in agricultural production systems.

Nitrogen is often the most limiting nutrient in agricultural production systems and N additions are commonly required to achieve maximum yields. During the past century, the use of synthetic N sources have surpassed the use of organic sources (manures and legume rotations) in agricultural systems throughout most of the world (Smil, 2001); a necessity to feed an increasing population. Synthetic N use in the United States increased from 2.5 to 11.7 Tg between 1960 and 2011 (USDA-ERS, 2013). However, a renewed interest in use of manure has recently occurred due to the increasing cost of synthetic N sources and a need to deal with the large amounts of manure generated by concentrated animal production systems. For example, the U.S. poultry industry generates about 11.4 Tg of broiler litter (a mixture of manure, feed, and organic bedding material such as peanut hulls or sawdust) each year (Mitchell and Tu, 2005). Application of poultry litter to cropland serves as an important means of its safe disposal while also providing a plant nutrient source and increasing soil organic matter. Regardless of source, it is necessary to improve agricultural N management to provide food and fiber for the world's growing population.

Current fertilization recommendations often exceed plant N demand (Mulvaney et al., 2009). Estimates of worldwide nitrogen use efficiency (NUE) are 30 to 50% in most agricultural soils (Delgado, 2002), leaving the excess subject to runoff, leaching, volatilization, and loss as nitrous oxide (N_2O), a potent greenhouse gas (GHG) contributing to global climate change (IPCC, 2007). Poultry litter applied to cropland may also increase emissions of methane (CH_4), another potent GHG (Sistani et al., 2011), as well as N_2O. There is also concern it, too, may lead to water impairment through NO_3 leaching and runoff (Williams et al., 1998). Loss of N also poses other risks to the environment and to human health (Spalding and Exner, 1993). Consequently, efforts are being made by agricultural researchers to synchronize N applications with plant uptake to reduce N losses (Balkcom et al., 2003).

One new management practice being assessed to reduce N losses is use of EENFs which include slow-release, controlled-release, and stabilized N fertilizers (Halvorson et al., 2014). In the past, cost has limited application of these materials to high-value systems such as horticultural crops and turf (Hauck, 1985). However, advances in fertilizer technology have produced alternative N fertilizers which may be economically

D.B. Watts, G.B. Runion, and H.A. Torbert, USDA-ARS, National Soil Dynamics Lab., 411 S. Donahue Dr., Auburn, AL 36832; K.W. Smith Nannenga, Univ. of Minnesota, Crookston, 2900 University Ave. Crookston, MN 56716. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. Received 29 Apr. 2013. *Corresponding author (Dexter.Watts@ars.usda.gov).

Published in Agron. J. 106:745–752 (2014)
doi:10.2134/agronj13.0216

Abbreviations: AS, ammonium sulfate; EENF, enhanced-efficiency nitrogen fertilizer; ESN, Environmentally Smart Nitrogen; GHG, greenhouse gas; HVI, high volume instrumentation; NUE, nutrient use efficiency; PL, poultry litter; PLA, poultry litter + AgrotainPlus; SuperU, stabilized granular urea; U, urea; UAS, urea-ammonium sulfate.

viable for use in row-crop agriculture (Halvorson et al., 2014). For example, ESN, AgrotainPlus, and SuperU are products developed to control N release or modify soil-fertilizer reactions. Environmentally Smart Nitrogen is a controlled-released urea fertilizer containing a water permeable polymer coating that allows a gradual release of N during the growing season, where N release increases with moisture and temperature (ESN, 2013). AgrotainPlus is a fertilizer supplement containing both urease [N-(n-butyl)-thiophosphoric triamide] and nitrification (dicyandiamide) inhibitors (Koch, 2013). SuperU is a stabilized urea source containing the same urease and nitrification inhibitors as AgrotainPlus that are uniformly distributed throughout the granule during manufacturing. Use of nitrification and urease inhibitors, such as AgrotainPlus, with manure may reduce N losses associated with land application.

Regardless of the potential environmental benefits of either manure or alternative N fertilizers, their use will not be adopted by producers until their effects on crop yield are thoroughly evaluated. It is expected that EENFs, products developed to control N release or modify soil-fertilizer reactions, will increase crop growth and yield; however, there remains a paucity of information on this subject. While use of alternative N sources has been investigated in high-value crops such as vegetables (Guertal, 2000), effects in row crops are only beginning to be evaluated (Nelson et al., 2009; Halvorson et al., 2011), and no work to date has investigated the effects of EENFs in cotton. Further, current results have shown highly variable effects of EENFs on crop yield (Cahill et. al., 2010). Given that N release and plant uptake will vary by crop species, N source, climate, and soil type (Nelson et al., 2009; Cahill et al., 2010), much more research is needed to verify responses under varying conditions within different cropping systems. The objective of this study was to evaluate the effects of N source (standard inorganics, EENFs, and poultry litter) on cotton lint yield and fiber quality in the southeastern United States.

MATERIALS AND METHODS

Site Description

A field experiment was conducted from 2009 to 2011 at the Alabama Agricultural Experiment Station's E.V. Smith Research Center–Field Crops Unit (32°25′19″ N, 85°53′7″ W) near Shorter, AL. The soil was a Marvyn loamy sand which is representative of a Coastal Plain soil. The Marvyn series consists of deep, well-drained, moderately permeable soils formed from loamy marine sediment on Coastal Plain uplands. Climate for this region is humid subtropical with mean annual precipitation of approximately 1350 mm and an annual temperature of 18°C (Current Results, 2013). The experimental site had a soil organic matter content of 6.3 g kg^{-1} and an average pH of 6.4.

Experimental Design and Treatments

The experiment was conducted using a randomized complete block design with four replicate blocks based on landscape position. The experiment was conducted for three consecutive years with treatments applied to the same plots to simulate a continuous cropping system. Nitrogen fertilizer source treatments evaluated were: Urea (U; 46% N); Urea Ammonium Sulfate (UAS; 34% N); Ammonium Sulfate (AS; 21% N); SuperU (SU; 46% N); ESN (44% N); poultry litter (PL; 4% N); and poultry litter +AgrotainPlus (PLA; 4% N). Poultry litter used in this study was collected from a local broiler production facility (Table 1) and consisted of poultry manure and a bedding material mixture (wood shavings and/or sawdust). The PLA treatment consisted of surface broadcasting poultry litter followed by applying AgrotainPlus (0.5 g kg^{-1} poultry litter) on top of the litter using a six-nozzle handheld boom attached to an electric powered sprayer. All fertilizers were surface broadcast by hand at the recommended rate of 101 kg total N ha^{-1} (Mitchell and Phillips, 2010) 5 to 6 wk after planting each year. An unfertilized control (no N) was also included.

The agricultural production system used to evaluate N source impacts on cotton biomass consisted of no-till management with cereal rye (*Secale cereale* L.) as winter cover. Each experimental unit contained four planted rows spaced 1.0 m apart in 4.1 by 7.6 m (31 m^2) plots. Plots within blocks were separated with a 1.0 m buffer (unfertilized cotton row); a 7.6 m unfertilized fallow alley separated replicate blocks. The rye was planted in November of each year at a rate of 100 kg ha^{-1} using a no-till grain drill and killed 7 to 10 d before planting cotton by spraying with glyphosphate (N-phosphosnomethyl glycine) at a rate of 0.95 kg a.e. ha^{-1} and rolling with a roller/crimper. Cotton was planted at a rate of 17 seeds m^{-1} row each year. Three different varieties were used for this study, based on seed availability, which is a common practice for cotton farmers in the area. Deltapine 454 BT Stack was planted on 12 June 2009, Photogen 375 was planted on 13 May 2010, and Deltapine 0949 BT 2 Roundup Flex was planted on 17 May 2011. Herbicides and insecticides were applied to cotton as needed based on Alabama Cooperative Extension System's recommendations. During periods of drought stress, cotton received supplemental irrigation as needed using an overhead lateral irrigation system. Cotton was chemically defoliated and a boll opener applied when 60 to 70% of the bolls were opened. After harvesting each year, cotton stalks were shredded with a rotary mower.

Yield Harvest and Lint Analysis

Cotton yield was determined 2 wk after chemical defoliation by picking the entire length of the center two rows in each plot with a two-row spindle picker. Cotton was harvested on 9 Nov. 2009, 1 Oct. 2010, and 27 Oct. 2011. Cotton from each plot was collected in cloth bags and fresh weight measured. A subsample (approximated 1 kg) from each plot was ginned with

Table 1. Poultry litter chemical characteristics on a dry-weight basis.

Year	Moisture	C	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
	%		g kg^{-1}					mg kg^{-1}			
2009	15.1	34.4	40.4	20.6	42.1	32.7	11.0	3199	6430	596	620
2010	27.6	33.6	38.5	15.4	34.2	28.0	8.9	1443	244	440	358
2011	16.5	32.9	35.6	15.9	32.4	25.7	13.4	4931	203	843	464

a bench-top gin with lint, seed, and trash separated. Ginning percentage, calculated as (100 × lint weight)/(weight of lint + seed + trash), was used to convert seed cotton yield to lint yield. A subsample of the ginned cotton from each plot was sent to the USDA Agricultural Marketing Service (AMS) Cotton Division cotton classing office (USDA-AMS, Pelham, AL) for high-volume instrumentation (HVI) analysis of fiber properties (length, micronaire, strength, fiber length uniformity, reflectance, and yellowness) plus percent trash.

Data Analysis

Data analysis was conducted using the mixed model procedures (Proc Mixed) of the Statistical Analysis System (Littell et al., 1996). Error terms appropriate to the randomized complete block design were used to test the significance of N fertilizer treatments. Treatment means were separated using the PDIFF option of the LSMEANS statement; a significance level of α = 0.10 was established a priori.

RESULTS AND DISCUSSION

Climatic Conditions

Weather conditions varied markedly among the 3 yr of study (Fig. 1); however, precipitation was sufficient to produce crop lint yields in excess of 1000 kg ha^{-1} each year. Monthly precipitation data collected from the Alabama Agricultural Experiment Station's E.V. Smith Research Center show that totals were 1881 mm in 2009 with 832 mm occurring during the growing season, 899 mm in 2010 with 402 mm occurring during the growing season, and 1033 mm in 2011 with 482 mm occurring during the growing season. The wettest growing season occurred in 2009 and the driest in 2010; differences in precipitation percentages among these growing seasons ranged from 37% above to 34% below the 30-yr average (Current Results, 2013). Average growing season air temperatures were 24.2, 27.6, and 25.1°C for 2009, 2010, and 2011, respectively. Generally, monthly temperatures among growing seasons did not deviate more than 1°C from the 30-yr average during the course of this study, except in 2010 which was 15% above average. The wettest year (2009) had the lowest temperature and the driest year (2010) had the highest temperature.

Lint Yield and Ginning Percentage

In general, cotton lint yield responded to precipitation totals with the greatest yield occurring in 2009 and the lowest occurring in 2010 (Fig. 2). Lint yield differed among the 3 yr with 2009 > 2011 > 2010 (Table 2). As expected, addition of fertilizer, regardless of source, increased cotton yield compared to the unfertilized control across all 3 yr (Table 3). Although the year × N interaction was not significant, this trend was seen each year (Fig. 2). In all years, no significant differences were observed among fertilizer sources, indicating that the EENFs did not differ from the common inorganic fertilizers. It is interesting to note that yields for PL and PLA were among the lowest in 2009, but were among the highest in 2010 and 2011 (Fig. 2). Poultry litter mineralizes N slowly, with only 50 to 60% available the first year and the remainder becoming available in subsequent years (Delgado, 2002). In general, few differences in lint yield were noted among N sources in this study. This was not unexpected given that the recommended rate of 101 kg N ha^{-1} (Mitchell and Phillips, 2010) was used for all N sources. Further, other researchers have shown few differences between EENFs and traditions fertilizers in agricultural crops. Guertal (2000) found few differences in bell pepper (*Capsicum annuum* L.) yield or quality among sulfur-coated urea, polyolefin resin coated urea and liquid ammonium nitrate. Cahill et al. (2010) found no difference in corn (*Zea mays* L.) or wheat (*Triticum aestivum* L.) grain yield for NutriSphere, ESN, UCAN-23 compared with UAN in North Carolina. Similarly, Halvorson et al. (2011) reported that corn

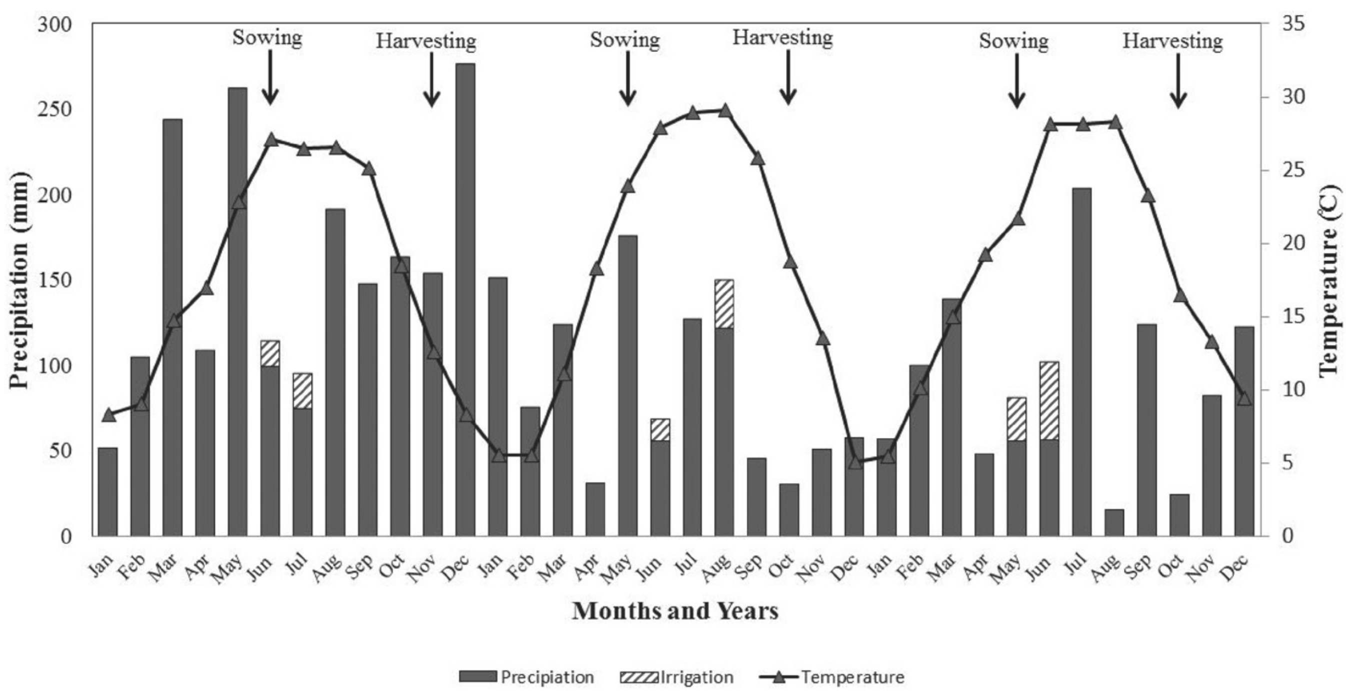

Fig. 1. Monthly average air temperature and precipitation totals at the Alabama Agricultural Experiment Station's E.V. Smith Research Center for 2009, 2010, and 2011.

grain yield was not reduced by the use of alternative N sources (ESN, SuperU, UAN+AgrotainPlus) compared with urea and UAN in Colorado. Sistani et al. (2011) also found no significant difference in corn yield among N sources (urea, UAN, ammonium nitrate, ESN, SuperU, UAN+AgrotainPlus, poultry litter, poultry litter + AgrotainPlus) in Kentucky. Out of 20 site-years, no consistent increase in barley (*Hordeum vulgare* L.) yield was observed with ESN compared with urea (Blackshaw et al., 2011). Lint yield results from this study do not support the higher cost of EENFs (Trenkel, 1997) compared to traditional fertilizers. However, despite the fact that EENFs did not improve or reduce yield, their potential environmental benefits (e.g., reduced N loss) may make them viable alternatives (Halvorson et al., 2011). For example, there have been discussions about the use of EENFs as a conservation practice for GHG reduction offsets (Smith et al., 2008). Further, given that all fertilizers were applied at the first square cotton stage (the general practice for standard inorganic fertilizers on loamy sand soils to reduce leaching), the EENFs used in this study (which are controlled-release or stabilized), may have increased lint yield if applied earlier. Application at planting could provide an economic cost advantage in some production systems. More research is needed on EENF application timing.

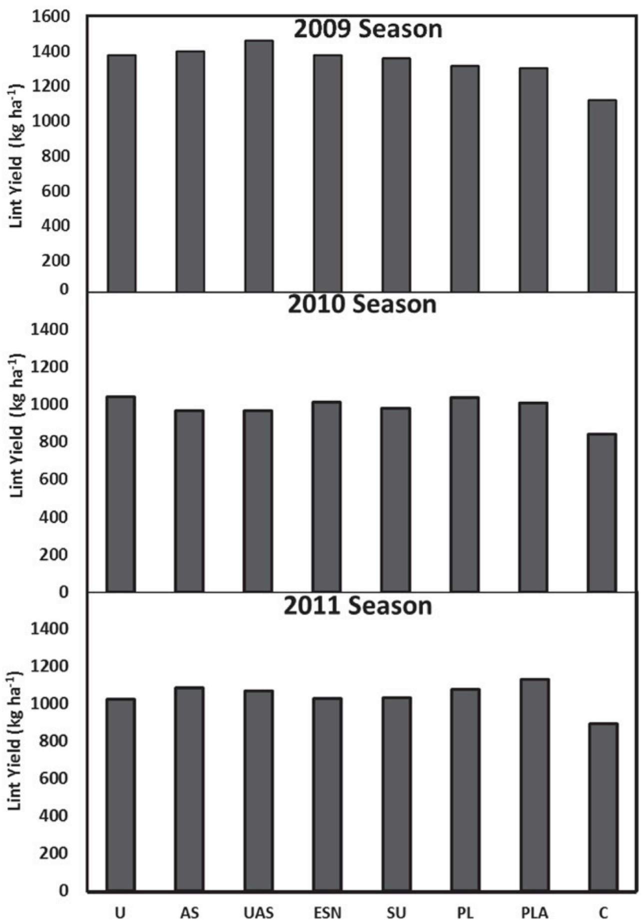

Fig. 2. Cotton lint yield for N sources urea (U), ammonium sulfate (AS), urea ammonium sulfate (UAS), ESN, SuperU (SU), Poultry litter (PL), Poultry litter + AgrotainPlus (PLA), and unfertilized control (C) during the 2009, 2010, and 2011 growing seasons. The year × N interaction was not significant at $P = 0.554$.

Ginning percentage, the weight of lint as a percentage of the machined picked seed cotton, differed among years (Table 2). Averaged across N treatments, ginning percentage was highest in 2009 and lowest in 2011 (Table 2). The highest ginning percentage occurred during the year with the greatest precipitation. Averaged across years, ginning percentage was higher in the control and both PL treatments than in the EENFs and inorganics (Table 3). The trend of higher ginning percentages for PL, PLA and C tended to occur across all 3 yr (Table 4). The fact that the control had a high ginning percentage was expected since it has been shown that low N supply increases ginning percentage (Tewolde et al., 2007) because N deficiency negatively affects seed growth more than lint growth (Tewolde et al., 2008). Previous research has also shown an inverse relationship between ginning percentage and N supply in cotton (Fritschi et al., 2003; Tewolde and Fernandez, 2003). Low N could also explain why both poultry litter treatments had a high ginning percentage in 2009 since available N was likely low due to slower mineralization of poultry litter, with only approximately 50% N available the first year, as discussed previously. However, the effects of PL and PLA treatments increasing ginning percentage persisted in 2011 when lint yield data would suggest these treatments supplied enough N to produce some of the highest yields. It is not known why this occurred, but perhaps poultry litter affects other aspects of N use or affects other plant nutrients which impact lint growth differently than seed growth.

Fiber Quality Analysis

Cotton fiber quality has been defined as the quality of cotton fibers needed for textile production. Particular quality attributes defined by the USDA-AMS (1980) are: length, uniformity index, strength, micronaire, color as reflectance (Rd) and yellowness (+b). This has resulted in the establishment of a system for base quality where premiums and discounts are assessed when cotton fibers diverge. Generally, premiums are given when cotton fiber quality increases in whiteness, (+b), length, strength, and micronaire and discounted when these qualities decrease. While yield is the most important factor to consider in cotton production, fiber quality must also be

Table 2. Lint yield, ginning percentage, and fiber quality components of cotton averaged across all treatments for the 2009, 2010, and 2011 growing seasons.

Treatment	Lint yield	Ginning	Micronaire	Length	Strength	Uniformity	Trash	Rd†	+b‡
	kg ha^{-1}	%		mm	kN m kg^{-1}		%		
2009	1341a§	44.2a	3.36c	28.6a	287.7a	84.40a	0.81b	79.5a	7.37a
2010	983c	43.8ab	4.52a	26.8c	287.6a	81.74b	1.63a	69.3c	7.49a
2011	1044b	43.4b	4.23b	27.8b	275.3b	81.52b	0.90b	75.4b	6.83b
P > *F*	<0.001	0.048	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

† Rd, reflectance.

‡ +b, yellowness.

§ Values within a column within a year followed by the same letter are not significantly different at $\alpha = 0.10$.

considered to maximize profits since these attributes are crucial for textile manufacturing of household and clothing products.

Micronaire

Micronaire is a measure of fiber fineness and maturity, which is measured as resistance of air flow through a unit fiber mass. Micronaire is considered low if ≤3.4 and high if ≥5; values of 3.5 to 3.6 and 4.3 to 4.9 are in the base range, while value 3.7 to 4.2 are considered premium. Micronaire varied significantly among the 3 yr, being low in 2009, in the base range in 2010, and at a premium in 2011(Table 2). Micronaire did not differ among N treatments when averaged across years (Table 3) with all values being in the premium range. Fertilizer source did not significantly affect micronaire throughout

Table 3. Lint yield, ginning percentage, and fiber quality components of cotton for N sources averaged across the three growing seasons.

Treatment†	Lint yield	Ginning	Micronaire	Length	Strength	Uniformity	Trash	Rd‡	+b§
	kg ha^{-1}	%	units	mm	kN m kg^{-1}	%			units
U	1148a¶	43.3b	4.00	27.9	285.4	82.7	1.07	75.2a	7.28bc
AS	1153a	43.4b	4.12	27.9	283.7	82.8	1.23	73.8c	7.37b
UAS	1166a	43.2b	3.94	27.6	280.7	82.5	1.23	74.2bc	7.32b
ESN	1140a	43.3b	4.00	27.9	287.6	82.8	1.08	75.3a	7.27bc
SU	1124a	43.2b	4.03	27.8	284.9	82.7	0.99	74.8ab	7.58a
PL	1144a	44.9a	4.05	27.6	280.1	82.5	1.12	75.2a	6.92d
PLA	1148a	44.7a	4.10	27.7	284.3	82.4	1.17	74.7ab	7.01d
C	959b	44.4a	4.07	27.5	281.7	82.1	1.01	74.8ab	7.11cd
P > F	<0.001	<0.001	0.570	0.294	0.448	0.271	0.512	0.027	<0.001

† Treatments are urea (U), ammonium sulfate (AS), urea ammonium sulfate (UAS), ESN, SuperU (SU), Poultry litter (PL), Poultry litter + AgrotainPlus (PLA), and unfertilized control (C).

‡ Rd, reflectance.

§ +b, yellowness.

¶ Values within a column followed by the same letter are not significantly different at α = 0.10; no mean separation is shown when *P* > 0.10.

Table 4. Ginning percentage and fiber quality components of cotton for N sources during the 2009, 2010, and 2011 growing seasons.

Treatment†	Ginning	Micronaire	Length	Strength	Uniformity	Trash	Rd‡	+b§
	%	units	mm	kN m kg^{-1}	%			units
				2009 Season				
U	44.4abc¶	3.30	28.8	294.2a	84.7	1.00	79.4	7.45
AS	42.8bc	3.48	29.0	277.0c	84.6	0.85	78.8	7.52
UAS	44.4abc	3.35	28.6	281.9bc	84.3	1.05	78.9	7.50
ESN	42.7c	3.38	29.0	288.3ab	84.8	0.82	80.1	7.32
SU	42.6c	3.35	28.7	288.3ab	84.8	0.62	79.2	7.65
PL	45.9a	3.38	28.4	294.9a	84.2	0.52	80.0	7.08
PLA	46.2a	3.32	28.4	288.8ab	83.9	0.90	79.8	7.15
C	44.8ab	3.35	28.2	288.3ab	83.8	0.70	79.7	7.30
				2010 Season				
U	43.6a	4.55	26.7	287.8abc	81.7	1.55	70.2	7.55
AS	43.8a	4.58	27.0	289.8abc	82.1	1.75	68.3	7.68
UAS	43.0a	4.42	26.8	284.1bc	82.0	1.55	69.4	7.58
ESN	43.9a	4.50	27.0	292.2ab	81.8	1.50	70.2	7.65
SU	44.2a	4.32	27.1	295.2a	81.9	1.55	69.6	7.72
PL	44.6a	4.48	26.7	281.5c	81.6	1.82	69.7	7.20
PLA	43.7a	4.72	26.7	285.6abc	81.4	1.62	68.6	7.28
C	43.3a	4.58	26.7	284.4bc	81.4	1.68	68.8	7.25
				2011 Season				
U	42.0d	4.15	28.1	274.1abcd	81.6	0.65	76.0	6.82
AS	43.6bc	4.30	27.8	284.1a	81.8	1.10	74.2	6.90
UAS	42.2cd	4.05	27.6	276.1abc	81.1	1.10	74.4	6.90
ESN	43.3bcd	4.12	27.7	282.2ab	81.8	0.92	75.5	6.82
SU	42.7cd	4.42	27.6	271.2cd	81.4	0.80	75.6	7.35
PL	44.3ab	4.30	27.7	264.0d	81.6	1.02	76.0	6.48
PLA	44.4ab	4.25	28.1	278.5abc	81.8	0.98	75.6	6.60
C	45.1a	4.28	27.7	272.4bcd	81.0	0.65	76.0	6.78
P > F#	0.013	0.588	0.541	0.030	0.968	0.532	0.833	0.978

† Treatments are urea (U), ammonium sulfate (AS), urea ammonium sulfate (UAS), ESN, SuperU (SU), Poultry litter (PL), Poultry litter + AgrotainPlus (PLA), and unfertilized control (C).

‡ Rd, reflectance.

§ +b, yellowness.

¶ Values within a column within a year followed by the same letter are not significantly different at α = 0.10; no mean separation is shown when *P* > 0.10.

P > F is for year × N interaction.

the study (Table 4). Further, there were no consistent trends among the fertilizer sources (Table 4). For example, SU had the lowest micronaire in 2010 and highest in 2011. Effects of N on micronaire are often inconsistent among varieties and/or environments with increases, decreases, and no effect being reported (Fritschi et al., 2003).

Fiber Length

Fiber length is important in textile processing as it is related to yarn fineness, strength, and spinning efficiency (Moore, 1996). Fiber lengths below 25.2 mm are considered short, those from 25.2 to 27.9 mm are medium, 27.9 to 32.0 mm are considered long, and above 32 mm are extra-long (Cotton Inc., 2013). Fiber length varied significantly among the 3 yr (Table 2), being long in 2009 and medium in 2010 and 2011. When averaged across years, fiber length was unaffected by N treatment, with all values falling in the medium to long range (Table 3). Fiber length followed this same pattern in all years (Table 4) with most values being in the long range.

Fiber Strength

Fiber strength is the force required to break a standard bundle of cotton fibers. Strength measurements are reported in g tex^{-1} with a tex unit being the wt (g) of 1000 m of cotton fiber (USDA-AMS, 1980). These units were converted to SI units of kilo Newton meters per kilogram (kN m kg^{-1}) as is common in the scientific literature (Tewolde et al., 2007). Essentially, fiber strength greatly influences yarn strength, so it is important in both textile production and end product use. Fiber strength below 245 kN m kg^{-1} is considered weak, 250 to 290 kN m kg^{-1} are considered base, 290 to 315 kN m kg^{-1} are strong and ≥315 kN m kg^{-1} are very strong. Fiber strength in this study was in the base range in all 3 yr, being significantly lower in 2011 than 2009 or 2010 (Table 2). Fiber strength was unaffected by N treatment when averaged across years (Table 3), with all values falling in the base range. Fertilizer N source effects on fiber strength were highly variable among the 3 yr of study (Table 4). It is interesting to note that fiber strength with PL was highest and AS lowest in 2009, while the opposite was true in 2011. Whether this was due to differences in varieties, environment or their interaction among years cannot be determined. Regardless of this variation in treatment effects among years, all strength measurements fell into the base or strong range and therefore would not have affected cotton value.

Fiber Uniformity

Uniformity is the ratio between the mean length and the upper half mean length of the fibers. Uniformity values below 79% are considered low or very low, 80 to 82% are average, 83 to 85% are high, and above 85% are very high (Cotton Inc., 2013). Fiber uniformity is important in processing because it reduces waste and yarn breakage (Glade et al., 1981). Uniformity was high in 2009 which would yield a premium (USDA-AMS, 2010), and was average in 2010 and 2011 (Table 2). Fiber uniformity was not affected by fertilizer N source when average across years (Table 3) and within each year (Table 4). Further, numerical differences among N treatments were small and would not affect cotton value.

Trash

A trash measurement describes the amount of non-lint materials (e.g., cotton leaves, stems, burs, and other contaminants such as dust and soil) in the fiber. Trash content is assessed from scanning the cotton sample surface with a video camera and calculating the percentage of the surface area occupied by trash particles. Trash content in the cotton lint should range between 0 to 1.6% to prevent a dockage fee.

Cleaning cotton of trash can be accomplished at various stages including harvesting (e.g., use of bur extractors), ginning (generally, use of one to three cleaners are employed at the gin), and textile manufacturing (additional cleaning may be required, depending on the desired end use product). An increase in trash content might indicate that more cleaners are required during ginning which can result in damage (breakage, shorter fiber length, and/or lower fiber strength). However, an economic analysis of various cleaning processes suggested that additional cleaning at the cotton gin might not be advantageous depending on textile needs (Bennett et al., 2010).

Trash in cotton lint varied significantly among the 3 yr (Table 2), being higher in 2010 than in 2009 or 2011 (Table 2) which may have resulted in a dockage fee in 2010. If weather affected plant and/or boll size, this could impact the percent trash at harvest. For example, numerous small bolls might have more trash than fewer large bolls which occurred in 2010 due to the dry and hot conditions. Nitrogen source had no effect on trash when averaged across years (Table 3) and within each year (Table 4) with the majority of values falling within acceptable standards (Cotton Inc., 2013).

Fiber Color

In the HVI classing system, color is quantified from two parameters: degree of reflectance (Rd) and yellowness (+b), based on colorimeter readings. Degree of reflectance shows the brightness of the sample and yellowness depicts the degree of cotton pigmentation. Of the three components of cotton grade, fiber color is most directly linked to cotton growth environment (Bradow and Davidonis, 2000). Cotton fibers are naturally white to creamy-white, but can be affected by climatic conditions, impact of insects and fungi, type of soil, and storage conditions. Pre-harvest exposure to weathering and microbial action can cause fibers to darken and to lose brightness (Perkins et al., 1984; Allen et al., 1995). Trash content, including foreign matter contamination, can also modify fiber color (Moore, 1996; Xu et al., 1998a, 1998b). Color measurements are also correlated with overall fiber quality so that bright (high Rd), creamy, white (low +b) fibers are of higher quality than the dull (low Rd), gray or yellowish (high +b) fibers associated with field weathering (Perkins et al., 1984). An official color grade diagram, established by the USDA, relates Rd and +b to the traditional color grades of cotton (Perkins et al., 1984). The range of the Rd reflectance scale is from +40 (darker) to +85 (lighter/brighter) and the +b yellowness scale range is from +4 (whiter) to +18 (yellower).

In all years of this study, Rd values were in the high range (bright) while +b values were in the low range (whiter). Reflectance varied significantly among the 3 yr with 2009 > 2011 > 2010 (Table 2). Yellowness was higher in 2009 and 2010 than in 2011. The Rd values resulted in lint grades of middling, low middling, and strict low middling for 2009, 2010, and 2011, respectively; in all 3 yr cotton fell into the white portion of the scale. Reflectance was higher for ESN, U, and PL than AS and UAS when average across years (Table 3); however, all values still fell in the high range. When averaged across years, +b was highest for SU and lowest for the two PL treatments and control. Despite significant effects, differences in Rd and +b among N sources were small; in no case did these differences impact lint grade or cotton value. In all years, N source had no effect on Rd or +b (Table 4).

Overall, N fertilizer source had little effect on aspects of cotton fiber quality. Other researchers have also reported that cotton lint quality was not greatly impacted by fertilizer N source (Mullins et al., 2003; Reiter et al., 2008). These researchers also indicated that noted differences in lint quality would not have affected premiums/discounts similar to results of this study.

CONCLUSIONS

Nitrogen is the most essential nutrient needed to optimized crop yield and economic return. However, N use efficiency of most fertilizer is just 30 to 50%. Recent development of EENFs to reduce excessive N loss are presently being marketed for agricultural production. This study is the first to demonstrate the impact of using EENF sources for top-dressing in a cotton production system in the Coastal Plain Region of the United States. Generally, EENF use did not show an advantage or disadvantage to traditional fertilizers in this study. While differences in lint fiber yield and quality among N sources were observed in this study, these were variable among years and could be due weather and/or variety. Furthermore, lint quality for all of the fertilizer sources generally were not in the discounted range for cotton fibers, suggesting that these differences will not likely influence net return. From a monetary standpoint, EENF use may not be economically advantageous. However, if EENFs can reduce N loss from agricultural fields they could be environmentally important. Clearly, more research is needed on the benefits of enhanced-efficiency fertilizer use as a tool in production systems to reduce N loss through leaching, runoff and N_2O flux in humid regions of the southeastern United States.

ACKNOWLEDGMENTS

The authors thank the International Plant Nutrition Institute's Foundation for Agronomic Research with funding from Agrium Inc., Agrium Advanced Technologies, and Agrotain International for financial support for this project. This publication is also based on work supported by the Agricultural Research Service under the ARS GRACEnet Project. We also thank the Alabama Cotton Commission, Cotton Incorporated, and the U.S. Poultry and Egg Association for additional funding support. The authors would like to express their thanks to the E.V. Smith Agriculture Research and Extension Center, Field Crops Unit for help in managing the field operations. Lastly, we appreciate Ashley Robinson, Barry Dorman, and Robert Icenogle for technical assistance.

REFERENCES

Allen, S.J., P.D. Auer, and M.T. Pailthorpe. 1995. Microbial damage to cotton. Text. Res. J. 65:379–385. doi:10.1177/004051759506500702

Balkcom, K.S., A.M. Blackmer, D.J. Hansen, T.F. Morris, and A.P. Mallarino. 2003. Testing soils and cornstalks to evaluate nitrogen management on the watershed scale. J. Environ. Qual. 32:1015–1024. doi:10.2134/jeq2003.1015

Bennett, B.K., S.K. Misra, and J. Richardson. 2010. A determination of cotton market price and premiums required to justify more lint cleaning in the gin plant. J. Cotton Sci. 14:199–204.

Blackshaw, R.E., X. Hao, K.N. Harker, J.T. O'Donovan, E.N. Johnson, and C.L. Vera. 2011. Barley productivity response to polymer-coated urea in a no-till production system. Agron. J. 103:1100–1105. doi:10.2134/agronj2010.0494

Bradow, J.M., and G.H. Davidonis. 2000. Quantitation of fiber quality and the cotton production-processing interface: A physiologist's perspective. J. Cotton Sci. 4:34–64.

Cahill, S., D. Osmond, R. Weisz, and R. Heiniger. 2010. Evaluation of alternative nitrogen fertilizers for corn and winter wheat production. Agron. J. 102:1226–1236. doi:10.2134/agronj2010.0095

Cotton Inc. 2013. U.S. cotton fiber chart. Cotton Inc. www.cottoninc.com/CottonFiberChart/?Pg=5 (accessed 8 Mar. 2013).

Current Results. 2013. Average annual precipitation and temperature in Alabama. Current Results Nexus. www.currentresults.com/Weather/Alabama/average-alabama-weather.php (accessed 8 Mar. 2013).

Delgado, J.A. 2002. Quantifying the loss mechanisms of nitrogen. J. Soil Water Conserv. 57:389–398.

ESN. 2013. ESN Smart Nitrogen. Agrium Advanced Technologies. www.smartnitrogen.com/how-esn-works (accessed 24 July 2013).

Fritschi, F.B., B.A. Roberts, R.L. Travis, D.W. Rains, and R.B. Hutmacher. 2003. Response of irrigated Acala and Pima cotton to nitrogen fertilization: Growth, dry matter partitioning, and yield. Agron. J. 95:133–146. doi:10.2134/agronj2003.0133

Glade, E.H., Jr., K.J. Collins, and C.D. Rogers. 1981. Cotton quality evaluation: Testing methods and use. USDA-ERS ERS-668. U.S. Gov. Print. Office, Washington, DC.

Guertal, E.A. 2000. Preplant slow-release nitrogen fertilizers produce similar bell pepper yields as split applications of soluble fertilizer. Agron. J. 92:388–393.

Halvorson, A.D., S.J. Del Grosso, and C.P. Jantalia. 2011. Nitrogen source effects on soil nitrous oxide emissions from strip-till corn. J. Environ. Qual. 40:1775–1786. doi:10.2134/jeq2011.0194

Halvorson, A.D., C.S. Snyder, A.D. Blaylock, and S.J. Del Grosso. 2014. Enhanced-efficiency nitrogen fertilizers: Potential role in nitrous oxide emission mitigation. Agron. J. 106:715–722 (this issue). doi:10.2134/agronj2013.0081

Hauck, R.D. 1985. Slow-release and bioinhibitor-amended nitrogen fertilizers. In: O.P. Engelstad, editor, Fertilizer technology and use. 3rd ed. SSSA, Madison, WI. p. 293–322.

IPCC. 2007. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, editors, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK.

Koch. 2013. AgrotainPlus nitrogen stabilizer EZ FLO formula label. Koch Agronomic Serv. http://agrotain.com/getattachment/a6b1347b-0860-435b-8ecf-3bd52c9ccadb/agrotain_plus_label.pdf.aspx?ext=.pdf (accessed 24 July 2013).

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS System for mixed models. SAS Inst., Cary, NC.

Mitchell, C.C., and S. Phillips. 2010. Nitrogen recommendations. In: C.C. Mitchell, editor, Research-based soil testing and recommendations for cotton on Coastal Plain soils. Southern Coop. Ser. Bull. 410. Alabama Agric. Exp. Stn, Auburn. p. 9–17.

Mitchell, C.C., and S. Tu. 2005. Long-term evaluation of poultry litter as a source of nitrogen for cotton and corn. Agron. J. 97:399–407. doi:10.2134/agronj2005.0399

Moore, J.F. 1996. Cotton classification and quality. In: E.H. Glade, Jr., L.A. Meyer, and H. Stults, editors, The cotton industry in the United States. USDA-ERS Agric. Econ. Rep. 739. U.S. Gov. Print. Office, Washington, DC. p. 51–57.

Mullins, G.L., C.D. Monks, and D. Delaney. 2003. Cotton response to source and timing of nitrogen fertilization on a sandy Coastal Plain soil. J. Plant Nutr. 26:1345–1353. doi:10.1081/PLN-120021046

Mulvaney, R.L., S.A. Khan, and T.R. Ellsworth. 2009. Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production. J. Environ. Qual. 38:2295–2314. doi:10.2134/jeq2008.0527

Nelson, K.A., S.M. Paniagua, and P.P. Motavalli. 2009. Effects of polymer coated urea, irrigation, and drainage on nitrogen utilization and yield of corn in a claypan soil. Agron. J. 101:681–687. doi:10.2134/agronj2008.0201

Perkins, H.H., Jr., D.E. Ethridge, and C.K. Bragg. 1984. Fiber. In: R.J. Kohel and C.F. Lewis, editors, Cotton. ASA, CSSA, and SSSA, Madison WI. p. 437–509.

Reiter, M.S., D.W. Reeves, and C.H. Burmester. 2008. Cotton nitrogen management in a high-residue conservation system: Source, rate, method, and timing. Soil Sci. Soc. Am. J. 72:1330–1336. doi:10.2136/sssaj2007.0314

Sistani, K.R., M. Jn-Baptiste, N. Lovanh, and K.L. Cook. 2011. Atmospheric emissions of nitrous oxide, methane, and carbon dioxide from different nitrogen fertilizers. J. Environ. Qual. 40:1797–1805.

Smil, V. 2001. Enrichng the Earth. MIT Press, Cambridge, MA.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar et al. 2008. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. London Ser. B 363:789–813.

Spalding, R.F., and M.E. Exner. 1993. Occurrence of nitrate in groundwater–A review. J. Environ. Qual. 22:392–402. doi:10.2134/jeq1993.00472425002200030002x

Tewolde, H., and C.J. Fernandez. 2003. Fiber quality response of Pima cotton to nitrogen and P deficiency. J. Plant Nutr. 26:223–235. doi:10.1081/PLN-200052633

Tewolde, H., M.W. Shankle, K.R. Sistani, A. Adeli, and D.E. Rowe. 2008. No-till and conventional-till cotton response to broiler litter fertilization in an upland soil: Lint yield. Agron. J. 100:502–509. doi:10.2134/agronj2007.0137

Tewolde, H., K.R. Sistano, D.E. Rowe, A. Adeli, and J.R. Johnson. 2007. Lint yield and fiber quality of cotton fertilized with broiler litter. Agron. J. 99:184–194. doi:10.2134/agronj2006.0016

Trenkel, M.E. 1997. Controlled-released and stabilized fertilizers in agriculture. Int. Fertilizer Industry Assoc., Paris.

USDA-AMS. 1980. The classification of cotton. USDA Agric. Handb. 566. U.S. Gov. Print. Office, Washington, DC.

USDA-AMS. 2010. Cotton price statistics 2009–2010. In: Annual report. Vol. 91(13). USDA-Agric. Marketing Serv. Cotton Program, Memphis, TN. p. 8.

USDA-ERS. 2013. Fertilizer use and price. USDA-Economic Research Service. www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx (accessed 26 July 2013).

Williams, A.E., J.A. Johnson, L.J. Lund, and Z.J. Kabala. 1998. Spatial and temporal variations in nitrate contamination of a rural aquifer. California J. Environ. Qual. 27:1147–1157.

Xu, B., C. Fang, R. Huang, and M.D. Watson. 1998a. Cottoncolor measurements by an imaging colorimeter. Text. Res. J. 68:351–358. doi:10.1177/004051759806800505

Xu, B., C. Fang, and M.D. Watson. 1998b. Investigating new factors in cotton color grading. Proceedings Beltwide Cotton Conference, San Diego, CA. 5–9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN. p. 1559–1565.