Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi 10 (1):1-7, 2015
ISSN 1304-9984, *Araştırma Makalesi*

Evaluation of Cotton Growth and Yield Response to Nitrogen and Sulfur Fertilization-I

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Geliş tarihi: 22.09.2014, Yayına kabul tarihi: 27.04.2015

Abstract: Field experiments were conducted to evaluate cotton growth and yield response to nitrogen and sulfur applications at the experimental areas of Department of Field Crops, Çukurova University, Adana, Turkey, in 2011 and 2012. Sulfur treatments of 0, 15, 30, 45, and 60 kg S ha^{-1} were broadcast at planting. Nitrogen treatments of 0, 60, 120, 180, and 240 kg N ha^{-1} were divided in to three dosage. Important increases in number of fruiting branches and open bolls per plant and seed cotton yield were measured at 30 kg S ha^{-1} while no significant increase was observed at 60 kg S ha^{-1}. The highest number of open bolls per plant, seed cotton yield and boll weight were observed with the treatment consisting of 45 kg S ha^{-1} and 120 kg N ha^{-1}. The seed cotton yield and boll weight tended to decrease as more N was applied however they were increased when N was applied with S. The N application had positive response on yield with S application and increasing N application in these situation positively affected on yield also. Joint effects of N and S on leaf nitrogen and sulfur content were found. It can be concluded that 120 to 180 kg ha^{-1} nitrogen and 45 to 60 kg ha^{-1}sulfur applications rates had better results than the rest of other N and S combinations.

Key words: Cotton, leaf nitrogen content, number of open bolls per plant, seed cotton yield

Azot ve Kükürt Gübrelemesinin Pamuk Büyüme ve Verimine Etkisi-I

Özet : Tarla denemeleri azot ve kükürt uygulamalarının pamuk büyüme ve verimine etkilerini değerlendirmek amacıyla Ç.Ü.Ziraat Fakültesi araştırma alanında 2011-2012 yıllarında yürütülmüştür. Kükürt 0, 15, 30, 45 ve 60 kg ha^{-1} dozlarında ekimle birlikte toprağa uygulanmıştır. Azot 0, 60, 120, 180 ve 240 kg ha^{-1} dozlarında, üçe bölünerek uygulanmıştır. Meyve dalı sayısı, açmış koza sayısı ve kütlü pamuk veriminde 30 kg S ha^{-1} uygulaması ile önemli artışlar sağlanırken, 60 kg S ha^{-1} uygulamasında daha fazla artış gözlenmemiştir. En yüksek açmış koza sayısı, kütlü pamuk verimi ve koza ağırlığı 45 kg S ha^{-1} ve 120 kg N ha^{-1} uygulamalarında elde edilmiştir. Kütlü pamuk verimi ve koza ağırlığı daha yüksek dozda azot uygulandığında azalma, daha yüksek dozda kükürt uygulandığında artma eğilimine girmiştir. Azot uygulandığında kükürt uygulamasına önemli verim tepkisi ortaya çıkmış, azot dozunun artması durumunda verim artışı oluşmuştur. Yaprak N ve S içeriği yönünden her iki elementin ortak etkileri gözlenmiştir. Sırasıyla 120 ve 180 kg N ha^{-1} ile 45 ve 60 kg S ha^{-1} dozlarında azot ve kükürt uygulamalarının, diğer uygulama dozlarına oranla daha iyi performans ortaya koydukları sonucuna varılmıştır.

Anahtar kelimeler: Pamuk, yaprak azot içeriği, açmış koza sayısı, kütlü pamuk verimi

Introduction

Since the early1900s cotton has been a major crop grown in rotation with wheat in the Çukurova region. Cotton is grown on fertile soils in Çukurova, which have become depleted in N and organic matter over time. The soils of Çukurova region vary much in their capacity to supply N and have generally been responsive to nitrogen. They are no longer able to supply the cotton crop's need for N. Cotton is one of the crops utilize large amounts of nitrogen. Because of direct effects of N on crop development, it is imperative to apply adequate N fertilizer. To achieve maximum yield, cotton growers may need to supply N fertilizer at rates up to 200 kg N ha^{-1}. Farmers in the region use a nitrogen as a fertilizer for their cotton production every year, whether soils have adequate or low nitrogen. The level of nitrogen fertilizer probably has more influence on the growth, behavior and yield of cotton than any other single plant nutrient and it is required most consistently and in larger amounts than other nutrients for cotton production (Hou et al., 2007). Crops that have a high N requirement must have adequate sulfur to optimize N utilization. Nitrogen and sulfur are closely related, synergistic and of vital importance for plants because S is part of a major constituent of amino acids, which in turn constitute the building blocks of proteins (Ceccotti, 1996). Healthy cotton needs both nitrogen and sulfur to form amino acids, proteins and chlorophyll-as much as 5.4 kg of sulfur for every bale of yield. Soils low in organic matter, whether they're the sandy soils or low organic- matter silty soils, tend to be low in sulfur. Because the cotton plant needs both nitrogen and sulfur to produce the components of foliage, seeds, and lint, it's important to keep the two companion nutrients in balance with each other. Because N and S work together to build protein, an ample and balanced supply of both nutrients is needed for plants to get the full benefit of each element. More attention needs to be paid to S requirements of cotton in environments where S deficiencies may become somewhat more common due to increased use of S free fertilizers, adoption of high yielding cultivars and more intensive cropping systems. Nitrogen and sulfur supplies have a strong influence on the physiological and phenological characteristics of crop as well as on the quality of cotton seed. Thus, it is obvious that more information is needed about the responses of high-yielding cotton cultivars to S applications, particularly, under nitrogenous fertilization. The fertilizer N requirements of cotton in the region have been determined but when adequate fertilizer S was not applied. Likewise, the S requirement for cotton production in the region has been determined but when adequate fertilizer N was also applied. The present study was conducted to examine the impacts of N and S applications on growth, yield and yield components of cotton.

Material and Methods

The experiments were conducted at the experimental areas of Agricultural Faculty of Çukurova University, Adana, Turkey (37° 00' 02" N, 35° 18' 00" E; altitude of 161 m), using the cultivar SG-125 in 2011 and 2012. The experiment was arranged in factorial based on randomized complete block design with three replications. Treatments comprised five nitrogen fertilizer rates (0, 60, 120, 180, and 240 kg N ha^{-1} from ammonium nitrate source), five sulfur fertilizer rates (0, 15, 30, 45, and 60 kg S ha^{-1} from gypsum source). Nitrogen was applied broadcast as a top dressing in three splits by 1/3 at planting, 1/3 at first bloom and 1/3 at peak bloom stages. Whole amount of sulfur fertilizer was broadcast and incorporated in the soil at the time of planting. All experimental units also received 70 kg P/ha (triple super phosphate) as basal fertilizer at planting. Soil nitrate-nitrogen is determined by the cadmium reduction method (Keeney and Nelson, 1982). Extractable sulfate sulfur was determined by monocalcium phosphate extraction method (Hoeft et al., 1973). The trial soil was slightly alkaline having a pH of 7.5, low in organic matter 0.67%, low in nitrate-N (37 ppm), low in sulfate-sulfur (10 ppm). The study area in general experiences a typical Mediterranean climate with dry-hot summers and mild-rainy winters. Temperatures and rainfall during the crop growing season have been shown in Table 1.

Table 1. Average air temperature and rainfall at the experimental site during 2011 and 2012.
Tablo 1. Deneme yerinin 2011 ve 2012 yılına ilişkin ortalama hava sıcaklık ve yağış verileri.

	2011				2012			
Month	Mean T (°C)	Max T (°C)	Min T (°C)	Total rainfall (mm)	Mean T (°C)	Max T (°C)	Min T (°C)	Total rainfall (mm)
April	16.5	28.0	3.0	117.3	18.1	32.0	6.0	36.0
May	20.2	31.0	11.0	30.0	20.8	33.0	12.0	97.0
June	24.5	36.0	17.0	0.0	26.7	41.0	17.0	35.5
July	27.9	36.0	18.0	0.0	29.3	41.0	17.0	18.3
August	28.8	37.0	19.0	0.0	29.3	39.0	18.0	0.0
September	26.9	39.0	18.0	0.0	27.0	39.0	17.0	0.0
October	20.8	34.0	8.0	6.0	22.6	35.0	13.0	51.9

Monthly average of maximum temperature during the cropping period (April to October) ranged from 28.0°C to 39.0°C, and 32.0°C to 41.0°C during 2011 and 2012, respectively. Corresponding values for mean temperature ranged from 16.5°C to 28.8°C (August) and 18.1°C to 29.3°C (July and August). Cropping season total rainfall was 147.3 and 238.7 mm during 2011 and 2012, respectively (Table 1). Experiments were planted 25 April 2011 and 5 May 2012. Plots were 42 m^2 wide and 10 m long, with a 1.4 m untreated area between each plot. Six rows of seed, 70 cm apart, were sown down each plot. Standard production practices of the region were followed. At flower initiation stage, samples were obtained by removing 25-30 leaves from the uppermost fully expanded main stem leaves from each plot. Sulfur content of leaves was measured using an ICP-AES while N was determined by Kjeldahl method. The experiments were harvested on late October. In both years, ten plants were randomly chosen from the center four rows of each plot to determine number of open bolls and main stem nodes plant^{-1} and number of node to 1st fruiting branch. Twenty bolls were randomly collected from ten plants to determine boll weight and seed cotton weight boll^{-1}. Seed cotton yield was determined by harvesting the four center rows from each plot and weighing the seed cotton. Data for traits studied were analyzed statistically separately and combined over years as a factorial experiment in a randomized complete block design. Main and interaction effects were compared using LSD test at 0.05 level of probability.

Results

A significant yearxN-ratexS-rate interaction occurred for number of node to first fruiting branch. The N-rate and S-rate interaction was significant for number of node to first fruiting branch, number of main stem nodes, number of open bolls per plant, seed cotton yield, boll weight, seed cotton weight per boll, leaf N and S content and N:S ratio. The main effects of N-rate and S-rate were significant for number of node to first fruiting branch, number of main stem nodes, number of open bolls per plant, seed cotton yield, boll weight, seed cotton weight per boll, leaf N and S content and N:S ratio. YearxN-rate interactions were significant for number of main stem nodes, boll weight and seed cotton weight per boll. YearxS-rate interactions were not significant for any traits studied. Applications of N at 120 kg ha^{-1} and 180 kg ha^{-1} significantly increased the number of open bolls per plant over the control in both years.

Table 2. Number of harvestable bolls plant^{-1}, node number of first fruiting branch and number of main stem nodes per plant as affected by N and S rates

Tablo 2. N ve S dozlarının bitkide hasat edilebilir koza sayısı, ilk meyve dalı boğum sayısı ve ana gövde boğum sayısına etkileri

	Number of open bolls plant^{-1}			Node to 1st fruiting branch			Number of main stem nodes plant^{-1}		
	2011	2012	Mean	2011	2012	Mean	2011	2012	Mean
N rate (kg ha^{-1})									
0	17.8 d[1]	18.0 d	17.9 e	3.9 d	3.2 d	3.6 e	17.6 d	16.5 d	17.1 c
60	24.0 b	23.5 b	23.7 c	4.2 c	3.6 c	3.9 d	19.7 b	18.2 c	18.9 b
120	29.4 a	28.9 a	29.2 b	4.3 c	3.9 b	4.1 c	20.9 a	20.1 a	20.5 a
180	29.5 a	30.0 a	29.8 a	5.1 b	4.8 a	4.9 b	20.3 ab	19.8 ab	20.1 a
240	19.7 c	19.6 c	19.7 d	5.6 a	5.1 a	5.3 a	18.6 c	18.9 bc	18.8 b
LSD	0.97	1.19	0.56	0.25	0.29	0.17	0.81	0.96	0.54
S rate (kg ha^{-1})									
0	21.5 c	21.3 c	21.4 c	4.5	3.8 c	4.2 c	18.4 c	17.2 d	17.8 d
15	24.7 b	24.4 ab	24.5 b	4.6	3.9 bc	4.3 bc	19.2 bc	18.4 c	18.8 c
30	24.4 b	24.1 b	24.3 b	4.7	4.2 ab	4.5 ab	20.2 a	19.7 a	19.9 a
45	25.7 a	25.5 a	25.6 a	4.6	4.3 a	4.5 ab	19.6 ab	19.6 a	19.7 ab
60	24.2 b	24.8 ab	24.5 b	4.7	4.4 a	4.6 a	19.7 ab	18.7 bc	19.2 bc
LSD	0.97	1.19	0.80	NS	0.29	0.19	0.81	0.96	0.64

1: Means of the same column followed by the same letter were not significantly different at the 0.05 level using LSD test.

Averaged across years, maximum number of open bolls per plant was attained when 180 kg N ha^{-1} was applied (Table 2). Application of 45 kg ha^{-1} S significantly increased the number of open bolls per plant compared with the control in both years and averaged across years. The lowest values of number of node to first fruiting branch were exhibited with the control and the highest with the applications of nitrogen at 240 kg ha^{-1} and 180 to 240 kg N ha^{-1} in 2011 and 2012, respectively. Number of node to first fruiting branch raised progressively with increase in N rates in both years and averaged across years. In general, cotton plants treated with 240 kg N ha^{-1} set fruits at higher nodes (Table 2). In 2011, there was no number of node to first fruiting branch response to applied sulfur. In 2012, number of node to first fruiting branch significantly raised up to 45 kg S ha^{-1} rate. Averaged across years, the highest S rate gave the the highest number of node to first fruiting branch. When concerning the interactions, maximum number of node to first fruiting branch was recorded in the treatment (240 kg N ha^{-1}+60 kg S ha^{-1}) while minimum number of node to first fruiting branch) was observed in the no nitrogen and sulfur treated control plots (data not shown). The highest number of open bolls per plant was observed with the treatment consisting of 45 kg S ha^{-1} and 120 kg N ha^{-1} (data not shown). Maximum number of main stem nodes per plant was achieved when 120 kg N ha^{-1} was applied in both years. Averaged across years, applications of N at 120 and 180 kg ha^{-1} significantly increased number of main stem nodes per plant. Applications of 30 and 45 kg ha^{-1} S significantly increased the number of main stem nodes compared with the control in both years (Table 2). Averaged across years, the number of main stem nodes was significantly greater at 30 kg S ha^{-1} S rate. Nitrogen at 60 kg ha^{-1} significantly increased the seed cotton yield over the control in both years. Maximum response of seed cotton yield to nitrogen occurred with application of 120 kg ha^{-1}. Application of higher N rates did not increase seed cotton yield further in both years and averaged across years. There were significant effects of sulfur on seed cotton yields, with being lowest at the control. There was 21.9% seed cotton yield response to S fertilizer at rate of 45 kg ha^{-1} (Table 3). The N and S interaction was significant for seed cotton yield. Maximum seed cotton yield was observed with the treatment consisting of 45 kg S ha^{-1} and 120 kg N ha^{-1}(data not shown). In 2011, application of N significantly increased the boll weight up to rate of 120 kg ha^{-1}. Application of higher N rates did not increase boll weight further. S rates had no significant influence on boll weight. In 2012, boll weight was significantly increased by applications of nitrogen except the rate of 60 kg ha^{-1}(Table 3).Averaged across years, application of 120 kg N ha^{-1} increased boll weight by 19.7% compared to the control. Application of S 15 kg ha^{-1} gave the same boll weight as the control, while applications of 30, 45 or 60 kg S ha^{-1} increased boll weights in 2012 and averaged across years.

Table 3. Seed cotton yield, boll weight and seed cotton weight per boll as affected by N and S rates
Tablo 3. N ve S dozlarının kütlü pamuk verimi, koza ağırlığı ve koza kütlü pamuk ağırlığına etkileri

	Seed cotton yield (kg ha^{-1})			Boll weight (g)			Seed cotton weight per boll (g)		
	2011	2012	Mean	2011	2012	Mean	2011	2012	Mean
N rate (kg ha^{-1})									
0	1737 d[1]	1782 d	1760 d	6.78 d	7.08 c	6.93 d	4.82 d	5.14 c	4.98 d
60	1981 c	1963 cd	1972 cd	7.72 b	7.70 b	7.71 c	5.89 b	5.64 b	5.77c
120	3523 a	3407 a	3465 a	8.35 a	8.26 a	8.30 a	6.20 a	6.11 a	6.15 a
180	2957 b	2913 b	2935 b	7.57 bc	8.29 a	7.93 b	5.91 b	6.17 a	6.04 ab
240	1993 c	2077 c	2035 c	7.38 c	8.43 a	7.91 b	5.65 c	6.28 a	5.96 b
LSD	237.0	293.1	225.8	0.19	0.19	0.17	0.19	0.19	0.13
S rate (kg ha^{-1})									
0	2131 b	2137 b	2134 c	7.45	7.79 b	7.62 b	5.49 b	5.65 b	5.57 b
15	2463 a	2445 a	2454 b	7.47	7.81 b	7.64 b	5.46 b	5.88 a	5.67 b
30	2511 a	2495 a	2503 ab	7.63	8.02 a	7.82 a	5.83 a	5.86 a	5.85 a
45	2635 a	2568 a	2602 a	7.69	8.10 a	7.89 a	5.87 a	5.98 a	5.93a
60	2451 a	2495 a	2473 b	7.55	8.04 a	7.79 a	5.83 a	5.95 a	5.89 a
LSD	237.0	293.1	172.0	NS	0.19	0.13	0.19	0.19	0.13

1: Means of the same column followed by the same letter were not significantly different at the 0.05 level using LSD test.

When considering the interaction, maximum response by an increase of 34.7 % over the control was obtained when N and S were applied at rates of 120 and 45 kg ha^{-1}, respectively (data not shown). Maximum response of seed cotton weight per boll to nitrogen occurred with application of 120 kg ha^{-1} in 2011 and averaged across years (Table 3). Application of higher N rates did not increase seed cotton weight per boll further. Nitrogen applied at all three rates (120, 180 and 240 kg ha^{-1}) significantly increased seed cotton weight per boll compare with 60 kg ha^{-1} and no nitrogen treatments in 2012. Sulfur applied at all three rates (30, 45 or 60 kg ha^{-1} S) significantly increased seed cotton weight per boll compared with 15 kg ha^{-1} to no S treatments in 2011 and averaged across years. Sulfur applied at all four rates significantly increased seed cotton weight per boll over the control in 2012. Increasing rates of N and S significantly increased leaf N content in both years and averaged across years. Averaged across years, leaf N concentration varied from 2.58 to 3.93 % and from 3.13 to 3.49 % by the rates of N and S applications, respectively. Maximum leaf S content was achieved when the highest rate of nitrogen and sulfur was applied. Averaged across years, leaf S concentration varied from 0.22 to 0.35 % and from 0.20 to 0.37 % by the rates of N and S applications, respectively. Leaf S of the control treatment was 0.20 which is on the below side of the reported sufficiency range of 0.25 to 0.8% (Hodges and Hadden, 1992). According to this criterion, leaf S concentration was not sufficient under zero S treatment; while all other leaf S concentrations were sufficient regardless of S application rate and year in this study

(Table 4). In 2011, maximum N:S ratio was observed when 120 kg N ha^{-1} was applied, while the no sulfur treated control gave the highest N:S ratio. In 2012 and averaged across years, applications of N at 120 and 180 kg ha^{-1} significantly increased N:S ratio. In general, the N:S ratio decreased as the rates of sulfur applications increased. Concerning the interaction, the N:S ratio in leaves was found to decrease from 15.3:1 to 8.7:1 with increasing S from N60S0 to N60S60 kg ha^{-1}. At N120, the ratio decreased from 17.1:1 to 9.6 when S was increased from N120S0 to N120S60 kg ha^{-1}. At N180, the ratio decreased from 16.5:1 to 9.8 when S was increased from N180S0 to N180S60 kg ha^{-1}. The ratio was found to be higher at N120 than at N60 or N180 applications (data not shown). Each rate ofsulfur fertilization produced a lower N:S ratio than the control, there was difference between the ratios of the four application rates. The N:S ratio of 12.3:1 found for the cotton in this study was good agreement with the N:S value of 10-15, which has an acceptable value for most crops (Campbell, 2000).

Table 4. Leaf N and S contents and N:S ratio as affected by N and S rates
Tablo 4. N ve S dozlarının yaprak N ve S içerikleri ile N:S oranına etkileri

	Petiole N (%)			Petiole S (%)			N:S		
	2011	2012	Mean	2011	2012	Mean	2011	2012	Mean
N rate (kg ha^{-1})									
0	2.55 e[1]	2.62 e	2.58 e	0.22 d	0.21 d	0.22 d	11.4 c	11.6 c	11.5 c
60	2.82 d	2.84 d	2.83 d	0.26 c	0.25 c	0.26 c	11.6 c	12.5 b	12.1 b
120	3.60 c	3.59 c	3.60 c	0.28 b	0.28 b	0.28 b	13.4 a	13.1 a	13.2 a
180	3.72 b	3.75 b	3.73 b	0.30 b	0.30 b	0.30 b	13.0 b	13.1 a	13.1 a
240	3.92 a	3.93 a	3.93 a	0.35 a	0.35 a	0.35 a	11.6 c	11.4 c	11.5 c
LSD	0.033	0.023	0.017	0.023	0.023	0.017	0.333	0.344	0.279
S rate (kg ha^{-1})									
0	3.12 e	3.13 d	3.13 e	0.20 e	0.20 e	0.20 e	15.5 a	15.5 a	15.5 a
15	3.24 d	3.25 c	3.25 d	0.24 d	0.24 d	0.24 d	13.5 b	13.5 b	13.5 b
30	3.33 c	3.38 b	3.36 c	0.28 c	0.28 c	0.28 c	11.8 c	12.2 c	12.0 c
45	3.44 b	3.47 a	3.45 b	0.32 b	0.32 b	0.32 b	10.7 d	10.8 d	10.8 d
60	3.49 a	3.49 a	3.49 a	0.37 a	0.36 a	0.37 a	9.4 e	9.6 e	9.5 e
LSD	0.033	0.033	0.016	0.023	0.023	0.016	0.333	0.344	0.236

1: Means of the same column followed by the same letter were not significantly different at the 0.05 level using LSD test.

Discussion

The positive effect of node to first fruiting branch on seed cotton yield shows that as the node to first fruiting branch lies at lower level, then number of sympodial branches which bear bolls directly will be recorded earlier, due to the reason the lower node to first fruiting branch value of cotton plant might bear more number of bolls and contributed for seed cotton yield. Yield increases in this study were from increased boll numbers and boll weight due to treatments. Cotton plants treated with N and S fertilizers produced significantly more bolls compared with no N and no S treated plants, weighing about 8 g and resulted in higher seed cotton yield. Increased number of bolls $plant^{-1}$ was an indicator of decreased abscission of squares and bolls. Increased photosynthetic activity related to N and S assimilation as a result of the balanced supply of nitrogen and sulfur to the crop and the active role of N in new growth of cotton plant. The number of bolls observed in this study agrees with those obtained by Ram et al. (2001). While photosynthetic efficiency is directly affected by nitrogen, sulfur does so indirectly by improving the nitrogen utilization efficiency (Ahmad and Abdin, 2000). Consequently, the crop supplied with adequate of S during the growth and development produced the optimum number of bolls and also optimized the weight of bolls due to availability of higher amounts of photoassimilates. Also, the increased supply of photosynthates to bolls would likely provide an opportunity for seeds to grow to their full size, with an increase in boll weight. Improvements in these growth and yield attributes led to a higher seed cotton yield. Result obtained in this study is similar to that of Dubey et al. (2000). Because the cotton plant needs both nitrogen and sulfur to produce the components of foliage, seeds, and lint, it's important to keep the two companion nutrients in balance with each other. When S is deficient in relation to the nitrogen supply, accumulation of the non protein compounds occurs, resulting in the N to S ratio greater than 15:1. N:S ratio of 12.3:1 found in this study was in good agreement with the N:S value of 10-15 reported for most crops. If tissue tests come back with a lower N:S ratio, the crop needs additional sulfur as well as nitrogen. Values approaching and exceeding 18 indicate that there is not enough S present for the plant to use N efficiently. This situation can occur even when sufficient plant tissue concentrations of both N and S are present (Campbell, 2000).

It is concluded that S fertilization up to 45 kg ha^{-1} increased both number of open bolls per plant and seed cotton yield of cotton. However, node to first fruiting branch, number of main stem nodes per plant, seed cotton yield, boll weight and seed cotton weight per boll enhanced up to 30 kg S ha^{-1}. Seed cotton yield, boll weight, and seed cotton weight per boll enhanced up to 120 kg N ha^{-1}. Maximum seed cotton yield was recorded from the plot fertilized at the 120 kg N ha^{-1} and 45 kg S ha^{-1}. The present study results show that sulfur applications, especially in the presence of large amounts of nitrogen, to a soil considered to be S low under field conditions, my have considerable effects on yield and yield components of cotton plants.

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