YIELD RESPONSE OF COTTON TO FOLIAR NITROGEN AS INFLUENCED BY SINK STRENGTH, PETIOLE AND SOIL NITROGEN

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Abstract

Late-season foliar-nitrogen (N) fertilization based on petiole nitrate concentration during boll development is a widely used production practice in cotton. The objectives of this study were: (1) to examine the response of cotton plants to foliar-N fertilization based on petiole N, two boll loads (low and high), and two soil-N levels (low: 55 kg N ha^{-1}; high: 110 kg N ha^{-1}), and (2) study the effect of soil-N levels on the petiole characteristics of the leaf positioned fourth from the top of the canopy. High boll load plants in both soil-N level had significantly greater yield than low boll load plants in either soil-N level. Also, the foliar-N sprays in high boll load plants out yielded the non-sprayed high boll plants of high soil-N, as well as, low and high boll plants in low soil-N. Petiole lengths of big leaves in low and high soil-N levels were significantly greater than their small leaves. The same was true for petiole diameter. The petiole diameters, leaf area, and chlorophyll of small and big leaves of high soil-N level were significantly greater than in the low soil-N levels. Petiole dry weight was similar between low and high soil-N levels, whereas the boll dry weight was significantly greater in high soil-N levels than in low-soil-N levels. High soil-N level resulted in greater petiole NO_3 than the low soil-N. These findings suggested that although the petiole characteristics varied between low and high soil-N levels, the size of the sink determined the plants need for additional N, and therefore, governed plant response to foliar-applied N.

Introduction

Nitrogen (N) demand by cotton (*Gossypium hirsutum* L.) plants is high, especially during the reproductive phase when bolls import large amounts of N from the leaves (Thompson et al., 1976; Zhu and Oosterhuis, 1992) due to reduced root activity (McMichael, 1990). This causes a decline in leaf physiological activity accompanied by leaf senescence (Wullschleger and Oosterhuis, 1990) reducing the yield. In such situations, foliar fertilization has been considered as an effective method to replenish N in the leaves (Kannan, 1986). Studies in our laboratory clearly documented the absorption of foliar-applied N as high as 80% and thereafter its rapid translocation to the developing bolls (Zhu and Oosterhuis, 1992). In addition, foliar-N applications have been reported to increase yield in crops such as wheat (Smith et al., 1987) and soybean (Garcia and Hanway, 1976). Foliar-N fertilization has also ameliorated cotton yields by allowing increased production of assimilates for bolls (Mathur et al., 1968; Oosterhuis et al., 1989). However, results from the studies on the effects of foliar-N applications on cotton yields have been inconsistent (Anderson and Walmsley, 1984; Smith et al., 1987). The variable yield results of cotton from foliar fertilization may be associated with the indeterminate growth habit of cotton plants which makes it difficult to correctly time foliar-N applications, especially during late-season.

Petiole analysis has been used to predict the N requirement of cotton (Maples, et al., 1977), however, studies have shown a lack of positive yield responses of cotton to petiole directed foliar-N applications later than three weeks after flowering (Keisling et al., 1992). We hypothesized that the response of the cotton plants to foliar-N fertilization depends not only on the soil N status, but also on the physiological conditions of the plant concerning the activity of the developing boll load. This “sink” strength of the boll load for N is related to boll number, boll size, and plant N status (Oosterhuis et al., 1989). The specific objectives of this study were to (1) measure and understand the plant factors governing the response of the cotton plant to foliar-N fertilization, and (2) study the effect of soil-N levels on the characteristics of the petiole used in cotton production to diagnose plant N status.

Materials and Methods

The study was conducted on long-term N plots at the Cotton Branch Experiment Station, Marianna, AR, on a Loring Silt Loam (fine-silty, mixed, thermic Typic Fragiudalt). Cotton cultivar Deltapine 50 was planted on 5 May 1993. Plots were comprised of six, 15 -m long rows spaced 0.9 m apart and thinned to a density of 10 plants m^{-2}. Standard mechanical and chemical measures were followed to control weeds and insects. Furrow irrigation was applied as needed each year to minimize moisture stress effects on the plants. Two fertilizer N levels, 55 kg N ha^{-1} (low-N level) and 110 kg N ha^{-1} (high-N level) were chosen for this investigation. N levels were established prior to planting by the addition of ammonium nitrate to long-term N plots which had been receiving the same N rate for the past twenty years.

Two boll loads, low boll load (LBL) and high boll load (HBL) were created in these two soil-N levels. The LBL was established by removing the bolls larger than 2.5 cm in diameter from the middle two rows at weekly intervals starting two weeks after first flower. The HBL consisted of the normal boll number set by the plants. Foliar N was applied at the rate of 11.2 kg N ha^{-1} in the form of urea (46%

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N) when petiole N analysis indicated N requirement according to Arkansas Cooperative Extension Service recommendations (Bonner, 1993). Petiole samples were taken weekly and foliar-N sprays were applied according to the results (Maples et al., 1992).

Treatments consisted of (1) LBL in low soil-N, (2) LBL in low soil-N + foliar sprays, (3) HBL in low soil-N, (4) HBL in low soil-N + foliar-N sprays, (5) LBL in high soil-N, (6) LBL in high soil-N + foliar-N sprays, (7) HBL in high soil-N, (8) HBL in high soil-N + foliar-N sprays. The experimental design was a randomized complete block, split-split design, with four replications. The main plots were N levels, first split was for boll load, and second split was for foliar-N fertilization.

The yields and components of yield were determined by hand picking 3-m lengths of row from each plot.

Petiole Characteristics

To study petiole characteristics, two separate experiments were conducted. In the first experiment, the uppermost fully expanded main-stem leaves, positioned fourth from the top of the canopy were separated into two groups: small and big leaves. Fifteen leaves from each group were harvested 104 days after planting from two soil-N regimes, 55 (low) and 110 kg N ha^{-1} (high) and the following measurements were taken: petiole length, diameter, dry weight, nutrient concentrations, leaf area, chlorophyll (using a Minolta SPAD meter), and boll dry weight. In the second experiment, 15 uppermost fully expanded leaves positioned fourth from the top of the canopy were harvested 111 days after planting from the two soil-N regimes, 55 and 110 kg N ha^{-1}. The leaves were separated into petioles and leaf blades and the measurements recorded on the petioles were similar to previous experiment. The boll load was not altered in both petiole studies.

Results and Discussion

A boll count of approximately 5 bolls per plant was maintained in the LBL plants until harvest. The boll load in the HBL plants was about 12 and 14 bolls per plant for low and high soil-N, respectively, at harvest. Pre-plant soil nitrate status in the low- and high soil-N plots prior to planting and fertilizer N addition was 4.14 and 4.82 kg N ha^{-1}, respectively.

Petiole Analysis

Analysis of petiole nitrate levels indicated that at the low soil-N, both the LBL and HBL plants needed additional N in the form of foliar fertilization (Table 1) according to current Arkansas Cooperative Extension Service recommendations. The LBL plants of the low soil-N treatment needed additional N three weeks after the boll load was reduced, whereas the HBL plants of the low soil-N level required N after two weeks. The demand in both LBL and HBL treatments continued until the seventh week of the boll removal, after which there was no further demand for additional N.

In contrast to LBL and HBL plants of the low soil-N level, the LBL and HBL plants in the high soil-N level exhibited a requirement for N only very late in the season after boll removal. The LBL plants in the high soil-N level did not indicate a need for N until five weeks after boll removal, whereas the HBL plants indicated a need for N four weeks after boll removal. The response of plants with low and high boll loads under low and high soil-N levels demonstrated the important and critical role of the size of the developing boll load in determining plant N requirement as indicated by petiole analysis for N (NO_3). The LBL and HBL plants under the high soil-N level did not require additional N after the foliar applications (Table 1).

Yield Response

The LBL and HBL plants under low and high soil-N levels with and without foliar N yielded differently. The details of yield data are described in Table 2. Results from the long-term N trial in 1993 showed that maximum yield response was obtained from 110 kg N ha^{-1} (Bondada et al., 1996).

As expected, the HBL treatment outyielded the LBL treatment. Of more consequence, however, was that there was a significant response to foliar-applied N by the HBL treatments but not by the LBL treatments at both low and high soil-N levels (Table 2). This showed the critical importance of the size of the develioping boll load in determining the plant need for additional N and, therefore, in governing plant response to foliar-applied N. There was a trend for the foliar-N treatments in general to outyield the non-foliar-N treatments, although this was only significant for the HBL treatments, thereby confirming the benefits of foliar fertilizing with N.

Petiole Characteristics

The petiole characteristics, petiole length and diameter, and leaf area and chlorophyll of the small and big leaves positioned fourth from top of the canopy varied with soil-N levels (Tables 3 and 4). There was no significant difference in the petiole lengths of big leaves between low (55 kg N ha^{-1}) and high (110 kg N ha^{-1}) soil-N levels (Table 3). The same was true for petiole lengths of small leaves between low and high soil-N levels. However, petiole lengths of the big leaves from low and high soil-N were significantly greater than the small leaves (Table 3).

Within each soil-N level, the petiole diameter of big leaves was significantly greater than the small leaves. Unlike petiole length, the petiole diameter of small leaves of low and high soil-N was similar, whereas the petiole diameter of big leaves from high soil-N was significantly greater than the petiole diameter of big leaves from the low soil-N treatment. The same was true for small leaves.

The leaf area of big and small leaves from high soil-N was greater than the leaf area of small and big leaves from low soil-N (Table 4). The chlorophyll levels of leaves from high soil-N was greater than the chlorophyll levels of leaves from low soil-N. In plants with low soil-N, the chlorophyll levels were similar between the small and big leaves. However, the chlorophyll of big leaves was greater than the chlorophyll of small leaves in the high soil-N (Table 4). Petiole dry weight from the low soil-N was greater than the petiole dry weights from the high soil-N level (Fig. 1). However, the dry weight of the boll closest to the fourth leaf was greater in the high soil-N. This indicated that the petioles of high soil-N translocated most of its assimilates to the developing bolls. Petiole length was similar between the two soil-N levels, however, the petiole dry weight was greater in the high soil-N level (Fig. 2). In contrast, leaf area and chlorophyll levels (Fig. 3) as well as the N and P concentrations (Fig. 4) were greater in high soil-N than in low soil-N level.

Conclusions

The study demonstrated the important role of the size of the developing boll load in determining plant response to foliar-N fertilization. Furthermore, the research confirmed the benefits of foliar feeding with N, provided the plant N status, as indicated by petiole analysis, is taken into consideration along with fertilizer N status and the plant requirement for N as indicated by the boll load.

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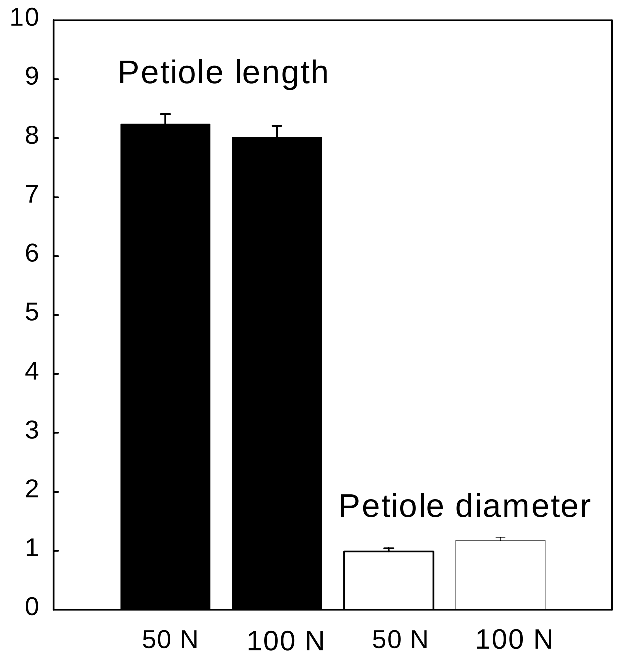

Figure 1. Effect of soil-N levels on dry weights of petiole and the boll closest to the fourth leaf from the top of the canopy.

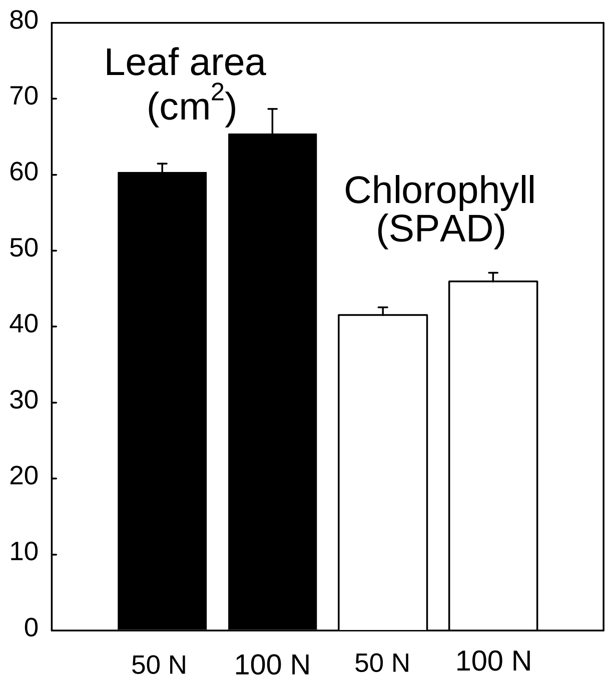

Figure. 2. Effect of soil-N levels on the length and diameter of the petiole of the leaf positioned fourth from the top of the canopy.

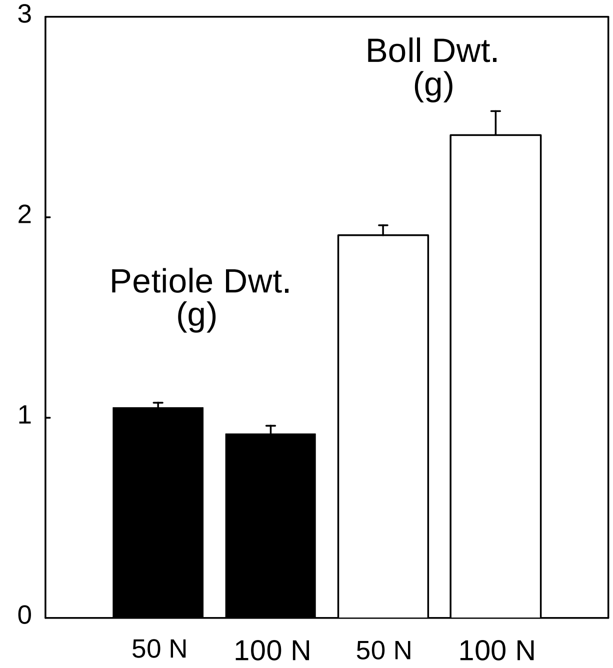

Figure 3. Effect of soil-N levels on the leaf area and chlorophyll of the leaf positioned fourth from the top of the canopy.

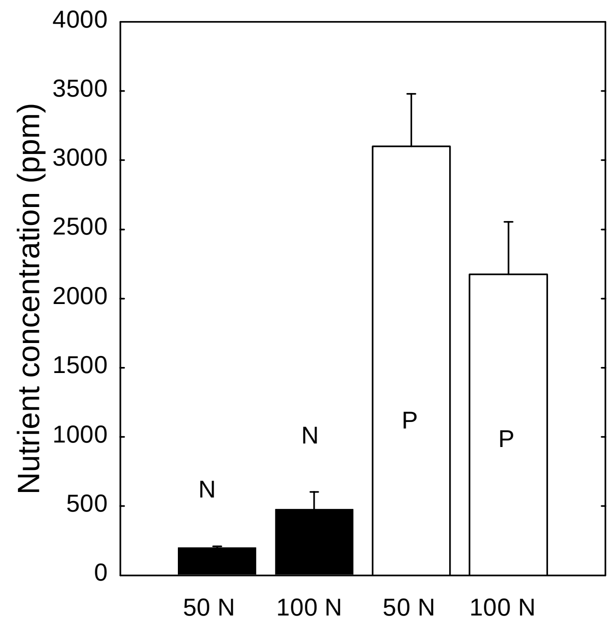

Figure 4. Effect of soil-N levels on nutrient concentrations of the petiole of the leaf positioned fourth from the top of the canopy.

Table 1. Foliar N application to low- and high-boll-load cotton plants under two fertilizer N rates.

Fertilizer		Petiole-directed foliar N application[z]					
		2[Y]	3	4	5	6	7
Low N	Low boll load	N[X]	Y	Y	Y	Y	Y
(55 kg N ha^{-1})	High boll load	Y	Y	Y	Y	Y	N
High N	Low boll load	N	N	N	N	Y	N
(110 kg N ha^{-1})	High boll load	N	N	N	Y	Y	N

[z] According to recommendation (Maples et al., 1992).
[y] Weeks after boll removal.
[x] N = no N requirement as indicated by petiole analysis; Y = N requirement as indicated by petiole analysis, and foliar N was applied at the rate 10 kg N ha^{-1}.

Table 2. Effect of fertilizer N rate, boll load, and foliar N on cotton yield.

Fertilizer (kg N ha^{-1})	Boll Load	Foliar Nitrogen (kg N ha^{-1})	Yield (kg seedcotton ha^{-1})	
50	Low boll load	0	783	cd[z]
50	Low boll load	50	970	bc
50	High boll load	0	1035	b
50	High boll load	50	1258	a
100	Low boll load	0	776	d
100	Low boll load	10	782	bcd
100	High boll load	0	884	b
100	High boll load	20	1170	a

[z] Means within a column followed by the same letter are not significantly different at P = 0.05.

Table 3. Effect of soil N levels on the petiole characteristics of the leaf positioned fourth from the top of the canopy.

Treatments	Petiole length (mm)	Petiole diameter (mm)
55 kg N ha^{-1} Small leaf	7.21 ± 0.22	1.28 ± 0.04
55 kg N ha^{-1} Big leaf	9.01 ± 0.16	1.42 ± 0.06
110 kg N ha^{-1} Small leaf	7.01 ± 0.19	1.43 ± 0.08
110 kg N ha^{-1} Big leaf	8.96 ± 0.43	1.62 ± 0.12

Table 4. Effect of soil N levels on leaf area and chlorophyll of the leaf positioned fourth from the top of the canopy.

Treatments	Leaf area (cm^2)	Chlorophyll (SPAD)
55 kg N ha^{-1} Small leaf	56.27 ± 2.94	35.00 ± 0.52
55 kg N ha^{-1} Big leaf	86.01 ± 2.67	36.35 ± 0.43
110 kg N ha^{-1} Small leaf	64.09 ± 3.56	41.37 ± 0.53
110 kg N ha^{-1} Big leaf	92.11 ± 5.65	43.17 ± 0.18