Introduction

The nitrogen (N) requirements of the cotton (*Gossypium hirsutum* L.) crop have been well documented (Bassett et al., 1970). Nitrogen demand by a cotton plant is high, especially during the reproductive phase (Oosterhuis et al., 1983) when bolls import large amounts of N from the leaves (Zhu and Oosterhuis, 1992). Nitrogen fertilization is a critical practice in cotton production because soils on which cotton is grown are more often deficient in N than any other plant nutrient, and N fertilization represents a significant cost in cotton production. Foliar fertilization with N to supplement soil applications provides a method to ensure adequate fertilizer during reproductive growth. However, inconsistent results have often been experienced with foliar-applied N, and it has been speculated that this may be associated with crop and environmental conditions, and the nature of the chemical applied. The objectives of the studies reported here were to study the characteristics of the cotton leaf cuticle, the effects of water-deficit stress, and the absorption of foliar-applied nitrogen.

Methods and Materials

Field studies were conducted on a Typic Fragiudults soil using cotton cultivar Stoneville 506 planted in four-row plots 5 m in length. A randomized block design with three replications was used. Cultural practices including herbicides, insecticides and furrow irrigation were applied according to recommendations. Light and electron microscopy were used to characterize the anatomical details and ultrastructure of the leaf cuticle and epicuticular wax as described by Oosterhuis et al. (1981). In addition, tissue samples were taken from well-watered and water-stressed plots and the molecular wax composition of the cuticle determined (Bondada et al., 1996). In the second study, 800 sympodial leaves at main-stem node 10 were marked. The plots were irrigated 2 weeks prior to ^{15}N treatment to ensure a well-watered condition for crop growth favorable for N absorption and translocation. Four leaves in a similar position from each of three replicates were selected and the leaves painted with 0.4 ml (pH 6-7) ^{15}N-urea solution containing 22 mg N from 2.0% atom excess urea using a small paint brush. Approximately 85% of 22 mg N was applied to the leaves with the rest of it remaining in the brush and glass vial. The amount of N was calculated by estimating the quantity required for a typical leaf adaxial surface to give an approximate equivalent rate of 10 kg N ha^{-1}, i.e. 4.5 mg N/leaf. Application was made late afternoon (1900 CDT) and plants were harvested at 1-day intervals and separated into component parts for ^{15}N analysis (Mulvaney, 1986). In the third study, leaves at the first fruiting positions of main-stem node 10 were randomly selected from well-watered and water-stressed plots, and treated with ^{15}N-urea at 06h00, 13h00, and 19h50. Six hours after each application, three treated leaves were sampled from each plot and the cuticle wax content, ^{15}N analysis and leaf water potentials of the leaves determined.

Results and Discussion

The Cotton Leaf Cuticle

The cuticle constituted a continuous waxy covering over the underlying epidermis, interspersed with numerous stomates and glandular trichomes. Superimposed on this was the epicuticular layer of predominantly lipid material. Also noted was the presence of waxy ledges extending partially over the stomatal pore, and the presence of an internal cuticle extending through the stomatal pore and covering some of the substomatal mesophyll cells. The thickness of the leaf cuticle varied from 30 μm to 45 μm. The leaf accumulated 91.7 μg cm^{-2} of wax.

Absorption of Foliar-Applied ^{15}N Urea

Foliar-applied urea N was rapidly taken up by the sympodial leaf, with 30%, 47% and 70% recovery within 1 h, 24 h and 192 h after application, respectively. The increase in ^{15}N in the bolls coincided with a progressive decline in the treated leaves. Rapidly developing fruits were the major sinks for foliar-applied N with the boll closer to the site of application being a much stronger N sink than the next closest boll along the branch with 34% and 8% ^{15}N recovery 192 h after application in the first and second bolls, respectively. The percentage of ^{15}N recovered in the main-stem leaves, sympodial leaves at the second fruiting positions, and in the remainder of the plants was negligible.

Effects of Water Deficit

Water deficit stress increased the cuticle thickness by 33% and also changed the qualitative composition of cuticular waxes to more long chain molecular waxes of greater hydrophobicity that reduced fertilizer absorption (Bondada et al., 1997). The thickness of the leaf cuticle increased with leaf age from 20 to 60 days after leaf unfolding. This was correlated with a decrease in absorption of foliar-applied ^{15}N-urea (Bondada et al., 1996). Water deficit impeded the absorption of the foliar-applied urea by the sympodial leaves, as well as the subsequent translocation within the branch. Applications made either late afternoon or early morning were more effectively absorbed than those made at mid-day, and this was more pronounced for water-stressed plants.

Conclusions

The surface features, anatomical details, and wax molecular composition of the cotton leaf cuticle were characterized. The leaf cuticle was shown to respond to environmental conditions of water stress, by increasing in thickness and changing the molecular composition of the waxes to more long chain hydrophobic waxes. The thickness of the leaf cuticle increased with leaf age and this was correlated with a decrease in absorption of foliar-applied ^{15}N-urea. Foliar N applications made either late afternoon or early morning were more effectively absorbed than those made at mid-day, and this was more pronounced for water-stressed plants. Foliar-applied urea N was rapidly taken up by the sympodial leaf, with 30% recovery within 1 h after application. Rapidly developing fruits were the major sinks for foliar-applied N. In general, foliar fertilization with urea N was shown to be a viable means of incorporating N into the cotton plant for improved efficiency and rapidity of utilization of the nutrient for maximum growth and yield.

References

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