Effect of Phosphorus Deficiency on Cotton Physiology

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RESEARCH PROBLEM

Phosphorus (P) is an essential element in plants, required for vital structural and metabolic functions. A shortage of P will lead to a breakdown of plant membranes and reduce energy transfer within the plant. Crop fertilization programs must insure adequate P to support the critical role of this element in plant metabolism. Improving P fertilizer recommendations and increasing P use efficiency will increase grower profit margin and reduce the potential for offsite loss of P in drainage waters. Rapid introduction of modern cotton (Gossypium hirsutum L.) cultivars and changes in production practices, in the past several decades, have created a need to update the science base of cotton P fertilization recommendations. The objectives of this study were to quantify the effects of P deficiency on the physiological growth of cotton.

BACKGROUND INFORMATION

Phosphorus (P) is an essential macronutrient required for energy transfer (i.e., ATP and NADPH); genetic information (i.e., DNA and RNA); and formation of phospholipids; and it plays an important role in membrane integrity. Phosphorus is mobile in the plant such that young leaves or developing bolls can be nourished from the labile P of older tissues; i.e., P is redistributed from older to younger parts. In cotton, the critical-P concentrations range from 0.20 to 0.31% (Crozier et al., 2004; Cox and Barnes, 2002). For cotton grown in the southern regions of the USA, the critical-P concentration range in the upper mature leaf at first flower or first square is 0.30 to 0.50% (Plank, 1988). In Arkansas, a critical-P concentration range for petioles is not used because P is not recommended by the petiole monitoring program. Prior to 2006, no P fertilizer was recommended for cotton when modified Mehlich-3 (1:7 extraction ratio)-extractable phosphorus was detected. 

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P was >100 lb P/acre. In 2002, approximately 95% of the soil samples submitted from cotton fields had soil-test P >100 lb/acre. This suggests that past P-fertilization practices have resulted in buildup of P in Arkansas soils and recommendations need to be updated. Information on the range of tissue-P concentrations that are sufficient for currently grown commercial cotton cultivars is an important component of developing improved P-management recommendations.

MATERIALS AND METHODS

The experiment was conducted in a growth chamber at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark. The growth chamber was programmed for a 12-hour photoperiod, with day/night temperatures of 30/20°C and relative humidity of 60 to 80%. The cotton cultivar DDL 444 was planted in 2-L pots filled with washed sand. Each pot had a 2-cm diameter hole in the base for drainage. After emergence, seedlings were thinned to one plant per pot. All pots were watered with one-half strength Hoagland’s nutrient solution during the first four weeks after planting to maintain a sufficient nutrient and water supply. Four weeks after planting, all pots where flushed with deionized water and separated into two groups: P-sufficient and P-deficient. The P-sufficient treatment continued to receive the half-strength nutrient solution with P, while the P-deficient treatment received half-strength Hoagland’s nutrient solution without P. Four plants in each treatment were harvested weekly for four weeks after the initiation of the P treatments. The effects of P deficiency on leaf photosynthesis, quantum yield of PSII, membrane leakage, and chlorophyll SPAD were determined. The experimental design was a completely randomized design with five replications. A t-test was performed to determine whether significant (P≤0.05) differences existed between treatment means.

RESULTS AND DISCUSSION

Withholding P caused photosynthesis to significantly decline below that of cotton plants in the P-sufficient treatment two, three, and four weeks after treatments began (Fig. 1A). Quantum yield of PSII, as a measure of plant stress, reflected significant stress in the P-deficient plants the first week after treatment was imposed and three weeks later (Fig. 1B). Membrane leakage also increased significantly the third and fourth week of the treatment for the P-deficient treatment compared to the P-sufficient plants (Fig. 1C). The rapid effect of P deficiency on membrane leakage was expected in view of the critical role of P in the formation of phospholipids in plant membranes. Membrane leakage is a measure of cell integrity and provides a sensitive indicator of the plant stress suffered due to P deficiency. Finally, phosphorous deficiency caused significantly higher chlorophyll content two, three, and four weeks after the beginning of the treatment in the P-deficient treatment compared to the P-sufficient plants (Fig. 1D).
PRACTICAL APPLICATION

This growth room study quantified the effect of P deficiency on the physiological growth of cotton plants. Phosphorus deficiency caused a reduction in leaf photosynthesis and quantum yield of PSII, while resulting in increased membrane leakage and chlorophyll SPAD compared to phosphorus-sufficient plants.

LITERATURE CITED

Fig. 1. The effect of P-deficiency on (A) leaf photosynthesis, (B) Quantum yield PSII, (C) membrane leakage, and (D) Chlorophyll SPAD measured weekly starting 28 days after planting when P was withheld from the P-deficient treatment. The asterisk (*) indicates significant differences at $p \leq 0.05$ between P treatments within a sample week.