MINERAL NUTRITION AND OZONE DAMAGE TO PIMA COTTON

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Abstract

The San Joaquin Valley of California (SJV) is subject to substantial ozone air pollution. Pima cottons developed in Arizona have been introduced into the SJV, where they exhibit symptoms suggesting ozone damage. We have investigated the potential for manipulation of nitrogen fertilization to reduce the effects of ozone exposure. We characterize the effect of ozone in exposure chambers on biomass, carbohydrate allocation, and hydraulic conductance of the resulting root systems (G), and the interaction of nitrogen fertilization with ozone exposure. Ozone reduces allocation to roots and substantially reduces both biomass and K on a leaf area basis. Increasing nitrogen increases biomass but reduces relative allocation to roots, thereby decreasing K per leaf area. The optimal strategy appears to be moderately high levels of nitrogen, which allow production of substantial biomass, but not levels which favor excessive foliar development and reduce K per leaf area.

Introduction

Advanced Pima cotton lines were developed in Arizona, where ozone concentrations are typically low. Pima has recently been introduced into the San Joaquin Valley of California (SJV) where ozone air pollution is increasing. Yield losses due to ozone have been reported for many crops, including upland cotton. Anecdotal evidence suggests yield suppression and foliar ozone symptoms in Pima cottons.

We have shown that Pima cotton (cv. S-6) is sensitive to ozone in controlled exposure chambers (Grantz and McCool, 1992). Yield and fiber quality are also reduced. The allocation of carbon to root systems is reduced, which reduces the hydraulic conductance on a per plant basis, and to a reduced extent on a leaf area basis (Grantz and Yang, 1995). This could affect the ability of the existing leaf area to maintain high levels of gas exchange, and could therefore impact productivity.

Nitrogen deficiency is known to exert effects on carbon allocation that are opposite to those due to ozone (Radin and Mauney, 1986). N requirements for optimal biomass production are altered at elevated concentrations of ambient CO_2 (Rogers et al., 1993) We test the interaction of nitrogen fertilization and ambient ozone to determine the feasibility of using nitrogen fertilization to counteract some of the deleterious effects of ozone, without reducing yield potential to unacceptably low levels.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1203-1204 (1996)
National Cotton Council, Memphis TN

Materials and Methods

Seeds of Pima cotton (G. barbadense L.; cv Pima S-6) were sown in 350 mm x 450 mm tall pots containing UC Mix No. 2 (2/1/1 sandy loam soil/ peat moss/redwood shavings) amended with lime (3.01 kg m^{-3}), superphosphate (1.43 kg m^{-3}), and micronutrients. Plants were thinned to 1 seedling per pot and watered daily with half-strength Hoagland's solution containing either 150, 60.0, or 1.1 ppm N as NH_4NO_3 and 60 ppm K as KCl. Plants were grown in greenhouse exposure chambers (CSTR; Heck et al., 1978) exposed to 12-hr average ozone concentrations of 0.005 (control), 0.037, 0.074, or 0.111 µL L^{-1} and harvested at ca. 8 weeks after emergence, as described previously (Grantz and Yang, 1995).

Dry weights were determined following drying to constant weight in drying ovens, and hydraulic conductance per unit transpiring leaf area was determined as

$$G=F/\Delta\Psi$$

where G is hydraulic conductance (kg s^{-1} MPa^{-1} m^{-2} leaf area), F is transpirational flow through the intact plant determined gravimetrically, and $\Delta\Psi$ is the water potential gradient from the soil surrounding the roots to the transpiring leaves. Transpiration was determined every 3 s, averaged every 150 s, and accepted when these 150 s averages were constant (±10%) over 30 min.

Results and Discussion

At all levels of nitrogen fertility the effect of exposure to ozone was to reduce total biomass productivity (Fig. 1) and leaf area (not shown). The reduction in biomass productivity between plants exposed to charcoal filtered air and those exposed to the highest level of ozone was similar at all levels of nitrogen, though plants receiving the highest level of nitrogen produced ca. 15-20 fold more biomass than those receiving the lowest level of nitrogen.

An important determinant of productivity is gas exchange activity, which may be limited by shoot water status and by root function. An indicator of the relative balance of root and shoot function is the root to shoot dry weight ratio. As reported previously (Grantz and Yang, 1995), exposure to ozone substantially reduced the root to shoot ratio (Fig. 2). The relative reduction was similar (50-60%) at all levels of nitrogen fertility.

As expected, the effect of decreasing nitrogen fertilization was to increase the allocation of carbon to the root systems, and to decrease leafiness, thereby increasing the root to shoot ratio (Fig. 2). This response count-eracted the response to ozone exposure. However, to increase the root to shoot ratio to control levels, in plants exposed to the highest ozone con-centrations, an extremely low level of nitrogen fertilization was required (Fig. 2).

A measure of the balance of root and shoot function is the hydraulic conductance (G) of the root (which dominates the whole plant measure of hydraulic conductance presented here) expressed on the basis of the transpiring leaf area supported by the root system (Fig. 3). At nitrogen concentrations of 60 and 1.1 ppm, ozone exerted an inhibitory effect on K. This was largely abolished by the highest level of N fertilization (Fig. 3). As a result of the interacting responses of root and shoot development to ozone and to nitrogen, the intermediate level of nitrogen fertilization resulted in the highest value of G at low ozone concentrations, and in a value of G equivalent to that of the highest N plants at the highest ozone concentrations. The plants receiving the lowest level of N fertilization exhibited similar levels of G in charcoal filtered air, but very low levels of G per leaf area with increasing levels of ozone.

The levels of nitrogen fertilization examined in this study were chosen to span the range considered acceptable for adequate yield under field conditions, though conversion to application rates in the field are inexact and not presented here. It is clear that suboptimal N fertilization reduces biomass and yield sufficiently that any improvement in shoot water status associated with improvements in G are unimportant. However, the results shown in Fig. 3 support the concept that productivity in a specific air pollution environment might be improved by appropriate selection of a somewhat lower N fertilization rate than might be optimal under clean air conditions. Exact concentrations of N, and feasibility under field conditions, remain to be demonstrated.

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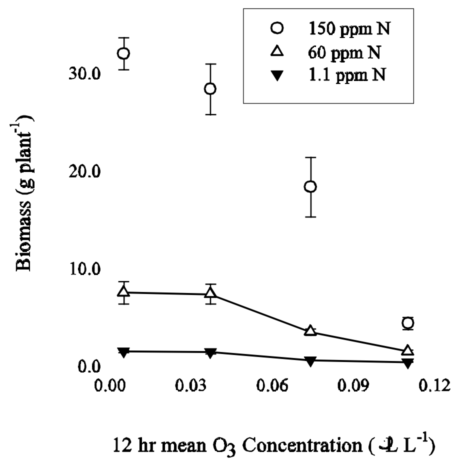

Figure 1. Relationship between biomass accumulation of Pima cotton plants, and 12 hour mean ozone concentrations, at three levels of Nitrogen fertilization.

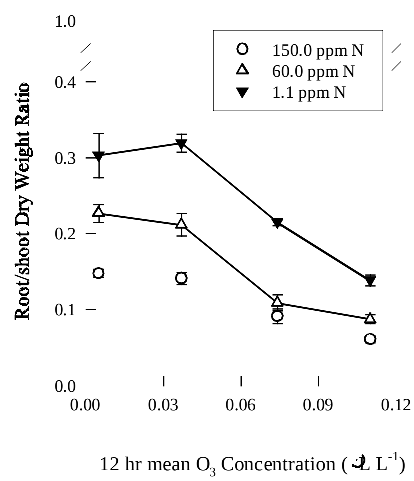

Figure 2. Relationship between root to shoot dry weight ratios of Pima cotton plants, and 12 hour mean ozone concentrations, at three levels of Nitrogen fertilization.

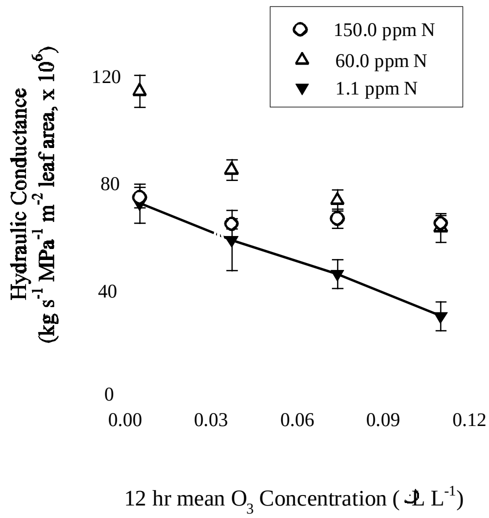

Figure 3. Relationship between hydraulic conductance per unit transpiring leaf area of Pima cotton plants, and 12 hour mean ozone concentrations, at three levels of Nitrogen fertilization.