Nitrogen and phosphorus requirements of cotton and wheat under changing atmospheric CO₂ concentrations

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Key words: atmospheric CO₂ enrichment, carbohydrate composition, nitrogen nutrition, phosphorus nutrition, shoot growth

Abstract

The influence of increasing atmospheric CO₂ on shoot growth, leaf nitrogen and phosphorus concentrations and carbohydrate composition was investigated in cotton and wheat. Shoot dry weight of both species was generally higher at elevated CO₂, especially at high rates of available soil N and P. Critical leaf N concentration was reduced but critical P concentration was increased in both species at high CO₂.

Introduction

The greater productivity of C₃ plants with increasing atmospheric CO₂ concentrations results from changes in balance between the photoreductive carbon cycle (PCR) and the photooxidative cycle (PCO) (Wallsgrove et al., 1983). These changes probably involve altered flux of carbon and nutrients through the various metabolic pools in the leaf (Conroy, 1992). Nitrogen (N) and phosphorus (P) are the most likely nutrients to be affected due to the quantities of these elements involved in the PCR and PCO cycles. Carbon allocation within the leaf is also likely to change. Consequently, N and P concentrations in the leaf required to produce maximum productivity (critical concentrations) are likely to be altered at high CO₂. We report the effects of CO₂ on the critical N and P concentrations for cotton and wheat.

Materials and methods

Soil was collected from the A horizon (0-150mm) of a yellow podzolic profile at Belanglo State Forest, near Moss Vale, NSW. The available P was less than 1 mg kg⁻¹ (Bray No. 1) (Bray and Kurtz, 1945), organic matter content was 5.0%, pH (CaCl₂) was 4.3 and the concentrations of exchangeable Ca, Mg, K, Na and Al were 0.56, 0.54, 0.12, 0.08 and 1.75 cmol(+)/kg⁻¹ respectively.

Six kg of dry soil was added to 7 L pots (0.4m tall, 0.15m dia.). The pH of the soil in each pot was adjusted to 6.5 with CaCO₃ and MgCO₃. Basal potassium (K) was applied to each pot at 150 g K m⁻² equally as K₂SO₄ and K₂CO₃. Micronutrients were applied to each pot at the following rates (g m⁻²): Fe, 3; Mn, 3; Zn, 0.6; Cu, 0.3; B, 0.3 and Mo, 0.006.

Wheat (Triticum aestivum L. cv. Hartog) and cotton (Gossypium hirsutum L. cv BT Siokra 1-4) were grown in three naturally lit, glasshouses at 23 - 27°C (day) and 19 - 21°C (night) and spaced to minimize the effects of competition. The CO₂ concentrations in the glasshouses were monitored and maintained at 350 ± 10; 550 ± 20 and 900 ± 20 μL L⁻¹ CO₂. The CO₂ was passed through Purafil to remove ethylene contamination. Effects of variation between and within each glasshouse were minimized by
reallocating pots and CO₂ treatments between glasshouses and re-randomizing pots each week.

In the N experiment, P as CaHPO₄ was added to each pot at 560 g P m⁻². N was applied weekly as a solution of KNO₃, Ca(NO₃)₂, Mg(NO₃)₂, (NH₄)₂SO₄, NH₄NO₃ (1:2:1:1:1) at rates: 0; 2.8; 5.6; 11.2; 22.5; and 45 g N m⁻². In the P experiment, P (as CaHPO₄) was applied at 0; 28; 56; 112; 280; and 560 g P m⁻² and N was applied at 64 mg N kg⁻¹ soil week⁻¹ as a solution of the same composition as used in the N experiment. Basal nutrients and P were mixed with the soil before planting.

For each species, two randomized complete block experiments were run concurrently. Within the CO₂ treatments, the N and P treatments were arranged factorially with 6 levels of either N or P and 4 replicates (pots). Yield data was analysed by ANOVA and lsd's (p<0.05) used to indicate treatment separation. Standard errors were calculated for other data excluding critical N and P curves which were fitted by inspection.

Plants were harvested at 36 after sowing (DAS) for wheat and after 38 days for cotton. The plants were separated in their various parts and leaf areas measured. The youngest, fully-expanded leaves were frozen in liquid N₂ and stored at -15°C until freeze dried. The remainder of the shoot was dried at 80°C for 48 hours, weighed and stored.

The freeze-dried leaves were ground and sub-samples were taken for N, P and carbohydrate analyses. Total P determination was by ICP (optical emission spectrometry) (ARL model 3520B) on a H₂SO₄/H₂O₂ digest. Total N was determined by thermal conductivity using a Leco FP-428 Nitrogen Determinator. Critical N and P concentrations were estimated by plotting shoot dry weight as a function of N and P concentration in the last, fully-expanded leaf (Hocking and Meyer, 1991b). Second-order polynomial equations were fitted to describe the relationship between shoot weight and N and shoot weight and P. Critical concentrations were calculated from the equations. Starch was assayed enzymatically (McCleary et al., 1992). Ethanol-soluble and water-soluble carbohydrates were extracted as described by Virgona and Barlow (1991). The total soluble carbohydrate concentration was measured in each fraction by the anthrone method (Yemm and Folkes, 1954).

**Results and discussion**

**Growth response to CO₂ at different P availability**

The highest addition rate of P was sufficient to obtain maximum growth rate (Fig. 1).

Shoot dry weight was generally higher in both cotton and wheat when the CO₂ concentration was increased from 350 to 900 μL L⁻¹ (Fig. 1). Cotton increased in dry weight between 350 and 550 μL CO₂ L⁻¹ only at highest P levels. In contrast, wheat dry weight increased with each CO₂ increment. However, the interaction between CO₂ and P was different for the two species. Wheat responded to CO₂ enrichment from the lowest addition rate although the relative increase in dry weight was greatest at high P rates (p < 0.05). In contrast, cotton only responded to CO₂ enrichment at 280 and 560 g P m⁻² (Fig. 1).

![Fig. 1. Influence of increasing atmospheric CO₂ concentrations on shoot dry weight of cotton and wheat grown with different levels of N and P availability. The plants were grown for 36 (cotton) and 38 (wheat) days at either 350, 550, or 900 μL CO₂ L⁻¹. Vertical bars indicate lsd (p < 0.05).](image-url)