SOIL MOISTURE INCREASES IN A TROPICAL SAVANNA UNDER FREE AIR CO_2 ENRICHMENT

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ABSTRACT

Soil moisture measurements in an Australian tropical savanna show accumulating soil water under three years of Free Air CO_2 Enrichment (FACE). Most of this accumulation is occurring below the rooting depth of grasses. Although this increase in stored soil water is only a fraction (< 0.3% yr^{-1}) of annual rainfall, it is cumulative and may advantage deep-rooted woody plants.

INTRODUCTION

The rising level of CO_2 in the atmosphere ([CO_2]) can directly affect plants both by enhancing carbon fixation and by increasing the efficiency with which they use water. The fertilizing effect of CO_2 has often been emphasized in the past. This has reinforced the notion that C3 plant species, in which photosynthetic rates are sensitive to changes in [CO_2], will contribute more to global vegetation changes than C4 species. But field experiments that capture plant-soil-atmosphere coupling are providing growing evidence of the relative importance of changing water fluxes, versus stimulated carbon fixation, under elevated [CO_2]. This would suggest a role where C4 plants could contribute strongly to global biosphere responses, through their increased efficiency of water use at elevated [CO_2]. The Australian Savanna Free Air CO_2 Enrichment (OzFACE) facility was established to investigate ecosystem responses of a tropical savanna to increased [CO_2]. In this paper we test and confirm the hypothesis that increased water use efficiency of tropical grasses under elevated CO_2 will lead to an increase in soil moisture.

METHODS

The OzFACE facility is located in a coastal tropical savanna in northeastern Australia, near Townsville, Queensland. Median annual rainfall for the site is 1083 mm. Herbaceous vegetation at the site is dominated by tropical C4 grasses. There is an open woody overstorey, but FACE rings have been located away from mature trees. The experiment uses six 14-m diameter FACE rings, each consisting of an octagonal arrangement of horizontal vent pipes that allow the controlled delivery of CO_2. Three [CO_2] treatments (550 μmol mol^{-1}, 460 μmol mol^{-1} and ambient [CO_2] *ca*. 360 μmol mol^{-1}) are arranged in a randomized block design. Each ring is subdivided into three equal segments for the application of split-plot treatments: a nutrient addition treatment, selective defoliation (the dominant grass, *Themeda triandra*, clipped to a height of 5 cm at four-weekly intervals through the growing season) and a control.

Soil moisture was monitored for a period of three years, from 1 May 2001 to 22 April 2004, at four-weekly intervals using a neutron moisture gauge, calibrated for soils at the site. Soil moisture was measured at a point near the centre of each split-plot segment at depths of 0.20, 0.35, 0.50, 0.70 and 1.00 m. The soil moisture for each soil profile was calculated as a weighted average of the measurements at each depth, taking into account the differences in intervals between sampling depths. For each sampling point, the rate of change in soil moisture was quantified as the slope of the least squares regression line fitted to the time-series of moisture measurements. These measures of change in soil moisture were then analyzed as a linear model with split-plot treatments nested within CO_2 treatments. The main effects of blocks and treatments were not of interest and were removed prior to analysis (by taking the residuals of a linear model that accounted for the effects of split-plot treatments nested within blocks). Interactions of CO_2 with split-plot treatments were tested by the inclusion of linear contrasts (fertilized versus control, and defoliation versus control) in the final statistical model.

RESULTS AND DISCUSSION

Elevated [CO_2] had a significant effect on soil moisture accumulation in this tropical savanna ($p = 0.028 < 0.05$), and there is no evidence that the response to [CO_2] was affected by nutrient addition ($p = 0.87 > 0.05$) or defoliation ($p = 0.91 > 0.05$) treatments. The diverging trends in soil moisture between [CO_2] treatments are illustrated in Fig. 1a. These changes equate to increases in soil water storage through the top 1.2 m of the soil profile of 2.8 mm yr^{-1} at 550 µm mol^{-1} and 2.8 mm yr^{-1} at 460 µm mol^{-1} relative to ambient conditions. Moisture accumulation was greatest at shallower soil depths (Fig. 1b). However, across the whole profile most (74% for both [CO_2] treatments) moisture accumulation has occurred below the rooting depth of grasses (defined here as 0 – 0.3 m).

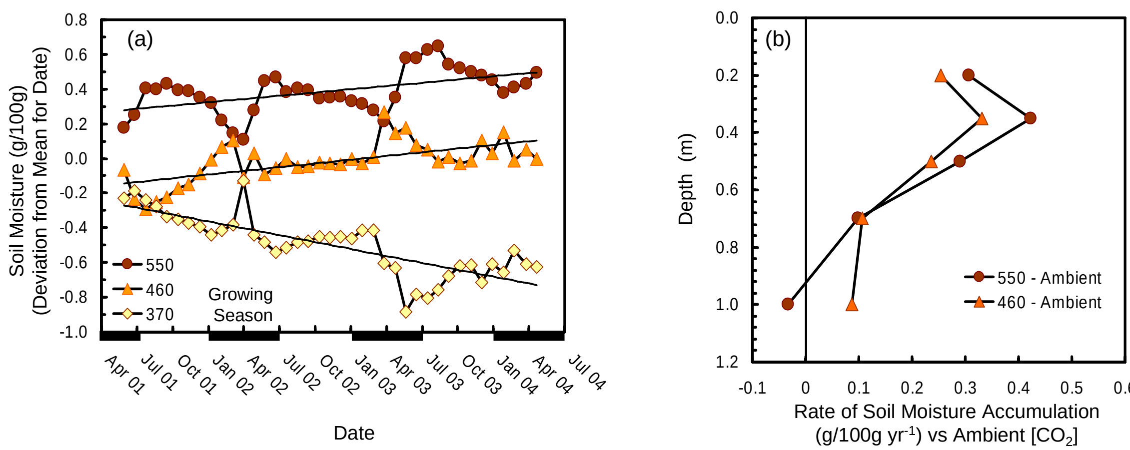

Fig. 1. (a) Relative trends in soil moisture under three [CO_2] treatments. Data have been seasonally detrended by subtracting the average moisture reading for each date from each moisture measurement for that date, and time series have been offset from each other on the y-axis for clarity. (b) Rates of increase in soil moisture for FACE treatments relative to ambient controls as a function of depth in the soil profile.

This result is consistent with results from grassland and forest FACE experiments (although no evidence of soil moisture accumulation was found in a desert FACE). The rate of increase in soil moisture at the OzFACE site represents only a fraction of annual rainfall (*ca*. 0.3% yr^{-1}), but this has been cumulative. Increases in grass standing biomass under FACE, and associated increases in leaf area and water use, would likely offset some of the gains in water use efficiency and could account for the relatively small rate of increase in soil moisture. Most of the increase in stored soil water is occurring below the rooting depth of grasses, where these savings in water use will be of no benefit to grasses but could instead favor deeper-rooted woody plants. This deep accumulation of soil moisture has implications both for the tree-grass balance in savannas and vertical transport of soil solutes (dryland salinity). It is not clear whether increased deep drainage under FACE is a temporary phenomenon, as the vegetation equilibrates with FACE treatments, or whether this reflects a sustained equilibrial response to elevated [CO_2].

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