OZFACE: AUSTRALIAN SAVANNAS FREE AIR CARBON DIOXIDE ENRICHMENT FACILITY

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1. INTRODUCTION

Over the past 200 years, the rate at which human activities have generated carbon dioxide has increased substantially. Almost half of these emissions are buffered by uptake into the oceans and assimilation into land-based ecosystems. But the excess emissions accumulate in the atmosphere, contributing to global warming and climate change. Currently, atmospheric CO_2 levels are rising at a rate of 1.5ppm (0.4%) per year. Aside from the potential for changes in climate, increases in CO_2 levels also have a direct impact on ecosystems. Free air CO_2 enrichment (FACE) experiments allow these effects to be tested on intact ecosystems and provide a means for testing extrapolations from controlled environment studies.

Tropical regions are expected to be amongst the most vulnerable to climate change, but most work on CO_2 and climate change to date has focussed on higher latitudes. Tropical savanna ecosystems will likely be sensitive to changes in atmospheric CO_2. It has been suggested that the relative photosynthetic advantage of C_3 over C_4 plants under elevated CO_2 will favour the establishment and increase of woody plants (Bond & Midgley 2000). But there is growing evidence against the assumption that C_4 grasses will be substantially less responsive to elevated CO_2 than C_3 plants under field conditions (Wand *et al*. 1999). Better knowledge of the responses of C_4 grasses, especially tropical species, is required to make more balanced comparisons with C_3 species, and to understand the relative responses of dry tropical ecosystems. Some have argued that enhanced grass production will increase the potential frequency and severity of fires (Allen-Diaz 1996), which would be detrimental to woody vegetation. There is also the potential for feedback effects of savannas on atmospheric CO_2 through the sequestration of carbon. Aside from possible vegetation changes, soils of tropical savannas could potentially serve as carbon sinks (Hall *et al.* 1995). Most savannas are under some form of extensive land use, usually involving livestock. Ultimately, therefore, responses of savannas will be dependent on human-mediated interactions (e.g., management of fire, grazing, wildlife and invasive species) (Le Houréou 1996). A greater understanding of these systems and their behaviour under future climates will assist in planning adaptation strategies.

The improved water relations of plants under enriched CO_2 conditions can mitigate the effects of moisture stress, especially in C_4 plants. This effect could potentially buffer savanna ecosystems from the influence of the high rainfall variability and periodic moisture stress typical of these ecosystems (Howden *et al.* 1999). Many Australian savannas are infertile, and nutrient limitations could also affect CO_2 responses. There is some debate as to whether low nutrient availability should be expected to constrain plant responses (Lloyd & Farquahar 2000). Possible interactive effects of CO_2 with moisture and nutrient limitations in savannas provide some interesting opportunities for studying system level responses to climate change.

Savannas cover about a quarter of Australia's land surface and account for about a third of its terrestrial carbon stores. Controlled environment studies have provided some understanding of the likely effects of elevated atmospheric CO_2 at the scale of individual plants, but we don't yet know how complex ecosystems, with their many interacting components, will respond. Likely impacts will have important implications for the pastoral industry, carbon sequestration (and potential trading of carbon credits) and other aspects of natural resource management. A FACE experiment was established in a northeast Queensland savanna to address some of these questions, with an emphasis on system level responses. We report here on some of the early results of this study.

2. METHODS

The OzFACE facility is located at Yabulu, about 20km northwest of Townsville on the eastern coast of Australia (19^o S, 147^o E). The site is a coastal savanna with an open tree layer of mixed eucalypt and acacia species, and has been protected from livestock grazing for the past 30 years. The herbaceous layer is composed almost entirely of perennial, tropical (C_4) grasses and is dominated by *Themeda triandra* Forssk. (kangaroo grass), a 'decreaser' species. The site was burned prior to the start of the study to remove accumulated moribund grass. Soils at the site are low fertility, solodic, sandy clay loams (0.7% organic C, 3.2 mg/kg nitrate N, 5 mg/kg P, 0.13 meq/100g K, 25% ESP, for top 10 cm). Median annual rainfall is 1083 mm, most of which falls between December and April, with a very dry intervening season. Interannual variation in rainfall is also high (600 – 1797 mm 1st-9th decile). The warmest month is January (average maximum 31.3°C) and the coolest month is July (average minimum 13.6°C). 2001-02 was a dry year, receiving only 832 mm rain, two thirds of which fell in a single week.

The FACE system consists of six ‘rings’, each 15 m in diameter, that allow the regulated delivery of CO_2 through an octagonal arrangement of horizontal, perforated pipes. Carbon dioxide levels are left unaltered in two of the rings at the current level (370 ppm), elevated to 460 ppm in two rings, and elevated to 550 ppm in the remaining two rings (the elevated levels representing concentrations of atmospheric CO_2 that could be reached by midway through this century). Each ring is divided into three wedge-shaped ‘segments’ for the application of manipulative treatments. Grazing is simulated in one segment by selectively clipping *Themeda* plants to a height of 7cm at four-weekly intervals during the growing season. One segment has nutrients added to simulate higher fertility savannas and to test for possible nutrient limitations to CO_2 responses. (Annual nutrient additions in kg/ha are as follows: 47 N, 10.4 P, 28.2 K, 12 S, 8.6 Ca, 2.4 Mg, 0.02 Zn and 0.04 Bo.) The last segment is left intact as a control. It was not possible to include mature trees, but seedlings of local eucalypt and acacia species have been planted to capture critical tree-grass interactions. The system uses a novel and cost-effective design, yet still achieves good regulation of CO_2 levels.

Baseline measurements of vegetation were taken in 2000 prior to the application of treatments in April 2001. Forty-five 0.5 x 0.5m quadrats were used to sample aboveground biomass and species composition in each ring segment using a non-destructive, calibrated estimation technique. These measurements are being repeated at the end of the growing season (April-May) each year. Aboveground primary production was measured by clipping vegetation from 0.5 x 0.5m quadrats at the end of the growth season and clipping the regrowth at the end of the following season (April-May). Seven quadrats are being sampled from each segment annually.

3. RESULTS

There have been some rapid changes in plant production and vegetation composition in response to the imposed CO_2 and within-ring treatments. Samples from the high CO_2 rings (550 ppm) had double the aboveground net primary production of ambient rings (Fig. 1a). Fertilized segments were consistently more productive than other within-ring treatments (i.e., there was no significant statistical interaction between CO_2 levels and within-ring treatments: ANOVA $p>0.05$).

In 2000, before the application of treatments, *Themeda triandra* accounted for 71% of aboveground herbaceous biomass at the site (with *Chrysopogon fallax* S.T. Blake and *Eriachne obtusa* R. Br. accounting for most of the remainder). By April 2002, average *Themeda* composition had dropped to 31%, but this loss varied strongly across CO_2 levels and within-ring treatments (without any significant interaction between CO_2 and within-ring treatments) (Fig. 1b). The smallest decreases in the relative abundance of *Themeda* occurred in the high CO_2 (550 ppm) rings and control segments, with largest losses in the clipped treatment (where *Themeda* material was selectively removed).

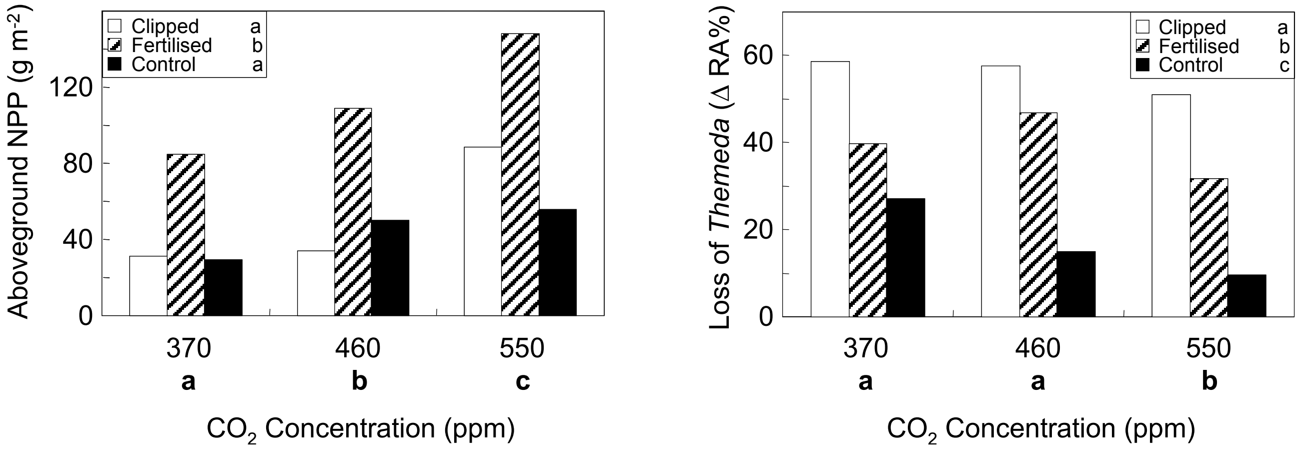

Figure 1. **a)** Differences in aboveground net primary production (NPP) between CO_2 levels and within-ring treatments. **b)** Decline in the dominance of *Themeda* (change in relative abundance (RA) from 2000 to 2002) as affected by CO_2 levels and within-ring treatments. (Treatments sharing the same letter were not significantly different: LSD $p>0.05$.)

4. DISCUSSION

The strong initial response of plant production to CO_2 fumigation is large compared to responses reported for other C_4 grasses (Wand *et al*. 1999). Since a major benefit of elevated CO_2 to C_4 grasses is an increase in water-use efficiency, the limited supply of rainfall over 2001-02 may have enhanced the response to CO_2. In years where moisture is less of a limitation to grass growth, the response of grass production to CO_2 may be less dramatic. We hypothesise that with such moisture-CO_2 interactions, elevated CO_2 will buffer the influence of interannual rainfall variation on grass production. The enhanced production could also potentially be an initial short-term response as plant-soil nutrient pools are redistributed, and the response could diminish if soil nutrients become depleted or if plants acclimate to elevated CO_2. The consistent response to CO_2 in both fertilised and unfertilised segments does not suggest that CO_2 responses are nutrient-limited at this stage. It will take several more years of data on grass production with responses from both wet and dry years to draw confident conclusions. But early indications are of a strong response to CO_2, favouring the argument that extrapolations of C_4 plant physiology have tended to underestimate responses under field conditions.

Changes in vegetation composition support the hypothesis that elevated CO_2 buffers the influence of rainfall variation in savannas. In the dry 2001-02 year, there was a large reduction in *Themeda* biomass, but this affect appeared to be moderated by CO_2 fumigation. In contrast, CO_2-moisture interactions at the Mojave Desert FACE experiment amplified rainfall variability: a wet year promoted the invasion of an annual grass and increased the productivity response of a perennial shrub, but these responses were not evident in a drought year (Huxman & Smith 2001). The physiological activity of plants in an arid system may be too severely constrained during drought years for a CO_2 response to be possible, which could explain the difference in behaviour from that hypothesized for semi-arid tropical ecosystems. The large reduction in *Themeda* in clipped segments mainly reflects the initiation of selective *Themeda* harvesting. Again, we will require several more years' data on species changes to be able to draw robust conclusions.

There have been very rapid ecosystem-level responses to CO_2 at the OzFACE facility. While these preliminary results suggest some strong initial responses, we will be continuing these data sequences to determine: if the magnitude of these responses diminishes over time; whether rainfall variation and nutrient levels interact with responses to elevated CO_2; and how plant community composition shifts in response to these influences.

5. ACKNOWLEDGEMENTS

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