THE ROLE OF WATER RELATIONS IN DRIVING GRASSLAND ECOSYSTEM RESPONSES TO RISING ATMOSPHERIC CO_2

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ABSTRACT

While rising atmospheric carbon dioxide (CO_2) is known to be an important contributor to radiative forcing of Earth's climate, more direct effects of this gas on photosynthesis and plant water relations have been underway for more than a century, and likely have already contributed to important ecosystem changes. Experiments conducted in native and semi-natural grasslands in which ambient CO_2 concentrations have been artificially increased have shown that increasing CO_2 often increases photosynthesis, results in higher soil and plant water content, and can enhance plant water use efficiency, the ratio of plant biomass produced per unit water transpired back to the atmosphere. While these responses may appear beneficial, there are long-term responses of ecosystems to CO_2 such as alterations in the cycling and availability of critical plant nutrients like nitrogen (N) which are likely to change over time and may significantly alter CO_2-enhanced production and forage quality. Herein we discuss these phenomena and speculate on the implications and the importance for world grasslands.

CO_2 AS WATER

In addition to stimulating photosynthesis, rising CO_2 cause stomata of most herbaceous plant species to close, a reaction that results in increased leaf and plant water use efficiency, higher plant and soil water status, and altered seasonal evapotranspirational dynamics (Morgan et al., 2004). Field CO_2 enrichment experiments conducted in grasslands over the past 15 years confirm the importance of water relations in driving ecosystem plant production and species responses to CO_2. For instance, comparisons of CO_2-induced biomass responses in sub-humid tallgrass prairie vs. semi-arid shortgrass steppe show that relative biomass responses occur more commonly and in greater magnitude in the shortgrass steppe than in the tallgrass prairie, and that relative response in both systems is greater in dry vs. wet years (Table 1). These results suggest that semi-arid regions like the shortgrass steppe may be among the world's most CO_2 responsive.

Table 1. Biomass produced in a tallgrass prairie and shortgrass steppe under ambient CO_2 (365 μL L^{-1}), elevated CO_2 (twice ambient), and the elevated/ambient biomass ratio in dry, average or wet precipitation years. [From *Owensby et al*., 1999, and *Morgan et al*., 2004]

Year	Precipitation	Ambient CO_2	Elevated CO_2	Elev./Ambient
Kansas Biomass (tallgrass prairie: 840 mm precip/yr)				
		------------ ($g\ m^{-2}$) -------------		
1989	Dry	175	260	1.49
1990	Average	570	570	1.00
1991	Dry	550	730	1.33
1992	Wet	510	500	0.98
1993	Wet	790	800	1.01
1994	Dry	770	900	1.17
1995	Average	620	590	0.95
Colorado Biomass (shortgrass steppe: 320 mm precip/yr)				
1997	Wet	119	153	1.29
1998	Average	140	200	1.43
1999	Wet	149	173	1.17
2000	Dry	44	85	1.95
2001	Average	110	143	1.30

LONGER-TERM RESPONSES

CO_2-enhanced plant production is often accompanied by lower plant N concentration [*King et al.*, 2004; *Milchunas et al.*, 2005], due in large part to the inability of soil N mineralization to keep pace with increased plant productivity. A widening of the ecosystem C/N ratio may eventually result from this dilution of plant N, and may feed-back and limit plant responses to CO_2. Available soil N may decline under elevated CO_2, and along with species shifts due to differential species sensitivities to CO_2 can result in a significantly altered plant community and reduced forage quality [*Milchunas et al.*, in press].

CHALLENGES IN INTERPRETING FIELD CO_2 EXPERIMENTS

A major challenge in CO_2 enrichment research is in determining how to interpret short-term experiments which are conducted as small elevated CO_2 islands in otherwise present-day environments. Such conditions do not incorporate land-atmosphere feed-backs to CO_2 and future climate change, nor do they reflect the long-term soil nutrient dynamics which ultimately will determine ecosystem responses to global change. These problems are especially relevant to semi-arid ecosystems where CO_2 responses are driven primarily by water, and need to be addressed by combined modeling/experimental approaches to more realistically scale our small plot CO_2 enrichment experimental results to a future CO_2 enriched world.

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