Effects of Elevated Atmospheric CO_2 on Biomass and Carbon Accumulation in a Model Regenerating Longleaf Pine Ecosystem

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ABSTRACT

Recent evidence suggests that the effects of elevated atmospheric CO_2 on individual plants may be a poor predictor of how these plants respond when grown in communities. A model regenerating longleaf pine ecosystem (longleaf pine, *Pinus palustris*, sand post oak, *Quercus margaretta*, wiregrass, *Aristida stricta*, rattlebox, *Crotalaria rotundifolia*, and butterfly weed, *Asclepias tuberosa*) was exposed to two levels of atmospheric CO_2 (ambient, 365 µmol mol^{-1} and elevated, 720 µmol mol^{-1}) for three years using open-topped chambers. Total biomass was 62% greater in CO_2-enriched chambers; however, biomass response of individual species varied with *Pinus* increasing, *Aristida*, *Crotalaria*, and *Asclepias* decreasing, and *Quercus* not significantly affected. These variable responses resulted in CO_2-induced alterations in community structure; *Pinus* comprised 88% of total biomass in CO_2-enriched plots but only 76% in ambient plots, while *Aristida*, *Crotalaria*, and *Asclepias* comprised 19% under ambient conditions but only 8% under high CO_2. Carbon (C) content followed a similar CO_2 response pattern as biomass which resulted in a significant increase of 12.2 Mg C ha^{-1} sequestered in standing biomass, with an additional increase of 1.6 Mg C ha^{-1} in litter. Therefore, while some members of this community may not be able to compete as well as atmospheric CO_2 concentration continues to rise, this ecosystem - due to the strong positive response of longleaf pine - should be a sink for atmospheric CO_2.

INTRODUCTION

Increased atmospheric CO_2 concentrations have been shown to increase plant biomass, on average, by almost 40% (Poorter 1993); however, all species do not exhibit equivalent responses to CO_2-enrichment. While individual plant response to elevated CO_2 can be, somewhat, predicted based on differences in physiology, structure, and symbiotic relationships, recent evidence suggests these factors can not be reliably used to predict responses when species are grown in communities (Ziska, 2003; Morgan et al. 2004). Since CO_2-induced shifts in competitive advantages among species may alter species composition and community structure (Wray and Strain 1987, Dijkstra et al. 2002), experiments examining the effects of CO_2-enrichment on plant communities are critical for furthering our understanding of ecosystem response to global climate change. In 1998, we constructed a model regenerating longleaf pine ecosystem composed of species representing differing structural and functional guilds. Here we report findings on the effects of elevated CO_2 on biomass and carbon content of this community.

MATERIALS AND METHODS

Five species chosen for study (common and representing major functional guilds)
- ✓ longleaf pine (*Pinus palustris* - a C_3 evergreen conifer)
- ✓ wiregrass (*Arisida stricta* - a C_4 bunch grass)
- ✓ sand post oak (*Quercus margaretta* - a C_3 broadleaf tree)
- ✓ rattlebox (*Crotalaria rotundifolia* - a C_3 perennial, herbaceous, N-fixing legume)
- ✓ butterfly weed (*Asclepias tuberosa* - a C_3, non-leguminous, herbaceous perennial)

Community constructed using 3 pines, 3 wiregrass, 2 oaks, 1 rattlebox, 1 butterfly weed
- ✓ placed randomly in 0.75 m^2 quadrats (6 spaces per quadrat left empty)
- ✓ planting densities reflective of natural longleaf pine-wiregrass systems

Open-top chambers used to deliver target CO_2 concentrations
- ✓ ambient = 365 µmol mol^{-1}
- ✓ elevated = 720 µmol mol^{-1}
- ✓ study was RCBD with 6 blocks; blocked along length of soil bin

Measurements taken
- ✓ Aboveground biomass of individual species
- ✓ Belowground biomass of individual species
- ✓ Litter biomass of individual species
- ✓ Carbon and nitrogen concentrations of all tissues and litter

Data analysis conducted using the mixed model procedures of the Statistical Analysis System

RESULTS

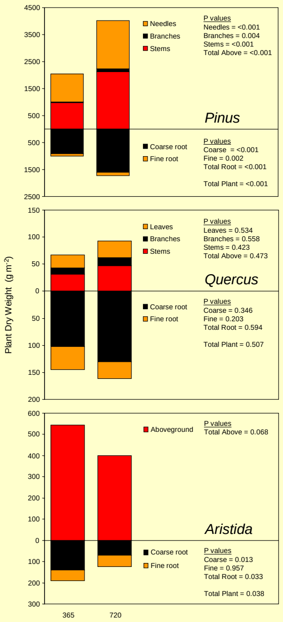

Figure 1. Dry weight (g m^{-2}) of longleaf pine (*Pinus*), sand post oak (*Quercus*), and wiregrass (*Aristida*) tissues for plants grown under ambient (365) and elevated (720) atmospheric CO_2 with associated statistics. (Note: y-axis scales vary).

Pinus:
- -height, diameter, dry weight of all tissues greater (88% increase)
- -litter dry weight significantly greater
- -allocation: branches & stems increased; needles & roots decreased
- -R:S lower

Quercus:
- -no significant differences in biomass between CO_2 treatments
- -allocation to fine roots decreased; trend for lower R:S

Aristida:
- -% mortality significantly higher
- -total clump area was 24% lower
- -dry weight of all tissues (except fine roots) lower (29% less dry weight)
- -litter dry weight increased
- -allocation and R:S not affected

RESULTS

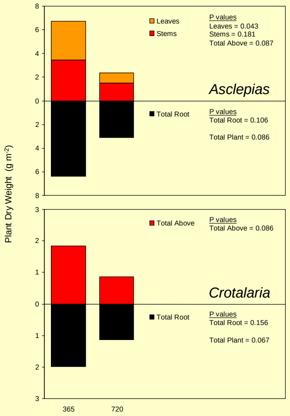

Figure 2. Dry weight (g m^{-2}) of butterfly weed (*Asclepias*) and rattlebox (*Crotalaria*) tissues for plants grown under ambient (365) and elevated (720) atmospheric CO_2 with associated statistics. (Note: y-axis scales vary).

Asclepias:
- -dry weight of all tissues lower (50% less dry weight)
- -allocation to leaves decreased; allocation to roots increased; R:S higher

Crotalaria:
- -dry weight of all tissues lower (~50% less dry weight)
- -allocation and R:S not affected

RESULTS

Community Responses to Elevated CO_2
- -aboveground biomass 69% greater
- -belowground biomass 41% greater
- -total litter mass 76% greater
- -community structure altered
- -*Pinus* comprised 88% of total biomass under CO_2; 76% in ambient
- -*Aristida*, *Crotalaria*, and *Asclepias* comprised 8 and 19%, respectively
- -*Quercus* did not differ between CO_2 treatments

Carbon Content
- -followed similar CO_2 response pattern as biomass
- -total C content (g m^{-2}) of plants and litter increased (65 & 74%)
- -increase of 12.2 Mg C ha^{-1} sequestered in standing biomass
- -increase of additional 1.6 Mg C ha^{-1} in litter
- -soil C content did not differ between CO_2 treatments

DISCUSSION AND CONCLUSIONS

- ✓ Experiments on community level responses to elevated CO_2 needed
- ✓ Overall community response to elevated CO_2 was positive (62% more biomass)
- ✓ Differential responses to CO_2 enrichment among species
- ✓ Responses did not always follow predicted, *a priori*, patterns (e.g., C_3 vs C_4; broadleaf vs confer; N-fixing vs non)
- ✓ Longleaf pine comprised 12% more total biomass under high CO_2
- ✓ Understory herbaceous species comprised 11% less total biomass under high CO_2
- ✓ System gained 11.4 Mg C ha^{-1} under high CO_2 over 3 years of study
- ✓ Productivity of longleaf pine forests will likely be enhanced by rising levels of atmospheric CO_2, however, community structure may be altered

REFERENCES

Dijkstra, P., Hymus, G., Colavito, D., Vieglais, D.A., Cundari, C.M., Johnson, D.P., Hungate, B.A., Hinkle, C.R. and Drake, B.G. 2002. Elevated atmospheric CO_2 stimulates aboveground biomass in a fire-regenerated scrub-oak system. Global Change Biology 8:90-103.

Morgan, J.A., Pataki, D.E., Korner, C., Clark, H., Del Grosso, S.J., Grunzweig, J.M., Knapp, A.K., Mosier, A.R., Newton, P.C.D., Niklaus, P.A., Nippert, J.B., Nowak, R.S., Parton, W.J., Polley, W.J. and Shaw, M.R. 2004. Water relations in grasslands and desert ecosystems exposed to elevated atmospheric CO_2. Oecologia 140:11-25.

Poorter, H. 1993. Interspecific variation in the growth response of plants to elevated CO_2 concentration. Vegetatio 104/105:77-97.

Wray, S.M. and Strain, B.R. 1987. Competition in old field perennials under CO_2 enrichment. Ecology 68:1116-1120.

Ziska, L.H. 2003. Evaluation of yield loss in field sorghum from a C_3 and C_4 weed with increasing CO_2. Weed Science 51:914-918.

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