

Response of Agronomic and Forest Species to Elevated Atmospheric Carbon Dioxide

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Abstract. *The effects of atmospheric carbon dioxide on corn, soybeans, loblolly pine, and sweetgum were studied in the field during a growing season. The plants were exposed to a range of concentrations of carbon dioxide day and night in open-topped, flow-through chambers. At a mean daytime carbon dioxide concentration of 910 parts per million, increases in total biomass ranged from 157 to 186 percent of the control values. Seed yield and wood volume increased and there were changes in plant anatomy and form. Net photosynthesis increased with increasing carbon dioxide concentration in soybeans and sweetgum, but was unaffected in corn. Water use efficiency also increased in corn, soybeans, and sweetgum.*

It is widely considered that atmospheric CO₂ concentrations are rising and that this is chiefly due to increased consumption of fossil fuels (1). There is, however, considerable debate over the climatic and biological consequences of this change in the earth's atmosphere (2, 3).

The essential role of plants in the carbon cycle makes them a logical starting point for assessing the impact of elevated CO₂ on living systems. Through photosynthesis, plants form the support system for the rest of the biosphere. Since carbon is a chief input in this food-producing process, any appreciable response of plants to changing CO₂ concentrations could have far-reaching implications. The gradual accumulation of CO₂ in the atmosphere and the paucity of long-term field data on CO₂ and plant growth suggest an immediate need for research in this area.

In this report we describe the design and implementation of a system permitting study of the effects of CO₂ on vegetation in the field and give the results of our first experiments with two agronomic and two forest species.

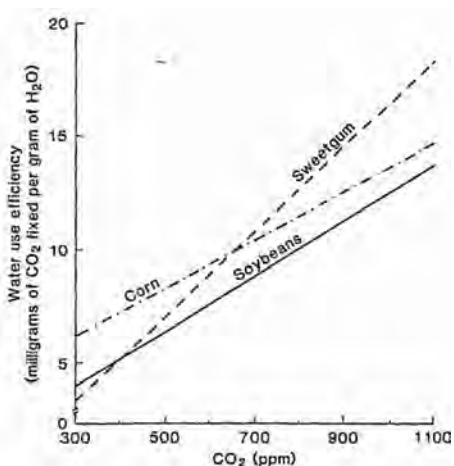


Fig. 1. Water use efficiencies for corn, soybeans, and sweetgum at various CO₂ concentrations. Values were fitted by the method of least squares and are based on 46 observations for soybeans, 50 for corn, and 15 for sweetgum.

Test atmospheres containing 340 ± 12 (background level), 520 ± 30, 718 ± 52, and 910 ± 52 parts per million (ppm) CO₂ (daytime values) were generated in transparent, open-topped chambers (2.4 m high by 3.0 m in diameter) (4-6) located in the field. Each chamber, essentially an open-ended cylindrical baffle, was constructed of a structural aluminum frame covered by Roll-A-Glass, a clear film of polyvinyl chloride. The bottom half of each chamber cover was double-walled, with the inside wall being perforated to distribute air uniformly into the chamber. A plenum box equipped with a 0.75-horsepower fan and a particulate filter supplied air at a rate of about 1.06 m³/sec. Pure CO₂ from a liquid receiver weighing 12.7 metric tons was metered day and night through a high-pressure manifold into the ventilation airstream to generate the three elevated CO₂ concentrations. The pressure of each delivery line was regulated separately. Background exposures with and without chambers were established, and all treatments were replicated three times. Carbon dioxide levels were continually monitored with an infrared CO₂ analyzer by sequentially sampling air from each open-topped chamber.

Four plant species—corn [*Zea mays* (L.) 'Golden Bantam'], soybean [*Glycine max* (L.) Merr. 'Ransom'], loblolly pine (*Pinus taeda* L.), and sweetgum (*Liquidambar styraciflua* L.)—were grown in 16.5-liter pots containing one part peat-lite, one part coarse sand, and two parts clay loam soil and exposed to the various CO₂ levels in the chambers for 3 months. The plants were watered and fertilized throughout the study. The soybeans received a nitrogen-free nutrient solution to prevent inhibition of nodulation and nitrogen fixation.

Stomatal conductance and net photosynthesis were measured with a steady-state micucuvette system (7). All measurements were made at 25° ± 0.1°C, 70 ± 1 percent relative humidity, a photon flux density of 1600 to 1800 μE/m²-sec, and a CO₂ concentration equal to

that present in a given treatment. Stomatal conductance decreased with increasing CO₂ for each species. Conductance for corn decreased from 1.8 to 0.8 cm/sec between 340 and 910 ppm CO₂. The rate of decrease dropped steadily as the concentration of CO₂ increased. No significant change in photosynthetic rate was observed for corn; the regression suggested a slight decrease (-0.006 mg of CO₂ per square decimeter per hour for each 1-ppm increase in CO₂). However, net photosynthesis increased linearly with CO₂ concentration for soybeans. The regression indicated that the rate increased by 0.036 mg of CO₂ per square decimeter per hour for each 1-ppm increase in CO₂. This difference in the photosynthetic response to CO₂ concentrations between C₃ and C₄ plants was observed previously (8, 9).

Growth was enhanced in all four species (Table 1). Yield increased for the two crop species and wood volume increased for the tree species. Substantial changes in seed quality (such as in the content of fat, protein, fiber, and moisture) did not occur.

There is a seeming discrepancy between the photosynthetic rates for corn (no significant CO₂ effect) and that species' increased biomass (Table 1). This increase in biomass without a concomitant increase in the photosynthetic rate per unit of leaf area is attributable to increased leaf area and increased water use efficiency. Plants growing in atmospheres containing 520 to 910 ppm CO₂ did not undergo the wilting that we commonly observed for control plants on hot summer afternoons, when the rate of water uptake was exceeded by the rate of water loss. Wilting on hot afternoons inhibits leaf expansion and photosynthesis at a time when other environmental factors are most favorable for rapid carbon fixation. Thus a corn plant growing in an atmosphere with a high level of CO₂ was able to continue fixing carbon

Table 1. Final dry weights of the test species as percentages of the control weights. There were 18 observations for corn, pine, and sweetgum and six for soybeans.

Species	Concentration of CO ₂ (ppm)				
	Chamber	340			
		No chamber (background)	520	718	910
Corn	100	93	158	148	160
Soybean	100	103	157	179	186
Pine	100				157
Sweetgum	100				160

and avoided wilting even though it had a greater leaf area.

Water use efficiency, defined as milligrams of CO₂ fixed per gram of water transpired, increased dramatically with increasing CO₂ concentrations for the species tested (Fig. 1). Although plants grown at high CO₂ levels were larger, they used available soil water at a much lower rate because of stomatal closure. For corn, water use efficiency was improved in CO₂-enriched atmospheres through lower transpiration rates. For soybeans and sweetgum, enhancement of photosynthesis also contributed to this improvement.

The leaves of soybeans, pine, and sweetgum thickened steadily as CO₂ levels rose. At 910 ppm CO₂, leaf thickness in these three species was 131, 110, and 121 percent of the control values, respectively. Thickness increased in all of the cell layers of pine and sweetgum leaves. In soybeans the greatest effect was the appearance of a well-developed third layer of palisade cells. As CO₂ levels increased for soybeans, more nodes, earlier anthesis, and less floral abscission were observed. Germinability of soybean seeds was not affected, however. Leaf thickness, node number, and reproduction in corn were not significantly altered by the CO₂ treatments.

These findings suggest positive growth responses to CO₂ enrichment for the agronomic and forest species studied. Further studies are needed to improve the experimental system and to provide additional data on the effect of CO₂ enrichment on vegetation.

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