Carbon Sequestration (Forests) - Summary

from the Center for the Study of Carbon Dioxide and Global Change

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As the CO_2 content of the air continues to rise, nearly all of earth's plants, including various forest ecosystems, will respond by increasing their photosynthetic rates and producing more biomass. These phenomena will allow long-lived perennial species characteristic of forest ecosystems to sequester large amounts of carbon within their wood for extended periods of time (Chambers et al., 1998), which could ultimately counterbalance CO_2 emissions produced by mankind's usage of fossil fuels. Thus, it is important to summarize what is known about forest and forest-species responses to atmospheric CO_2 enrichment and subsequent carbon sequestration.

In reviewing studies that have been conducted on individual trees, it is clear that elevated levels of atmospheric CO_2 increase photosynthesis and growth in both broad-leaved and coniferous species. When broad-leaved trembling aspen (*Populus tremuloides*) were exposed to twice-ambient levels of atmospheric CO_2 for 2.5 years, for example, Pregitzer et al. (2000) reported 17 and 65% increases in fine root biomass at low and high levels of soil nitrogen, respectively; while Zak et al. (2000) observed 16 and 38% CO_2-induced increases in total tree biomass when subjected to the same respective levels of soil nitrogen.

Similar results have been reported for coniferous trees. When branches of Sitka spruce (*Picea sitchensis*) were fumigated with air of 700 ppm CO_2 for four years, rates of net photosynthesis in current and second-year needles were 100 and 43% higher, respectively, than photosynthetic rates of needles exposed to ambient air (Barton and Jarvis, 1999). In addition, ponderosa pine (*Pinus ponderosa*) grown at 700 ppm CO_2 for close to 2.5 years exhibited rates of net photosynthesis in current-year needles that were 49% greater than those of needles exposed to air containing 350 ppm CO_2 (Houpis et al., 1999). Many more such responses of trees to atmospheric CO_2 enrichment can also be found in our Subject Index under the general heading of Trees.

From the preceding material, it is clear that elevated CO_2 enhances photosynthetic rates and biomass production in forest trees, both of which phenomena lead to greater amounts of carbon sequestration. In addition, elevated CO_2 enhances carbon sequestration by reducing carbon losses arising from plant respiration. Karnosky et al. (1999), for example, reported that aspen seedlings grown for one year at 560 ppm CO_2 displayed dark respiration rates that were 24% lower than rates exhibited by trembling aspen grown at 360 ppm CO_2. Also, elevated CO_2 has been shown to decrease maintenance respiration, which it did by 60% in western hemlock seedlings exposed to an atmospheric CO_2 concentration of nearly 1600 ppm (McDowell et al., 1999).

In a thorough review of these topics, Drake et al. (1999) concluded that, on average, a doubling of the atmospheric CO_2 concentration reduces plant respiration rates by approximately 17%. This finding contrasts strikingly with the much smaller effects reported by Amthor (2000), who found an average reduction in dark respiration of only 1.5% for nine deciduous trees species exposed to 800 ppm CO_2. The period of CO_2 exposure in his much shorter experiments, however, was but a mere 15 minutes. Hence, if the air's CO_2 content doubles, plants will likely sequester something on the order of 17% more carbon than ambiently-grown plants, solely as a consequence of CO_2-induced reductions in respiration. And it is good to remember that this stored carbon is in addition to that sequestered as a result of CO_2-induced increases in plant photosynthetic rates.

What is the fate of the extra carbon that is stored within plant tissues as a consequence of atmospheric CO_2 enrichment? Is it rapidly returned to the atmosphere following tissue senescence and decomposition? Or is it somehow locked away for long periods of time?

To answer these questions, it is important to note that atmospheric CO_2 enrichment typically reduces, or has no effect upon, decomposition rates of senesced plant material (see our Subject Index Summary on Decomposition). De Angelis et al. (2000), for example, noted that when leaf litter from Mediterranean forest species exposed to 710 ppm CO_2 for 3.5 years was collected and allowed to decompose at 710 ppm CO_2 for approximately one year, it decomposed at a rate that was 4% less than that observed for leaf litter produced and incubated at ambient CO_2 concentrations for one year. Similarly, leaf litter collected from yellow-poplar (*Liriodendron tulipifera*) seedlings exposed to 700 ppm CO_2 for four years contained 12% more biomass than leaf litter collected from seedlings grown at ambient CO_2, following two years of decomposition at their respective CO_2 growth concentrations (Scherzel et al., 1998). However, Hirschel et al. (1997) found no significant CO_2-induced effects on decomposition rates in tropical rainforest species, as Scherzel et al. (1998) also found for eastern white pine (*Pinus strobus*). Thus, it would appear that elevated CO_2 typically reduces or has no effect upon plant litter decomposition rates. In addition, it is important to note that none of these decomposition studies looked at wood, which can sequester carbon for long periods of time, even for millennia (Chambers et al., 1998), provided it is not burned.

Based upon several different types of empirical data, a number of researchers have concluded that current rates of carbon sequestration are robust and that future rates will increase with increasing atmospheric CO_2 concentrations. In the study of Fan et al. (1998) based on atmospheric measurements, for example, the broad-leaved forested region of North America between 15 and 51°N latitude was calculated to possess a current carbon sink that can annually remove all the CO_2 emitted into the air from fossil fuel combustion in both Canada and the United States. On another large scale, Phillips et al. (1998) used data derived from tree basal area to show that average forest biomass in the tropics has increased substantially over the last 40 years and that growth in the Neotropics alone can account for 40% of the missing carbon of the entire globe. And in looking to the future, White et al. (2000) have calculated that coniferous and mixed forests north of 50°N latitude will likely expand their northern and southern boundaries by about 50% due to the combined effects of increasing atmospheric CO_2, rising temperature, and nitrogen deposition.

The latter of these factors is an important variable. As indicated in the study of White et al. (2000), it can play an interactive role with increasing atmospheric CO_2 to increase plant growth and carbon sequestration. However, the magnitude of that role is still being debated. Nadelhoffer et al. (1999), for example, concluded that nitrogen deposition from human activities is "unlikely to be a major contributor" to the large CO_2 sink that exists in northern temperate forests. Houghton et al. (1998), however, feel that nitrogen deposition holds equal weight with CO_2 fertilization in the production of terrestrial carbon sinks; and Lloyd (1999) demonstrated that when CO_2 and nitrogen increase together, modeled forest productivity is greater than that predicted by the sum of the individual contributions of these two variables. Thus, anthropogenic nitrogen deposition can have anywhere from small to large positive effects on carbon sequestration, as well as everything in between.

In spite of these many positive findings, some people still worry that rising air temperatures will negatively impact carbon sequestration in forests. However, Liski et al. (1999) showed that carbon storage in soils of both high- and low-productivity boreal forests in Finland actually increased with increasing temperature, thereby putting to rest the idea that rising temperatures will spur carbon losses from soils and trees and exacerbate global warming. Similarly, King et al. (1999) showed that aspen seedlings increased their photosynthetic rates and biomass production as temperatures rose from 10 to 29°C, putting to rest the idea that high-temperature-induced increases in respiration rates would cause net losses in carbon fixation. Moreover, White et al. (1999) showed that rising temperatures increased the growing season by about 15 days for 12 sites in deciduous forests located within the United States, causing a 1.6% increase in net ecosystem productivity per day. Thus, rather than exerting a negative influence on forest carbon sequestration, if air temperatures rise in the future they will likely have a positive effect on carbon storage in forests and their associated soils.

In conclusion, as the air's CO_2 content continues to rise, the ability of earth's forests to sequester carbon should also rise. With more CO_2 in the atmosphere, trees will likely exhibit greater rates of photosynthesis and reduced rates of respiration. Together, these observations - along with the finding that atmospheric CO_2 enrichment has little or no effect on plant tissue decomposition rate - suggest that biologically-fixed carbon will experience greater residency times within plant tissues. And if this carbon is directed into wood production, which increases substantially with atmospheric CO_2 enrichment, some of it can be kept out of circulation for a very long time, possibly even a millennium or more.

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