Factors Associated with Carbon Sequestration

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Introduction

In the fall of 2007, Bruce Shepard, chancellor of University of Wisconsin-Green Bay (UW-GB), signed the American College and University Presidents Climate Commitment (ACUPCC). This commitment pledges that UW-GB will eliminate its campus greenhouse gas emissions over time. One aspect of this effort is to produce a carbon inventory for the university. With over 1,600 acres of vegetative land, carbon sequestration could play a role in the inventory. Defining carbon sequestration, and explaining the effect environmental factors have on the rate carbon is sequestered would be beneficial to this project.

Definition

The net carbon sequestered in an ecosystem is calculated using several factors from the forest carbon cycle (Fig. 1.1) (Gower, 2003). The uptake of carbon, called gross primary production (GPP), is the process where vegetation removes carbon dioxide (CO_2) from the atmosphere through photosynthesis and stores it in foliage, roots, and woody tissues. In photosynthesis, the CO_2 is converted into carbohydrates that plants use to create biomass. Plants respire CO_2 when they oxidize carbohydrates in order to grow, maintain, and repair tissue. In Figure 1.1, the sum of this respiration is labeled R_A for autotrophic respiration. The net primary production (NPP) is the difference between the GPP and R_A. In addition to the vegetation, the soil plays a role in this cycle. Soil organic content (SOC) is the carbon uptake of the soil (D) minus the respiration rates of the roots (R_R) and heterotrophs (R_H). The net ecosystem production (NEP) is the difference between the NPP and the heterotrophic respiration, which includes the vegetation and the soil. The NEP is considered the net carbon sequestered by an ecosystem and is labeled H in Figure 1.1. Uptake of CO_2 and allocation of carbon to respiration and biomass components (above-ground net primary production (ANPP) and below-ground net primary production (BNPP) is affected by water availability, nitrogen levels, temperature, stand age, and levels of atmospheric gases (Gower and Ahl, 2006). Since the cycle is affected by many variables, the NEP can differ greatly within species, soil types, and geographic areas.

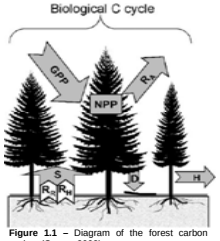

Figure 1.1 – Diagram of the forest carbon cycle – (Gower, 2003)

Factors

Water

Water availability has been tied to NPP. The larger the amount of annual precipitation and soil water-holding capacity, the larger the leaf area index (LAI) (Fig. 2.1). The amount of foliage a plant has is directly proportional to its productivity. The scarcity of water will cause the plant to reduce its photosynthetic capability, reducing its carbon uptake. This will result in less carbon being sequestered (Gower, 2001).

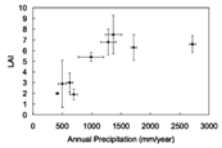

Figure 2.1 Relationship of average leaf area index (LAI) with annual precipitation (Gower, 2003).

Nutrients

Foliage contains the largest amounts of nutrients in a plant. Plants tend to optimize carbon allocation to maximize carbon gain. With infertile soils, plants allocate more biomass to roots to increase nutrient uptake (Gower, 2003). The highest levels of carbon sequestration can be observed with plants grown on fertilized land (Qian, et al. 2003).

Temperature

Increases in temperature have been demonstrated in empirical studies to increase soil heterotrophic respiration and decrease the amount of carbon the soil can uptake. This would reduce the soil's ability to be a carbon sink. Short-termed experiments have produced data, which don't support these models (Gower, 2003).

Age

Carbon sequestration tends to decrease over the lifespan of a plant. It has been hypothesized this is due to a decline in NPP from nutrient limitations and hydraulic constraints (Gower, 2003). This effect can be seen in several types of vegetation, forest (Fig. 2.2), and grasslands (Fig. 2.3). In addition to the decreased carbon sequestration rates, plants tend to allocate carbon to different tissue types (Howard, et al. 2004) (Fig. 2.4).

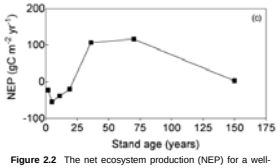

Figure 2.2 The net ecosystem production (NEP) for a well-drained boreal black spruce stand (modified from Gower, 2003).

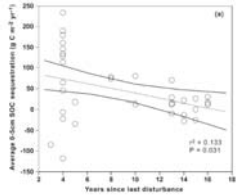

Figure 2.3 Changes in soil organic carbon (SOC) sequestration rate as a function of years since last disturbance. These prairies were planted on Alfisols and Mollisols. This graph shows the linear regression and the 95 percent confidence interval (modified from Kuckarik, 2007).

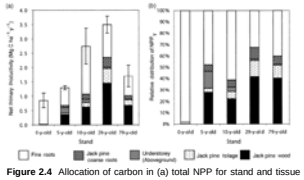

Figure 2.4 Allocation of carbon in (a) total NPP for stand and tissue type and (b) relative distribution of total NPP for tissue. These were from different aged jack pine stands in Saskatchewan, Canada (Howard, et al. 2004).

Atmospheric Gases

Recent studies in CO_2 and ozone, O_3, have shown these gases will affect carbon sequestration. Elevated atmospheric CO_2 levels allow more carbon to be available for plants to uptake. This has led to much research over the last decade as to how plants will allocate this resource. Short-term studies (King, et al. 2005), have shown an increase in NPP of approximately 20 percent. Along with increasing CO_2 levels, ground level ozone has also increased. When combined with ozone, NPP levels have decreased (Fig. 2.5).

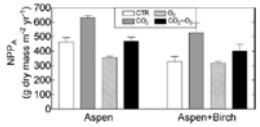

Figure 2.5 The NPPA for trees grown in ambient, elevated CO_2, elevated ozone, and elevated ozone and CO_2 FACE rings. (Data provided by Evan McDonald, U.S. Forest Service.)

Conclusion

Since carbon sequestration rates are affected by many variables, it is difficult to determine the NEP for a species. The sequestration rates used in the initial ACUPCC carbon inventory for UW-GB utilized previously published data due to the timeline for the capstone exercise. Jenkins, et al. (2003) warned against using such large-scale estimators on small-scale regional projects because localized variables may greatly affect the rate calculations. These ranges and errors could cause a 4-fold increase in the calculations of net carbon sequestered by the university's managed properties from 323 MTeCO$_2$yr^{-} to 2730 MTeCO$_2$yr^{-}. If this is unacceptable by the university, it should consider a long-term, on-site technique to be done periodically.

Sources

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