CARBON ALLOCATION IN AN OLD-GROWTH FOREST IN THE GREAT LAKES REGION OF THE UNITED STATES

J. Tang, and P.V. Bolstad

Department of Forest Resources, University of Minnesota, 1530 North Cleveland Avenue, Saint Paul, MN 5510; jtang@umn.edu

ABSTRACT

We measured components of ecosystem respiration and biomass from wood, foliage and roots in two stands in an old-growth hemlock-northern hardwood forest. Respiration was measured by the chamber method and upscaled to the stand level. Wood production was calculated from the increase in tree size. Foliage biomass was measured from litterfall. Root production was measured from in-growth root cores. Based on the measurements of respiration and biomass we calculated gross primary production (GPP) and net ecosystem production (NEP). The annual GPP was estimated as 1144 and 1089 g C m^2 y^{-1} in the hardwood and hemlock stands, respectively. GPP was partitioned into 131, 115, 270, 168, 257, 203 g C m^2 y^{-1} of wood, foliage, and root respiration, and wood, foliage, and root production, respectively, in the hardwood stand, and 206, 72, 155, 190, 139, 327 g C m^2 y^{-1} of wood, foliage, and root respiration, and wood, foliage, and root production, respectively, in the hemlock stand. The percentage of GPP allocated to wood, foliage and roots for growth and respiration was 20%, 23%, and 57%, respectively, for the hardwood stand, and 31%, 14%, and 55%, respectively, for the hemlock stand. The ratio of net primary production (NPP)/GPP was 30% in the hardwood stand and 33% in the hemlock stand.

INTRODUCTION

Large-scale ecosystem carbon modeling has been constrained by our limited knowledge in carbon allocation from GPP to respiration and biomass production. The fixed ratio of carbon allocated to wood, foliage and roots that many modelers used may be biased due to the variation in the ratio with forest stands or over the course of stand development. Studying carbon allocation is also important in understanding forest growth, succession, and responses to environmental stresses. Studies on carbon allocation and complete annual carbon budgets are limited relative to incomplete carbon budget studies such as carbon fluxes or biomass inventories. Combining eddy covariance measurements of NEP, chamber measurements of flux, and biometric measurements is necessary for detailed information on carbon allocation.

MATERIALS AND METHODS

The study area is located on the boundary of the Sylvania Wilderness and Recreation Area in the upper peninsula of Michigan, USA (46° 14' 31" N, 89° 20' 52" W). It is a hemlock – northern hardwood forest dominated by either eastern hemlock (*Tsuga canadensis*) or sugar maple (*Acer saccharum*). Trees ranged from 0-350 years old, but old trees dominated the canopy. The first study stand was dominated by sugar maple with DBH of 25.9 cm, basal area of 33.1 m^2 ha^{-1}, and leaf area index (LAI) of 4.1. The second stand was dominated by hemlock with DBH of 38.8 cm, basal area of 83.8 m^2 ha^{-1}, and LAI of 3.8.

Leaf biomass was measured from litterfall. DBH was measured with band dendrometers. Growth of roots was estimated with in-growth root cores. We measured soil, woody debris, stem, and leaf respirations using the chamber method (LI6400, LI-COR, Inc., Lincoln, NE, USA). We used exponential equations to analyze the relationship between respiration and temperature.

RESULTS AND DISCUSSION

The hardwood stand stored 12,548 g C m^{-2} of carbon, less than the hemlock stand that stored 14,232 g C m^{-2} of carbon. Wood, foliage and roots accounted for 94%, 1%, and 5%, respectively, of total carbon in both stands. The root/shoot ratio was 0.052 for the hardwood stand and 0.046 for the hemlock stand.

Fig. 1 shows autotrophic respiration, NPP, and heterotrophic respiration from wood, foliage and roots, and derived GPP in the hardwood and hemlock stands. The ratio of wood NPP to foliage NPP is 0.58 for sugar maple in the hardwood stand, and 1.72 for hemlock in the hemlock stand, indicating less efficiency for sugar maple than hemlock in fixing carbon in wood. Wood respiration was 14% greater than foliage respiration in the hardwood stand, while woody respiration was 1.9 times greater than foliage respiration in the hemlock stand. The ratio of root to soil respiration was 69% in the hardwood stand and 63% in the hemlock stand.

GPP was derived as 1057 and 990 g C m^{-2} y^{-1} in the hardwood stand and hemlock stand, respectively. GPP was partitioned into NPP of 314 g C m^{-2} y^{-1} and autotrophic respiration of 743 g C m^{-2} y^{-1} in the hardwood stand, and NPP of 328 g C m^{-2} y^{-1} and autotrophic respiration of 662 g C m^{-2} y^{-1} in the hemlock stand. The ratio of NPP/GPP was 30% in the hardwood stand and 33% in the hemlock stand. Total heterotrophic respiration was 270 and 259 g C m^{-2} y^{-1}, accounting for 86% and 79% of NPP in the hardwood stand and hemlock stand, respectively. NEP was derived as 44 and 69 g C m^{-2} y^{-1} in the hardwood stand and hemlock stand, respectively. Total ecosystem respiration was 1013 and 921 g C m^{-2} y^{-1}, or 96% and 93% of GPP in the hardwood stand and hemlock stand, respectively. The percentage of GPP allocated to wood, foliage and roots for growth and respiration was 20%, 23%, and 57%, respectively, for the hardwood stand, and 31%, 14%, and 55%, respectively, for the hemlock stand.

Our results of NEP and GPP are comparable with results from the eddy covariance method [*Desai et al.*, 2005]. NPP and NEP from this study are lower than a mature hardwood forest [*Curtis et al.*, 2002], consistent with the successional model that NPP declines with forest age and NEP approaches zero in old-growth forests [*Odum*, 1969; *Ryan et al.*, 1997].

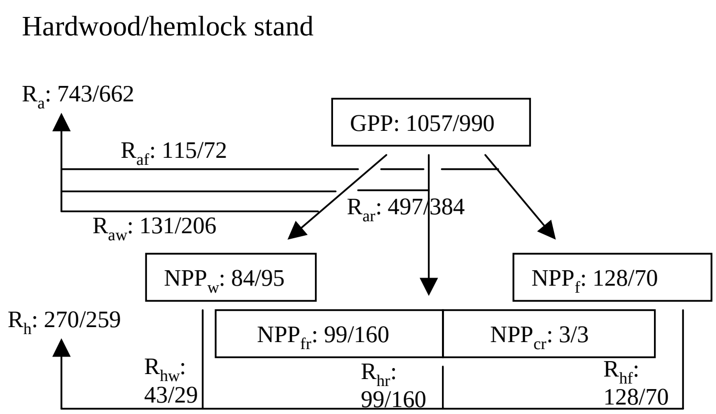

Fig. 1 Partitioning of GPP into R_a, NPP, and R_h from wood, foliage and roots in the hardwood and hemlock stands. The units of number are g C m^{-2} y^{-1}. The subscripts of *a* and *h* stand for autotrophic and heterotrophic, respectively; *aw*, *af*, *ar* stand for autotrophic from wood, foliage, and roots, respectively; *hw*, *hf*, *hr* stand for heterotrophic from wood, foliage, and roots, respectively; and *w*, *f*, *fr*, *cr* stand for wood, foliage, fine roots, and coarse roots, respectively.

ACKNOWLEDGMENTS

We thank E. Carey, D. Hudleston, L. Kreller, and many students for fieldwork assistance. This work was primarily funded by the Office of Science/BER, U.S. Department of Energy Terrestrial Carbon Processes program.

REFERENCES

Curtis, P.S., P.J. Hanson, P. Bolstad, C. Barford, J.C. Randolph, H.P. Schmid, and K.B. Wilson (2002), Biometric and eddy-covariance based estimates of annual carbon storage in five eastern North American deciduous forests, *Agricultural and Forest Meteorology*, *113* (1-4), 3-19.

Desai, A.R., P.V. Bolstad, B.D. Cook, K.J. Davis, and E.V. Carey (2005), Comparing net ecosystem exchange of carbon dioxide between an old-growth and mature forest in the upper Midwest, USA, *Agricultural and Forest Meteorology*, *128* (1-2), 33-55.

Odum, E.P. (1969), The strategy of ecosystem development, *Science*, *164*, 262-270.

Ryan, M.G., D. Binkley, and J.H. Fownes (1997), Age-related decline in forest productivity: Pattern and process, *Advances in Ecological Research*, *27*, 213-262.