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Net ecosystem production in a temperate pine plantation in southeastern Canada

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Abstract

Eddy covariance measurements of carbon dioxide (CO_2) and water vapour fluxes were made from June 2002 to May 2003 over a 65-year-old temperate conifer plantation forest in southern Ontario, Canada. This site is part of a newly initiated long-term tower flux measurement program over a chronosequence of white pine plantation forests, known as the Turkey Point Flux Station. Net ecosystem productivity (NEP) showed a strong dependence on environmental variables such as temperature, light regime, and vapour pressure deficit. In the summer, saturation water deficit exerted a strong control on photosynthetic uptake through decreased bulk surface conductance. There was a linear relationship between monthly carbon uptake and water loss. For each kilogram of water evaporated from the stand, approximately 2.15 g of carbon was sequestered. Annual NEP was 196 g C m^{-2} from June 2002 to May 2003. Annual gross ecosystem productivity (GEP) was 1442 g C m^{-2} and annual ecosystem respiration (R) was 1247 g C m^{-2}. A cross-site comparison of this site with 19 other, planted and natural, temperate conifer forests showed that NEP at the Turkey Point plantation was relatively low compared to other plantation forests of similar age group in Europe and North America. This analysis also showed that GEP and R of plantation forests was significantly higher than that of natural forests. In plantation forests, GEP and NEP linearly decreased with forest age, while R decreased little. Natural stands showed an increase in GEP and R with stand age, except for an old growth stand in western USA. This showed that photosynthesis, rather than respiration, plays a dominant role in net carbon uptake of both plantation and natural forests. In both, plantation and natural, stands there was a weak or no relationship between NEP and annual temperature and precipitation, while annual GEP and R was positively correlated to these environmental variables. The differences in carbon uptake among plantations and between plantation and natural temperate conifer forests were due more to physical and physiological differences among stands (e.g. stand age, tree density, leaf area index, site history, and adopted management practices in case of plantation forests), rather than differences in environmental variables.

Keywords: Net ecosystem productivity; Canopy conductance; Ecosystem respiration; Eddy covariance; Afforestation; White pine; Temperate conifer forests; Carbon balance

1. Introduction

Temperate conifer forests play a significant role in the global carbon cycle (Jarvis, 1995). They grow in

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mid-latitude regions of North America, western and central Europe and eastern Asia. The majority of temperate conifer forests, particularly in North America and Europe, are different-aged natural or plantation secondary growth stands, a consequence of large-scale deforestation and harvesting of primary forests in the 19th and 20th centuries, which was followed by abandonment and re-management of the lands (IPCC, 2002). In the global Fluxnet program, there are very few studies focusing on chronosequence of temperate conifer forests (Fluxnet, 2004). To this end, in the spring of 2002, the Climate Change Research Program (CCRP) of McMaster University, Hamilton, Ontario, Canada, initiated long-term, year-round observations of momentum, sensible heat (H), latent heat (LE), and CO_2 fluxes, in a chronosequence (1-, 15-, 30- and 65-year-old) of temperate conifer plantation forests (white pine, *Pinus strobus* L.) in southern Ontario, Canada, using the eddy covariance technique. These sites are know as the Turkey Point Flux Station, named after a nearby town of Turkey Point, located on the north-western side of Lake Erie. The sites are associated sites of the Fluxnet-Canada Research Network (FCRN; Fluxnet-Canada, 2004).

White pine is an important species in the North American landscape, because of its ability to adapt to dry environments. It grows efficiently on nutrient-poor, dry, sandy soils (Parker et al., 2001). Generally, it is the first woody species to flourish after a disturbance such as fire or clearing and over longer time periods helps more native forest species to establish through succession. White pine trees can live for about 350–400 years and their height may reach up to 45–60 m. These characteristics make white pine a preferred plantation (afforestation) species in eastern North America. A unique aspect of Turkey Point Flux Station is its geographic location between the boreal and the broadleaf deciduous forest transition zone. It provides an excellent opportunity to investigate and quantify the strength of the carbon sink or source for planted temperate conifer forests, and its sensitivity to seasonal and annual climate variability.

In this paper, we report CO_2 flux measurements over the 65-year-old white pine plantation stand from 1 June 2002 to 31 May 2003. The primary objectives are to: (i) describe diurnal and seasonal dynamics of CO_2 fluxes, (ii) investigate the relationship between NEP and environmental variables, (iii) determine linkages between photosynthetic uptake and water loss, and (iv) develop empirical relationships between photosynthesis and respiration to examine stand level physiological processes.

The secondary objective of this paper is to conduct a cross-site comparison of planted and natural, temperate, conifer forests to provide an insight into their responses to environmental, physical and physiological variables. In the literature, studies comparing carbon exchange processes in temperate conifer ecosystems are sparse. For example, Ceulemans et al. (2003), Falge et al. (2002), Law et al. (2002), and Baldocchi et al. (2001) have described key environmental controls on carbon uptake in conifer forest, but they have not focused much on the impact of stand physical and physiological characteristics, such as stand age, tree density, etc. and generation history (i.e. naturally generated or plantation) on carbon uptake or loss, particularly in temperate conifer forests. In this cross-site comparison study, eddy covariance flux data reported in the literature for 11 plantation and 9 natural temperate conifer forests was analyzed to explore the processes and environmental variables causing differences among plantations, and between plantation and natural forest sites. We hypothesized that (i) net ecosystem productivity in plantation conifer forests was higher than in naturally grown forests, (ii) net carbon uptake in both natural and plantation conifer forests increased with forest age, and (iii) differences in carbon sequestration among plantations and between plantation and natural temperate conifer forests were due to differences in temperature and precipitation, rather than physical and physiological parameters, or stand management practices in case of plantation forests.

2. Methods

2.1. Site description

The study site (42°42′44″N and 80°22′3″W) is located about 12 km southwest of the town of Simcoe in southern Ontario, Canada. Mono-culture and mixed deciduous (Carolinian species) and conifer (white and red pine) forests cover 18–25% of the land surface in this agricultural landscape. The climate of the region is temperate, with at least 150–160 frost-free days, which