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Energy and water balance of two contrasting loblolly pine plantations on the lower coastal plain of North Carolina, USA

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ABSTRACT

During 2005–2007, we used the eddy covariance and associated hydrometric methods to construct energy and water budgets along a chronosequence of loblolly pine (*Pinus taeda*) plantations that included a mid-rotation stand (LP) (i.e., 13–15 years old) and a recently established stand on a clearcut site (CC) (i.e., 4–6 years old) in Eastern North Carolina. Our central objective was to quantify the differences in both energy and water balances between the two contrasting stands and understand the underlining mechanisms of environmental controls. We found that the LP site received about 20% more net radiation (R_n) due to its lower averaged albedo (α) of 0.25, compared with that at the CC ($\alpha = 0.34$). The mean monthly averaged Bowen ratios (β) at the LP site were 0.89 ± 0.7, significantly ($p = 0.02$) lower than at the CC site (1.45 ± 1.2). Higher net radiation resulted in a 28% higher ($p = 0.02$) latent heat flux (LE) for ecosystem evapotranspiration at the LP site, but there was no difference in sensible heat flux (H) between the two contrasting sites. The annual total evapotranspiration (ET) at the LP site and CC site was estimated as 1011–1226 and 755–855 mm year^{-1}, respectively. The differences in ET rates between the two contrasting sites occurred mostly during the non-growing seasons and/or dry periods, and they were small during peak growing seasons or wet periods. Higher net radiation and biomass in LP were believed to be responsible to the higher ET. The monthly ET/Grass Reference ET ratios differed significantly across site and season. The annual ET/P ratio for the LP and CC were estimated as 0.70–1.13 and 0.60–0.88, respectively, indicating higher runoff production from the CC site than the LP site. This study implied that reforestation practices reduced surface albedos and thus increased available energy, but they did not necessarily increase energy for warming the atmosphere in the coastal plain region where soil water was generally not limited. This study showed the highly variable response of energy and water balances to forest management due to climatic variability.

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1. Introduction

Loblolly pine (*Pinus taeda* L.) is a common species in the southern United States and pine plantations are a major economic component in the region (Schultz, 1997; Fox et al., 2004). The productivity of loblolly pine plantations increased greatly during the past decades due to advances in tree genetic improvement and intensive silviculture practices that often involve water management such as drainage (Amatya et al., 1996), bedding, and applications of fertilization and herbicides (Albaugh et al., 2004). The impacts of intensive forest managements and land conversions on ecosystem services including energy partitioning (Gholz and Clark, 2002; Powell et al., 2005), water quantity and quality (Sun et al., 2004), forest productivity, and carbon sequestration (McNulty et al., 1996; Johnsen et al., 2001; Clark et al., 2004; Powell et al., 2008; Noormets et al., 2009) are of great interest to both scientists and policy makers.

Energy, water, and carbon cycles in forest ecosystems are tightly coupled through the evapotranspiration (ET) processes (Wilson and Baldocchi, 2000; Law et al., 2002; Noormets et al., 2006) (Fig. 1). Although land managers are more interested in water and carbon balances, quantifying forest energy balance offers insights to how management affects the forest microclimate and the feedbacks of land use change to climate change at a regional scale (Gholz and Clark, 2002; Powell et al., 2005; Restrepo and Arain, 2005; Jackson et al., 2005; Pielke et al., 2007; Liu et al., 2008). Uncertainty about the combined consequences of afforestation or deforestation on regional climate and greenhouse gas

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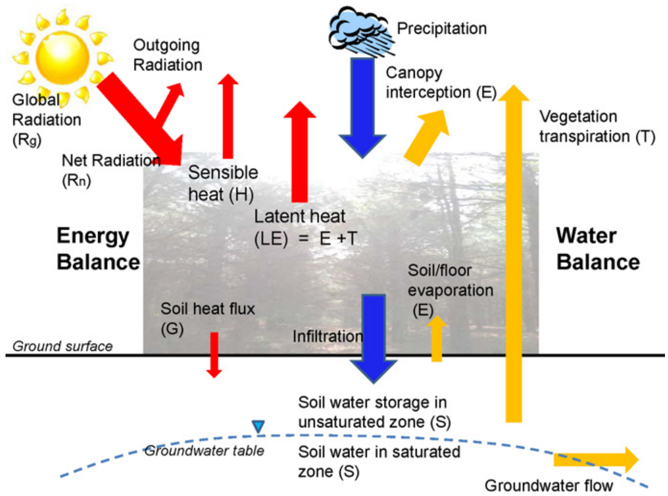

Fig. 1. A sketch to show the coupling of energy and water cycles in a drained II loblolly pine forest.

emissions indicates the need for more research on the physical and biological effects of forest management in the mid-latitude region (Bala et al., 2007; Juang et al., 2007).

ET is a major component of the water balance of forested watersheds in the Southeastern U.S., consuming about 50–90% of the incident precipitation (Gholz and Clark, 2002; Sun et al., 2002; Lu et al., 2003; Ford et al., 2007). Changes in land use/land cover and climate impact the regional hydrological cycle (DeWalle et al., 2000; Sun et al., 2008a), climate (Liu et al., 2008), and ecosystem functions directly through altering the evapotranspiration processes. Evapotranspiration is also linked to ecosystem productivity (Law et al., 2002) and biodiversity (Currie, 1991), and ET is the only variable that directly links hydrologic and biological processes in most ecosystem models (McNulty et al., 1994; Hanson et al., 2003). The functional recovery of the hydrology of afforested or reforested watersheds depends on the recovery of ET, but the processes are not well understood due to the dynamic and complex nature of the ET processes (van Dijk and Keenan, 2008; Sun et al., 2008a).

In spite of the importance of forest ET, direct measurements of ET at the landscape scale have become possible only in the past decade (Wilson and Baldocchi, 2000; Gholz and Clark, 2002; Powell et al., 2005; Stoy et al., 2006). Watershed-scale ET is usually estimated as the residual of precipitation, runoff, and change in soil water storage. This water balance method is limited to estimating long-term average (i.e., annual) when the change in water storage is negligible and other fluxes can be measured accurately (Wilson et al., 2001; Ford et al., 2007). The sapflow-based techniques to estimate ecosystem-level ET is limited to uniform stands that have few tree species with minor ET from understory plants (Wullschleger et al., 1998; Ewers et al., 2002; Ford et al., 2007). The most common practice to estimate short-term forest ET and runoff is employing the widely used Penman-Monteith equation (McCarthy et al., 1992) or empirical ET models driven by readily available meteorological variables (Amatya et al., 1995; Amatya and Skaggs, 2001; Lu et al., 2003; Harder et al., 2007; Sun et al., 2008b; Zhou et al., 2008; Amatya and Trettin, 2007). The eddy covariance method has gained popularity for simultaneously measuring both ET and CO_2 fluxes with high temporal scale due to performance improvements and reduced costs of fast-response monitoring sensors in recent years. A complete comparison among the pros and cons of major ET estimation methods is found in Wilson et al. (2001) and Shuttleworth (2008).

As part of the United States-China Carbon Consortium (USCCC) (Sun et al., 2009), this study focuses on the carbon and water fluxes from plantation forests characteristic of drained forested wetlands in the coastal plain of North Carolina, USA. The specific objectives of this paper were to: (1) contrast the key energy and water fluxes between two loblolly pine stands under two management statuses and age and (2) explore the environmental controls on the energy and water balances at multiple temporal scales.

2. Methods

2.1. Site description

The study site (35°48′N, 76°40′W) is located in the Albemarle Sound drainage area near the city of Plymouth within the outer coastal plain mixed forest province of North Carolina in the Southeastern U.S. (Noormets et al., 2009) (Fig. 2). Locally called the Parker Tract, this site has been managed by the forestry industry for timber production. The area is dominated by loblolly pine plantations with various ages and native hardwoods forests. The near flat area has poorly drained soils with a ground elevation less

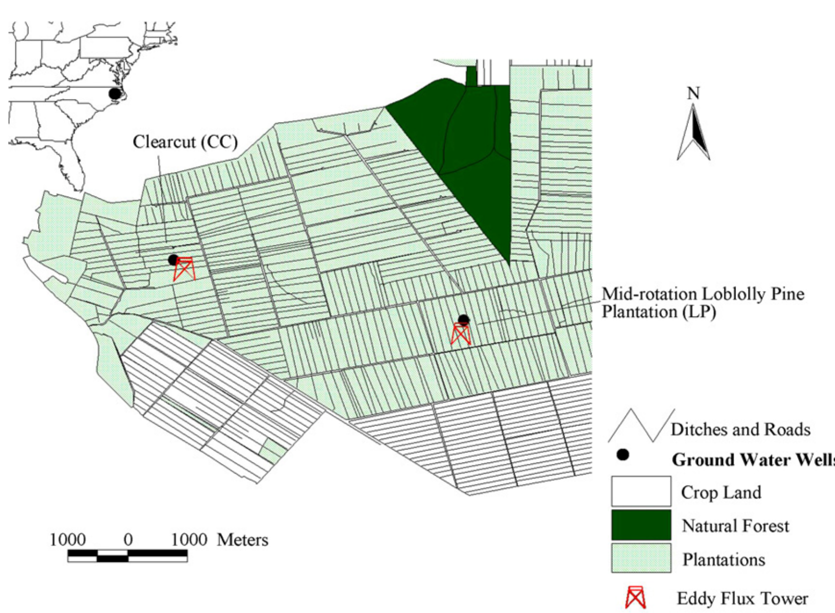

Fig. 2. Research site location and instrumentations.