Evapotranspiration of a Mid-Rotation Loblolly Pine Plantation and A Recently Harvested Stands on the Coastal Plain of North Carolina, U.S.A.

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Abstract

Evapotranspiration (ET) is the primary component of the forest hydrologic cycle, which includes plant transpiration, canopy rainfall interception, and soil evaporation. Quantifying ET processes and potential biophysical regulations is needed for assessing forest water management options. Loblolly pines are widely planted in the coastal plain of the Southeastern US, but their water use is rarely directly measured. This study aims to quantify ecosystem ET and its components by direct measurements of sap flow, canopy interception, and eddy fluxes. Our research sites included a 13-year old loblolly pine plantation and a recently harvested stand on Weyerhaeuser's Parker Tract in Washington County, eastern North Carolina. Sap flow data were collected with sensors at different sapwood depths and circumferential positions for 8 loblolly pines using thermal dissipation probes. Sapflow flux measured at individual trees was scaled up to the stand level. Sap flow flux density was empirically correlated to meteorological factors to examine the biological and physical controls. Precipitation above tree canopy, throughfall, and stem flow were measured to quantify canopy interception. Two separate flux towers at the centers of two stands were installed in measure eddy flux for water and carbon fluxes and microclimate since October 2004. Comparisons of ET estimates between sapflow methods and the eddy covariance method showed a 20% difference. Recently-cut stand had similar ET as the mid-rotation plantation stand.

KEYWORDS: Transpiration, Interception, Evapotranspiration, Sap flow, Thermal Dissipation Method, Water Balances

Introduction

Loblolly pine plantations are a major economic component in the Southeast United states. In the past fifty years the pine plantation silviculture has developed from 2 million acres in 1950s to 32 million acres by the end of 20th century (Fox, 2004). Pine productivity also increased significantly during this period due to advances in intensive silviculture practices that often involve water management such as drainage, especially in the wetlands.

Evapotranspiration (ET), composed of soil evaporation, plant transpiration and interception, is one of the major components within the hydrologic cycle, second only to precipitation in the water cycles of southern forests (Lu et al., 2003). In particular, hydroperiod of southern forested wetlands is mostly controlled by the balances of precipitation and ET (Sun et al., 2000; Amatya et al. 1996). Quantifying the amount of ET helps to manage forest ecosystems to maximize ecosystem productivity and ecological services (e.g. water quality). However, ET is difficult to quantify in practice due to its dynamic nature in both time and space.

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Most hydrologic studies on ET estimate this variable as the differences among the hydrologic fluxes. Direct measurements of forest ET are rare (Riekerk, 1985; Liu, 1996). A common practice of estimating ET is using mathematical models, such as the Penman-Monteith equation (McCarthy et al., 1991; Amatya et al., 1996). A number of methods have been developed to measure ET, or components of ET including hydrological, meteorological, physiological or remote-sensing methods. The scales of these measurements ranged from the leaf to regional scales. However, accurately quantifying the wetland ET is still a challenge for hydrologists due to the complexity of underlying surface condition and limitation of field methods. Combination of different methods may help minimize the estimation errors of each method (Wilson et al. 2001).

In this study, the eddy-covariance and Granier-type sap flow methods were used to quantify the evapotranspiration and transpiration for a loblolly pine plantation (LP) and a contrasting clear cut hardwood stand (CC). Our overall goal is to understand the causal effects of forest management on water balances in drained forested wetlands on the coastal plain of North Carolina. A separate study that focuses on carbon and water flux is reported by DeForest in this volume.

Methods

Site description

The lands are located on a 10,000 ha Parker Tract watershed near the city of Plymouth in eastern North Carolina costal plain (N 35° 48', W 76°39'). The forested land contained various chronosequences of loblolly pine plantations and native hardwoods managed by the Weyerhaeuser Company that drains into Albemarle Sound, NC. The topography is flat (<0.1% slope) and drained with a network of field ditches (90 to 100cm deep; 80 to 100m spacing) and canals, which divide the watershed into a mosaic of regularly shaped fields and blocks of fields. The soils are organic and are classified as a Loamy, mixed, dysic, thermic Terric Haplosaprists. Mean annual temperature is 15.5°C, and mean annual precipitation is 1295 mm. The growing season is typically 195 days.

The site consists of a recent mature native hardwood (75 yrs) clear cut (CC) that was bedded and planted with loblolly pine seedling and a young 13-year old loblolly pine plantation (LP). The recent clear cut is around 70 ha and the loblolly pine plantation is about 120 ha.

While the recent clear cut stand was planted with loblolly pine seedlings, this area was covered with annual plants and shrubs that reached a maximum height of 2.5 meters. This weedy groundcover was dense and was primarily composed of *Eupatorium capillofolium* (dog fennel) and *Smilax rotundifolia* (greenbrier). This stand also contained several large slash piles of course woody debris. The young loblolly stand has little groundcover or understory except an understory of *Acer rubrum* (red maple) near the ditches.

Sap flow measurement

Measurements of sap flow were made using thermal dissipation probes (TDP). These probes operated on the constant power principle (Granier, 1987). The probes were constructed of polyetherketone (PEEK) tubing with a 1.2 cm aluminum tip crimped to the final top of the PEEK tubing. The sensor design was developed by James (2002). The signal from sap flow sensors were measured by a data logger (CR10, Campbell Scientific, Logan, Ut) equipped with a 32-channel multiplexer (AM416; Campbell Scientific). The data were collected every 10 minutes.

For the loblolly pine trees, the designed depths were 1cm, 2cm, 3cm, 5cm. Sensors of depths of 1cm, 2cm and 3cm were installed on June and 5cm sensors were added on August. 6 trees were chosen for monitoring the sap flow. Each tree was installed with sensors on both the north side and south side.

Clearwater et al. (1999) discussed the potential errors in the method and suggested to use multiple short probes to reduce the errors. Ford et al. (2004) presented a general mathematical function that describes the spatial distribution of sap flux in stems of trees with tracheid xylem anatomy. The empirical equation is as follows:

$V=119K^{1.231}$ (Granier, 1987)

$$K=\frac{\Delta T_m-\Delta T}{\Delta T}$$

V: Sap flow density (g $m^{-2}s^{-1}$)

K: empirical parameter

ΔT_m: Maximum temperature difference in a day (°C).

ΔT : Temperature difference (°C)

The water loss for a single tree can be calculated by the following equation

$F=\Sigma\pi\,(r_k^2-r_{k-1}^2)V_k$ (Hatton et al. 1990)

F: Total water loss across the stem profile (cm^3).

r_k: The distance from the stem center to the k^{th} sensor.

V_k: the sap flow density of k^{th} sensor ($cm^3cm^{-2}s^{-1}$).

The sap flux density of the deeper stem was estimated by the sap flux density distribution pattern found by Ford et al (2004) in the loblolly pine.

We scaled up data of single trees to whole stand by the following equation:

$F_{stand}=F_{AT}*S_s/S_t$

F_{stand}: Stand water loss (cm^3)

F_{AT}: Average tree water loss for single trees (cm^3).

S_s/S_t: Percentage of basal area of whole stand to the average tree.

Eddy-covariance method

Turbulent water fluctuations were measured at 60ft above the forest floor using the 3-D sonic anemometer (wind and sonic temperature) and an infrared gas analyzer (CO_2 and H_2O analyzer, Li-7500, Li-Cor, Lincoln, NE) in both sites. The data were processed with the "EC Processor" software. The 30-minute mean flux of LE was computed as the covariance of vertical wind speed and the concentration of water, after removing spikes in raw data (over 6 standard deviations), correcting sonic temperatures for humidity and pressure, and rotating wind coordinates around 2 axes so that mean vertical and mean cross-wind vectors equal zero for the 30-minute period. The data were corrected by double rotation method using the Webb-Pearman-Leuning expression (Webb et al., 1980; Paw et al., 2000; Massman & Lee, 2002).

The average ET in half hour could be estimated by transferring the LE (latent heat) to water volume by the equation:

$ET=LE*1800/1000/(2501-2.368*T)$

Where ET: evapotranspiration (mm/0.5h)

LE: latent heat flux ($J*m^{-2}s^{-1}$)

T: average air temperature in Celsius

The measured eddy fluxes are interpreted as representing total forest evapotranspiration. Studies showed that rainfall greatly influences the reliability of the eddy flux data (Meiresone, et al. 2003, Kumagai, et al. 2005). Some of our data gaps in raining days proved the influences of rainfall.

Throughfall measurement

Three automatic logging raingages and 10 manual raingages were used to record throughfall continuously. They were put under the stand canopy. Throughfall was collected and dumped every field visit (at least every 2 week). The throughfall was calculated as the weighted average of measurements in different locations under the canopy.

Stemflow measurement

Two sets of hoses and containers were installed on two trees to measure the stem flow of loblolly pine. The volume of water in the boxes will be measured at least every two weeks.

RESULTS AND DISCUSSION

ET of Loblolly pine plantation and clear cut stand

Some data gaps were found for ET and transpiration data. When the eddy covariance data were processed by EC-Processor, some extremes were deleted. Some TDP sensors also had extreme values or data gaps (Table 1).

For ET measured by the eddy-covariance method, the values of Loblolly pine and Clear cut stands are close in June and July. This may indicate that the vegetation on the coastal plain play a minor effect on the total ET during this period. The sufficient soil water for ET in the coastal wetland may be the reason to explain the similarity of the ET of these two places. On August and September, the Average ET of CC was higher than the LP.

The two study sites agreed well on hourly means of ET in some periods of June and July (Figure 1). Since these two sites were only 4 miles away, their weather conditions were similar in meteorology such as vapor pressure deficit, temperature and solar radiation. There difference mainly lies on the vegetation hydraulic conductivity and leaf area index. Daily variation of ET in the LP is bigger than that in the CC (Figure 2), although their mean values are close. This may be arisen from the instability of the EC processor.

Components of ET of loblolly pine plantation

The transpiration of Loblolly pine measured by the Granier method accounted for about 50% of total ET measured by eddy covariance method. The interception accounted for 20% of total precipitation. The total stemflow from May to September only accounted for 1.6% of total precipitation and could be neglected when analyzing the water balance. The summary of transpiration and interception accounted for 80% of ET measured by the eddy covariance in July and August.

Because the evaporation is small in closed canopy stands, the ET was approximated as the sum of canopy interception and tree transpiration. These two items only accounted for 80% of total ET measured by the eddy covariance method. This 20% discrepancy may be caused the system errors. Similar conclusions were reported by Wilson (2001) using the same methods.

In June, sensors of three depths (1cm, 2cm and 3cm) were used to scale up sap flow to the tree. From the diurnal variation of sap flux density (Figure 3), the value was biggest on the 2cm depth. The values of 1cm depth and 3cm depth had similar ranges.

Table 1. Measurement Periods of ET and Transpiration (Tr) from June to September, 2005.

	June	July	Aug	Sep
ET for CC	11^{th}-26^{th}, 30^{th}	1^{st}-31^{st}	1^{st}- 8^{th}, 17^{th} –31^{st}	1^{st}-12^{th}
ET for LP	10^{th}-22^{nd} ,25^{th} –28^{th}	8^{th}-18^{th}	5^{th} –15^{th}	5^{th}-9^{th}
Tr for LP		17^{th}-26^{th}	6^{th}-15^{th}, 18^{th}-28^{th}	9^{th}-17^{th}

Table 2. Monthly ET in Loblolly Pine Plantation (LP) and Clear Cut land (CC) by EC method and Tr of LP by sap flow measurement

Month	ET of CC (mm)		ET of LP (mm)	
	total	Daily average	total	Daily average
Jun.	103.5	3.45	107.7	3.59
Jul.	119.1	3.84	126.5	4.08
Aug.	118.1	3.81	94.3	3.04

Sep.	96.7	3.22	63.6	2.12

Table 3. Monthly canopy interception (CI), throughfall (TF), evapotranspiration (ET) and precipitation (P) in Loblolly pine plantation

Month	ET of LP (mm)	Tr of LP (mm)	Interception(mm)	Throughfall (mm)	Precipitation (mm)	ET/P	I/P
Jun.	107.7		39.8	1.0	184.9	0.582	0.215
Jul.	126.5	64.8	37.6	1.3	212.2	0.596	0.177
Aug.	94.3	62.3	37.9	0.7	148.9	0.633	0.255
Sep.	63.6	46.3		0.9	56.2		

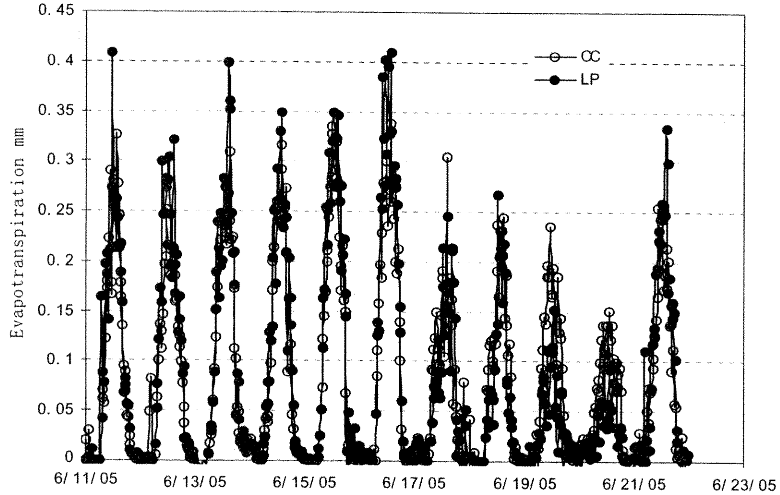

Figure 1. Diurnal changes of sapflow measured by the Granier method.

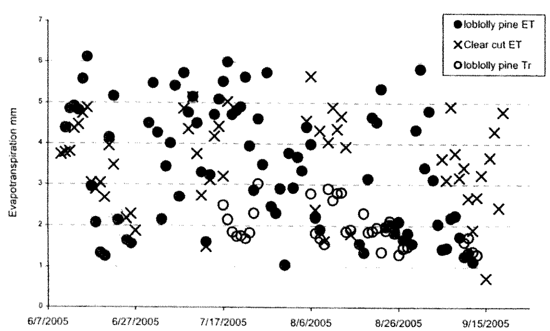

Figure2. Daily evapotranspiration of LB and CC measured by Eddy covariance method and transpiration of loblolly pine measured by sap flow measurements.

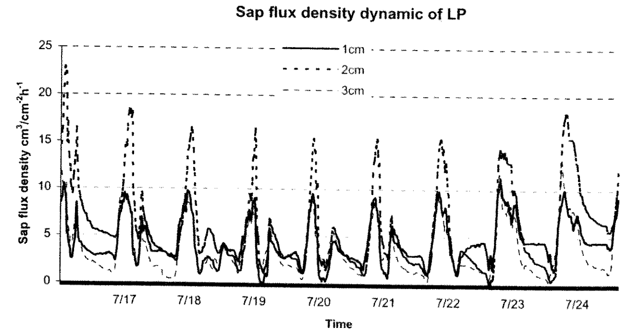

Figure 3. Daily sap flow rate with different sensor depths.

CONCLUSION

We measured the ET of a loblolly pine plantation and a clear cut stand with eddy covariance method and transpiration of loblolly pine plantation with a sap flow method. The ET of the two sites was similar in the early summer although the vegetation type is totally different. That may indicate the coastal wetlands could maintain some level of ET when the ground water is sufficient for vegetation to transpire. Transpiration measured by the sapflow method plus interception was about 80% of ET measured by the eddy covariance method. The error may come from the sapflow or eddy-covariance method. One potential source of error for sap flow method is the scaling process.

More TDP sensors for deeper xylem will be added to improve the precision. We also plan to install instruments to quantify the soil water balances as an independent way to estimate ecosystem ET. Hydrological modeling, as a useful reference, will serve as contrast of measured data. Combination of all these methods is expected to advance our understanding of the evapotranspiration process.

Acknowledgements

This study was supported by the Southern Global Change Program, USDA Forest Service, Raleigh, NC. We thank Sara Strickland, Michael Gavazzi and Johnny Boggs for site maintenance and Joe Bergman and the Weyerhaeuser Company for field assistance and providing study site.

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SOIL PROPERTIES IN NORTHERN VIRGINIA CREATED FORESTED WETLANDS

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ABSTRACT

Created wetlands provide the opportunity to study the rate at which wetland functions develop and replace those of impacted wetlands. Quantification of soil organic matter (SOM) accumulation in Northern Virginia created wetlands is not well documented. This study quantified and compared several soil properties (organic matter, total percent C, total percent N, C:N and pH) in the topsoil of eight created forested wetlands in Northern Virginia. The state of these wetlands range from recently planted, to having gone through four growing seasons. Soil was also collected from the site of a future wetland creation site, and from an existing mature forested wetland located adjacent to one of the created wetlands. SOM content, total percent C and total percent N and pH were comparable among the created wetlands that had undergone 2-4 growing seasons, with values that were less than the natural mature forested wetland. This indicates that these soil properties take longer than four growing seasons to be on a trajectory toward a mature forested wetland. However, the C:N ratio was similar in the mature forested wetland and the created wetlands that have undergone 2-4 growing seasons suggesting that a balance has been restored.

KEYWORDS: Carbon, Created Wetlands, Nitrogen, Soil Organic Matter, Virginia

INTRODUCTION

Wetlands are recognized as providing a variety of functions and values; one of which is their integral role in nutrient cycling. However, this role may differ between natural and created wetlands implying that created wetlands do not effectively replace lost wetland function. Created wetlands provide the opportunity to study the rate at which wetland functions develop and replace those of wetlands lost to development. Monitoring soil chemical properties in created wetlands provides data that can be used to evaluate the time required for the development of these soil properties, and to determine whether these wetlands are on a trajectory toward a mature forested wetland (Ponnamperuma, 1972; Vepraskas, 1992, Windham et al., 2004).

Dahl (1990) documented a 53% decrease in wetland area within the contiguous 48 states between 1780 and 1980. In Virginia, there has been a loss of 42% of the original wetland base Dahl (1990). Residential development and associated infrastructure are the largest factors affecting the loss of wetlands in northern Virginia.

Wetlands continue to be impacted in northern Virginia and the 'no net loss' policy requires suitable mitigation for wetland impacts. Wetland creation (which is one of the options to mitigate for wetland impacts) is employed to replace those wetlands lost to development. It is believed that the constructed wetlands will possess the functions of those they are intended to replace. However, in the case of created forested wetlands, the replacement of some functions may be delayed since the constructed wetlands generally start as an earlier stage of succession.

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