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Forest transpiration from sap flux density measurements in a Southeastern Coastal Plain riparian buffer system☆,☆☆

David D. Bosch[a,*], Laura K. Marshall[b,1], Robert Teskey[c,2]

[a] U.S. Department of Agriculture-Agricultural Research Service, Southeast Watershed Research Laboratory, 2316 Rainwater Road, PO Box 748, Tifton, GA 31793, United States
[b] Ohio Environmental Protection Agency, Southwest District Office, 401 East Fifth Street, Dayton, OH 45402, United States
[c] Warnell School of Forestry and Natural Resources, The University of Georgia, 180 E. Green Street, 203 Building 4, Athens, GA 30602-2152, United States

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ABSTRACT

Forested riparian buffers are prevalent throughout the Southeastern Coastal Plain Region of the United States (US). Vegetation in the riparian forest buffers in this region are primarily made up of slash pine (*Pinus elliottii* Engelm.), longleaf pine (*Pinus palustris* Mill.), and yellow poplar (*Liriodendron tulipifera* L.) trees. Because they make up a significant portion of the regional landscape, transpiration within these riparian buffers is believed to have an important impact on the hydrologic budget of regional watersheds. A riparian buffer along a first order stream in South-central Georgia US was selected for a sap flow study designed to provide measurements of tree transpiration. The forest provided a buffer zone that averaged 70 m in width from an upland field to the first order stream. Shallow water table conditions allowed direct interaction between the tree's root system and groundwater. Sap flux density, groundwater, and climatic data were collected to determine transpiration rates from different tree species and their relationship to potential ET rates and hydrologic and environmental conditions. Average sap flow rates ranged from 2 to 142 L day^{-1}. Sap flow was related to tree diameter, solar flux density, and daily vapor pressure deficit. An exponential relationship was developed that related measured average daily sap flow rate (L day^{-1}) to tree diameter at breast height (DBH) (mm) for the range of measured trees ($56 < \text{DBH} < 390$ mm) with a coefficient of 2.04 and an exponent of 0.01. On an area basis, the average transpiration for the studied 720 m^2 study area was 1114 mm for the observation period from April to December. This represented 103% of the potential evapotranspiration for a reference grass (PET) for that same period. While landscape position, and subsequently access to groundwater, did not appear to strongly influence sap flow rates, reduced soil water in the vadose zone led to reductions in tree transpiration. The data indicate that transpiration within regional buffers uses a disproportionate amount of water on a per area basis compared to upland land covers, an important consideration when examining overall water consumption in regional watersheds.

1. Introduction

Population growth, climate change, and climate variability have increased the demands on water resources across the United States (US) over the past two decades (Gleick, 2003). While water demand varies widely across the US, population growth across the southeastern (SE) US has been particularly rapid, leading to large increases in water demand across the region. Over the past 20 years, the SE US has had the fastest population growth rate in the US, with a 14% increase between 1990 and 2000 and an expected increase of 24% in the next 20 years (Sun et al., 2008). General circulation models predict the southern US will experience significant increases in air temperature and precipitation variability associated with global warming (Kittel et al., 1997; USGCP, 2000). Sun et al. (2008) related projected to current water use across the SE US and found that projected climate changes coupled with population increases would

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Abbreviations: BH, breast height; DBH, diameter at breast height; ET, Evapotranspiration; PET, potential evapotranspiration; TDP, thermal dissipation probe.

☆ [1] Contribution from the USDA-ARS, Southeast Watershed Research Laboratory, 2316 Rainwater Road, PO Box 748, Tifton, GA 31793, in cooperation with Univ. of Georgia Tifton Campus.

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* Corresponding author. Tel.: +1 229 386 3899; fax: +1 229 386 7294.
E-mail addresses: david.bosch@ars.usda.gov (D.D. Bosch), laura.marshall@epa.ohio.gov (L.K. Marshall), rteskey@uga.edu (R. Teskey).

[1] Tel.: +1 937 285 6357; fax: +1 937 285 6249.
[2] Tel.: +1 706 542 5055; fax: +1 706 542 8356.

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increase water demand by 5 to 45%, depending on the climate change model used.

Coupled with increasing water demands, the SE US has also experienced significant long-term decreases in warm season precipitation during the past 1000 years (Stahle and Cleaveland, 1992; Alexandrov and Hoogenboom, 2001). Most high resolution climate change models predict further reductions in rainfall throughout the region, with increasing drought severity (Dai, 2010) and potential decreases in summer precipitation of 20–30% (Mearns et al., 2003). Climate models that predict moderate increases in rainfall predict increases in evapotranspiration (ET) exceeding precipitation increases and thus the net predictions are for reductions in river discharge throughout mid- and low latitudes (Mulholland et al., 1997; Nijssen et al., 2001).

Because of the growing importance of fresh water supplies throughout the US, and the SE US in particular, accurate water budgets describing how much water is available and how the water is currently being used are critical. Within the SE US, as in many regions, ET by vegetation consumes a large portion of available water. This is true of natural vegetation as well as cultivated crops. Much of the SE US contains dense riparian forests. In much of the region, these riparian forests form dense stream corridors and interact with surficial aquifers. Where surficial aquifers interact with streamflow, baseflow fed by these surficial aquifers is a dominant component of streamflow (Shirmohammadi et al., 1984; ; Sheridan, 1997). In these cases, ET demand of the riparian buffers can impact groundwater and streamflow (Bosch et al., 1996).

Transpiration rates of woody vegetation are often estimated based on sap flux density. One of the commonly used methods for measuring sap flux is the Thermal Dissipation Probe (TDP) technique (Granier, 1985). The sap flux system is used to measure whole-tree water use in ecophysiological and forest hydrological studies (Lu et al., 2004). The TDP system measures sap flux density in the stem xylem which can then be converted to volumetric flow rate. Estimates of stand transpiration from the technique can vary widely depending on water availability, tree characteristics, and climate. Granier (1987) used the TDP technique to measure transpiration from a 24-year old Douglas fir (*Pseudotsuga menziesii* Mirb. Franco) plantation in Northern France from May through September. Tree diameters at breast height (DBH) ranged from 100 to 220 mm. Maximum stand transpiration reached 3.6 mm day^{-1}, while total stand transpiration for the 100 day observation period ranged from 117 mm (1.2 mm day^{-1}) for a thinned plot to 169 mm (1.7 mm day^{-1}) for a control plot. Ford et al. (2007) used the TDP technique to measure sap flow from forty 50 year old eastern white pines in western North Carolina, US. Daily canopy transpiration varied from near zero to 8 mm day^{-1}. Scaled up to represent total stand transpiration, annual totals ranged from 686 to 726 mm year^{-1}. Total stand ET, including tree canopy interception and assuming negligible soil evaporation was 1290 mm year^{-1} with an annual precipitation total of 1449 mm year^{-1}.

Prior studies have shown that forest transpiration can be dramatically impacted by groundwater availability and soil water. Teskey and Sheriff (1996) found that transpiration of a plantation of *Pinus radiata* trees operated near potential transpiration when soil water was high in the root zone while transpiration was significantly below potential during periods of water stress. Cermak and Prax (2001) showed that groundwater could supply up to 70% of the water required for forest transpiration under shallow water table conditions. For riparian forests growing on soils with a shallow and variable water table, the contribution of the water table to transpiration will vary with season. Within the riparian buffer, transpiration resulting from groundwater use by phreatophytes can be very significant. Bosch et al. (1996, 2003) demonstrated that in riparian corridors in the Coastal Plain region of Georgia, US, the water table in the riparian zone can be quite variable. During the late summer and fall seasons, high transpiration demands of the riparian forest in this region can lead to conditions where groundwater is supplied by intermittent streamflow (Bosch et al., 1996).

While precise estimates of transpiration are a critical component of water budgets, available data on natural vegetation are limiting. In particular, field measurements of forested riparian buffer transpiration are sparse. This study quantifies transpiration of riparian forest buffers through sap flux density measurements. Specifically, the objectives are:

1. Characterize transpiration rates from a mature riparian buffer system.
2. Relate transpiration rate to hydrologic conditions.
3. Compare transpiration to potential evapotranspiration (PET) and precipitation.

2. Methods

2.1. Study area description

The site selected for the research was located at the University of Georgia Coastal Plain Experiment Station Gibbs Farm near Tifton, GA US (lat 31.4395, lon −83.5883). The research area is a mature riparian forest located along a first order stream draining a 57 ha watershed (Fig. 1). The riparian forest contains an Alapaha loamy sand soil (loamy, siliceous, *thermic Arenic Plinthic Paleaqualts*) on a 2.5% slope, downslope from a tilled field on a 1.5% slope (Bosch et al., 1996). Over the year, the water table of the surficial aquifer varies from 0 to 3 m below the ground surface depending on landscape position and time of year (Bosch et al., 1996). The riparian forest trees are primarily slash pine (*Pinus elliottii* Engelm.), long leaf pine (*Pinus palustris* Mill.), and yellow poplar (*Liriodendron tulipifera* L.). The 5 m nearest the stream channel supports hardwoods including yellow poplar (*L. tulipifera* L.) and black gum (*Nyssa sylvatica* Marsh.). The forest provides a buffer zone that averages 70 m in width from the field to the stream.

The site is located within the Tifton Upland physiographic region. The climate of the Tifton Upland is temperate (Peel et al., 2007), providing abundant rainfall and a long growing season. Mean annual rainfall is 1208 mm (Sheridan and Knisel, 1989). Evapotranspiration estimates from water budget studies range from 58 to 83% of annual precipitation (Bosch et al., 1996). Average monthly temperatures range from 11 °C in January to 27 °C in July. Precipitation follows a seasonal pattern with generally low rainfall from September through November and an increase in precipitation in December through early May. Rainfall typically decreases in May and early June but increases in July and August due to summer thunderstorms and tropical depressions. The Hawthorn geologic formation is believed to be continuous throughout the region and serves as an aquiclude supporting the surficial aquifer in the Tifton Upland (Stringfield, 1966). The aquiclude is generally 2 to 5 m from the land surface (Shirmohammadi et al., 1986). The Hawthorn is overlain by Quaternary sands and surface soils that make up the surficial aquifer. Rivers and streams within the Tifton Upland are incised in the Hawthorn. The Hawthorn Formation generally has very low hydraulic conductivity and inhibits groundwater seepage losses from the valley alluvium (Stephens et al., 1968). Shallow phreatic aquifers feed dense stream networks and produce groundwater discharge in the alluvial material. Additional details on the study site are available in Bosch et al. (1996), Inamdar et al. (1999) and Lowrance et al. (1997).

An 18 by 40 m (720 m^2) area within the riparian buffer was selected for the sap flow studies (Fig. 1). The area primarily included