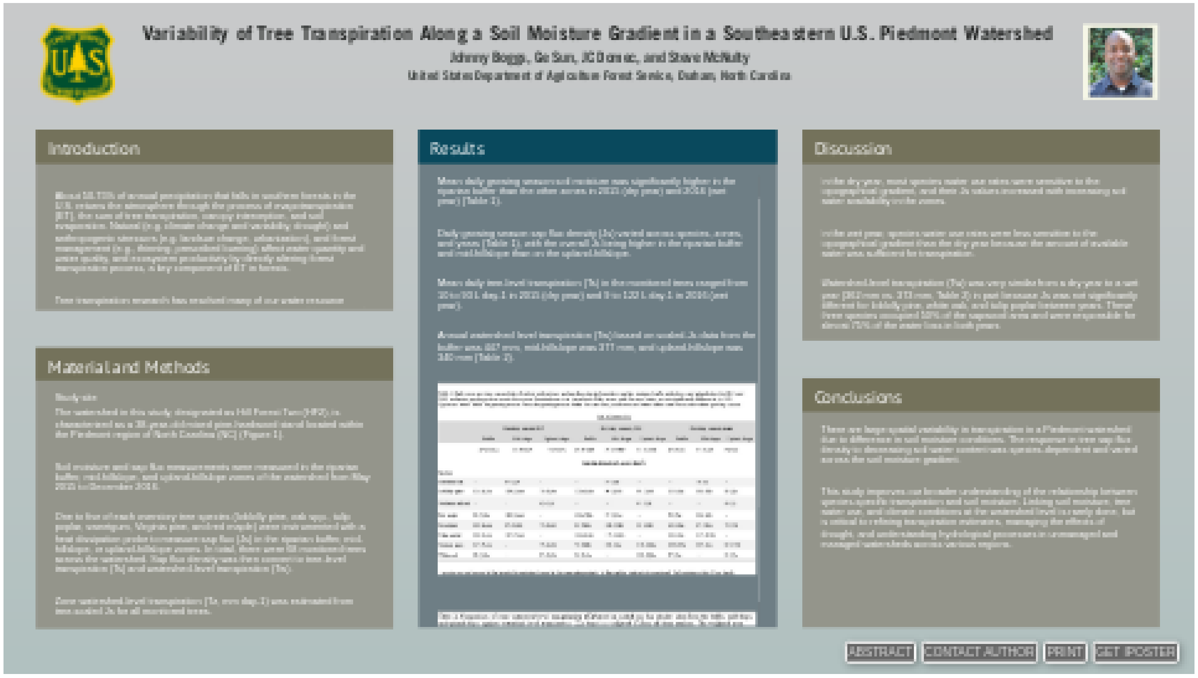
Variability of Tree Transpiration Along a Soil Moisture Gradient in a Southeastern U.S. Piedmont Watershed



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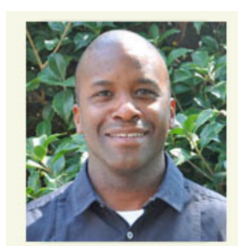

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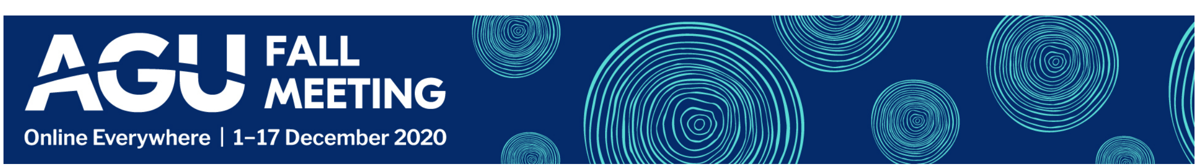

INTRODUCTION

About 50-75% of annual precipitation that falls in southern forests in the U.S. returns the atmosphere through the process of evapotranspiration (ET), the sum of tree transpiration, canopy interception, and soil evaporation. Natural (e.g. climate change and variability, drought) and anthropogenic stressors (e.g. landsue change, urbanization), and forest management (e.g., thinning, prescribed burning) affect water quantity and water quality, and ecosystem productivity by directly altering forest transpiration process, a key component of ET in forests.

Tree transpiration research has resolved many of our water resource concerns during the last decade. However, questions are still being raised about how to improve watershed-level transpiration, given the variations in species composition, topography, and soil moisture. In addition, variability in tree transpiration across a watershed is typically not considered (or well captured) by models and may be one contributing factor to over or under predictions of water loss from the forest at local and regional scales. Therefore, the objectives of this study are to 1) quantify tree sap flux density and transpiration across a topographical gradient in a wet and dry year and 2) compare watershed-level transpiration derived from three zones (riparian buffer, mid-hillslope, and upland-hillslope).

MATERIAL AND METHODS

Study site

The watershed in this study, designated as Hill Forest Two (HF2), is characterized as a 38-year-old mixed pine-hardwood stand located within the Piedmont region of North Carolina (NC) (Figure 1).

Soil moisture and sap flux measurements were measured in the riparian buffer, mid-hillslope, and upland-hillslope zones of the watershed from May 2015 to December 2016.

One to five of each overstory tree species (loblolly pine, oak spp., tulip poplar, sweetgum, Virginia pine, and red maple) were instrumented with a heat dissipation probe to measure sap flux (Js) in the riparian buffer, mid-hillslope, or upland-hillslope zones. In total, there were 68 monitored trees across the watershed. Sap flux density was then convert to tree-level transpiration (Ts) and watershed-level transpiration (Tw).

Zone watershed-level transpiration (Tz, mm day-1) was estimated from tree-scaled Js for all monitored trees.

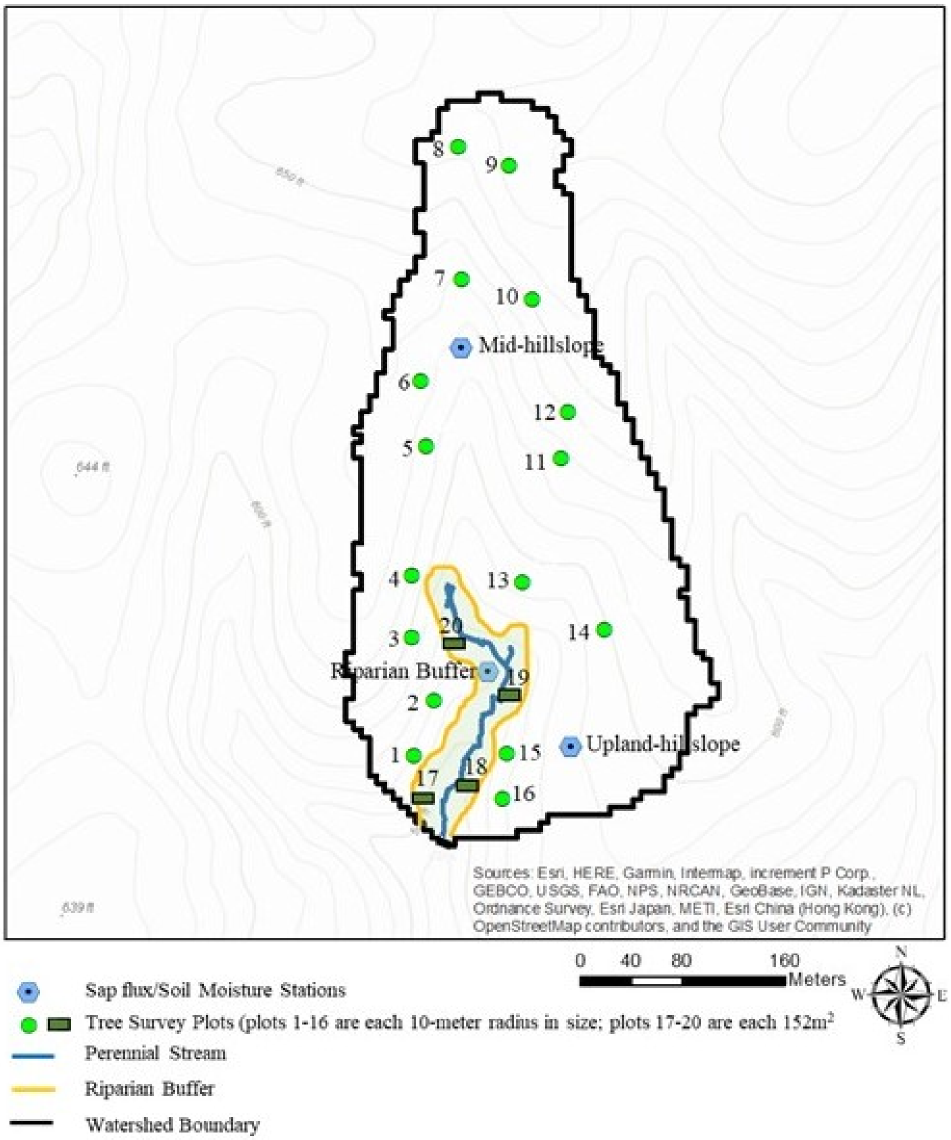

Figure 1. Study design in a 12 hectare headwater catchment in the Piedmont of North Carolina.

RESULTS

Mean daily growing season soil moisture was significantly higher in the riparian buffer than the other zones in 2015 (dry year) and 2016 (wet year) (Table 1).

Daily growing season sap flux density (Js) varied across species, zones, and years (Table 1), with the overall Js being higher in the riparian buffer and mid-hillslope than on the upland-hillslope.

Mean daily tree-level transpiration (Ts) in the monitored trees ranged from 10 to 93 L day-1 in 2015 (dry year) and 9 to 122 L day-1 in 2016 (wet year).

Annual watershed level transpiration (Tw) based on scaled-Js data from the buffer was 447 mm, mid-hillslope was 377 mm, and upland-hillslope was 340 mm (Table 2).

Table 1. Daily mean growing season (May-October) soil moisture and sap flux density from three sap flux stations (buffer, mid-slope, and upland-slope) in 2015 and 2016, and mean growing season across those years. Standard error is in parenthesis. Daily means with the same letters are not significantly different at $p < 0.05$. Uppercase letters define the growing season versus the growing season within the same zone, and lowercase letters define zone versus zone within growing season.

	Growing season, 2015			Growing season, 2016			Growing season, mean		
	Buffer	Mid-slope	Upland-slope	Buffer	Mid-slope	Upland-slope	Buffer	Mid-slope	Upland-slope
Soil Moisture (%)									
	20 (0.5)aA	15 (0.1)bA	6 (0.2)cA	26 (0.4)aB	20 (0.3)bB	11 (0.3)cB	23 (0.5)a	17 (0.2)b	9 (0.2)c
Sap flux density (J_s, g cm^{-2} day^{-1})									
Species									
Chestnut oak	-	67 (2)A	-	-	84 (3)B	-	-	76 (9)	-
Loblolly pine	124 (4)Aa	109 (4)Ab	75 (3)Ac	122 (4)Aa	99 (3)Ab	91 (3)Ab	123 (1)a	104 (5)b	83 (8)c
Northern red oak	-	-	42 (1)A	-	-	47 (1)B	-	-	45 (3)
Red maple	83 (3)Aa	108 (4)Ab	-	101 (3)Ba	99 (3)Aa	-	92 (9)a	104 (4)b	-
Sweetgum	109 (4)Aa	87 (3)Ab	75 (3)Ac	92 (3)Ba	108 (3)Bb	65 (2)Bc	101 (8)a	97 (10)a	70 (5)b
Tulip poplar	106 (3)Aa	115 (5)Ab	-	104 (4)Aa	115 (4)Ab	-	103 (1)a	115 (0.2)b	-
Virginia pine	137 (5)Aa	-	75 (3)Ab	79 (2)Bb	101 (4)a	110 (4)Ba	108 (29)a	105 (4)a	92 (17)b
White oak	98 (4)Aa	-	87 (3)Ab	96 (3)Aa	-	101 (3)Ba	97 (1)a	-	94 (7)a

- species was not present at that area in the watershed or not in close enough proximity to the sap flux station to be monitored. Soil moisture at the 10 cm depth.

Table 2. Comparison of zone watershed-level transpiration (T_z) based on scaled sap flux density data from the buffer, mid-slope, and upland-slope against watershed-level transpiration (T_w) based on weighted T_z from all three stations. The weighted area average to compute T_w from each zone was 10% for the riparian buffer, 45% for the mid-slope, and 45% for the upland-slope.

		Buffer T_z			Mid-slope T_z			Upland-slope T_z			Zone weighted buffer, mid-slope and upland-slope T_w		
Year	Precipitation	non-growing	growing	annual	non-growing	growing	annual	non-growing	growing	annual	non-growing	growing	annual
							mm						
2015	1027	78	369	447	57	311	368	88	248	336	73	288	362
2016	1178	107	339	446	60	325	385	94	250	344	80	293	373
Mean	1103	93	354	447	59	318	377	91	249	340	77	291	367

non-growing season (November-April) and growing season (May-October)

DISCUSSION

In the dry year, most species water use rates were sensitive to the topographical gradient, and their Js values increased with increasing soil water availability in the zones.

In the wet year, species water use rates were less sensitive to the topographical gradient than the dry year because the amount of available water was sufficient for transpiration.

Watershed-level transpiration (Tw) was very similar from a dry year to a wet year (362 mm vs. 373 mm, Table 2) in part because Js was not significantly different for loblolly pine, white oak, and tulip poplar between years. These three species occupied 50% of the sapwood area and were responsible for almost 75% of the water loss in both years

There were significant differences in Tw, depending on which Tz was used to compute Tw. Annual Tw based on scaled-Js data from the buffer was 447 mm, mid-hillslope was 377 mm, and upland-hillslope was 340 mm.

CONCLUSIONS

There are large spatial variability in transpiration in a Piedmont watershed due to difference in soil moisture conditions. The response in tree sap flux density to decreasing soil water content was species-dependent and varied across the soil moisture gradient.

This study improves our broader understanding of the relationship between species-specific transpiration and soil moisture. Linking soil moisture, tree water use, and climate conditions at the watershed level is rarely done, but is critical to refining transpiration estimates, managing the effects of drought, and understanding hydrological processes in unmanaged and managed watersheds across various regions.

ABSTRACT

Quantifying species-specific transpiration at different soil moisture levels is important for understanding the effects of environmental change including drought, floods, and urbanization on ecosystem responses. We measured sap flux density (J_S) during a wet and dry year in a 12-ha forested watershed dominated by chestnut oak (*Quercus Prinus*), loblolly pine (*Pinus taeda),* northern red oak (*Quercus rubra*), red maple (*Acer rubrum),* sweetgum (*Liquidambar styraciflua),* tulip poplar (*Liriodendron tulipifera),* Virginia pine (*Pinus virginiana*)*, and* white oak (*Quercus alba*). The tree transpiration (T_S) and watershed-level transpiration (T_W) was determined in three zones (riparian buffer, mid-hillslope, and upland-hillslope) of contrasting topography and soil moisture. In loblolly pine, Virginia pine, and sweetgum, J_S were significantly higher in the riparian buffer zone when compared to other zones, whereas J_S in tulip poplar and red maple were significantly lower in the riparian buffer than in the mid-hillslope. During the dry period, J_S in loblolly pine, white oak, sweetgum, and Virginia pine was less responsive to VPD on upland-hillslopes compared to the riparian buffer. In contrast, J_S in tulip poplar and red maple on the mid-hillslope were more responsive to VPD than on the riparian buffer, suggesting there was sufficient energy and soil water to maintain transpiration for these species. The average annual calculated T_W based on T_S data from the riparian buffer was 447 mm, mid-hillslope was 377 mm, and upland-hillslope was 340 mm. We conclude that there is a large spatial variability in tree and forest transpiration due to differences in the soil moisture regime and in the forest tree species composition.