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Water use and productivity of poplar and willow in SRC plantations in NE Germany along gradients of groundwater depth

Markus Schmidt[1], Tobias Böhme[1], Sören Krämer[1], Peter Rademacher[1], Dieter Murach[1]
[1] Eberswalde University for Sustainable Development, Faculty of Forest and Environment, Research Group Agrowood, 16225 Eberswalde, Germany
Markus.Schmidt@hnee.de

Introduction

Fast-growing tree species planted as short rotation coppice (SRC) may provide multiple ecosystem services, particularly in agroforestry systems such as alley cropping or shelter belts, e.g. wind and soil erosion control, soil fertility protection, carbon sequestration, increasing landscape structural richness and biodiversity, as well as supplying wood as a renewable source of biomass and energy.
In the federal state of Brandenburg, NE Germany, a large proportion of the arable land is characterized by **sandy soils**, relatively **shallow groundwater** levels of 1–2 m and typically **scarce precipitation** during the growing season (≤ 300 mm).
Therefore, a **deep-rooting, woody plant cover** in SRC systems may sustain dry spells with only minor or no reductions in yield and additionally offer benefits to adjacent annual crops. However, the productivity of SRC may vary greatly depending on soil type, nutrient and soil water availability.

Here we studied water use and productivity of willow and poplar trees in SRC plantations on agricultural land in relation to soil water availability, atmospheric conditions and stand structure on sites with gradients in groundwater depth.

Material

Poplar clone 'Max1' (*Populus nigra* x *P. Maximowiczii*)
Willow clone 'Inger' (*Salix triandra* x *S. viminalis)*

Volumetric soil water content: FDR-probes (PR2/6 Profile Probe, Delta-T Devices Ltd., UK)
Groundwater level: groundwater dip meter (Nordmeyer, Germany)
Tree water use / xylem sap flow: Thermal dissipation probes (Granier 1985), EXO-Skin stem heat balance probes (Dynamax Inc., USA)
Stem radius change: Diameter dendrometer (DD-S, Ecomatik, Germany)
Leaf area index: LAI2000 Plant Canopy Analyzer (LI-COR Inc., USA)
Meteorological variables on nearby open areas

Table 1: Site characteristics

SRC plantation	Wartin	Stendell		Kummerow	
Location	53.2324 N, 14.1624 E	53.1538 N, 14.1804 E		53.1349 N, 14.2210E	
Annual/growing season air temp.	c. 8 °C / 15 °C				
Annual/growing season precipitation	c. 500 mm / 300 mm				
Studied species	poplar	poplar	willow	poplar	willow
Slope gradient (°)	8.3	1.5	1.7	<0.3	
Soil texture	Sandy loam	Humous sand		(Humous) sand	
Transect length	65	130	150	(<5)	(<5)
Groundwater depth (m), min.	0 – >1.8	0.6 – >1.8	<0.1 – 1.6	0.8	
max.	0.8 – >1.8	>1.8	0.7 – >1.6	1.4	
Stand density, initial (stools ha^{-1})	c. 19000	c. 19000		c. 15000	
Age of shoot/stool during study (yrs)	5/5	3/6		3/6	
Leaf area index, range of max. (m^2 m^{-2})	1 – 7.5	3.9 – 9.5	1.4 – 6.9	4.2	3.7
Diameter at 1.3 m height, range (cm)	3.7 – 8.0	2.8 – 5.1	2.1 – 3.8	3.4 – 3.9	2.9 – 3.3
Height, range (m)	6.4 – 10.7	2.9 – 7.0	2.7 – 7.7	5.3 – 5.8	4.5 – 5.1
Above-ground woody biomass increment per tree, range (kg yr^{-1})	0.4 – 7.4			0.7 – 1.4	0.4 – 0.6

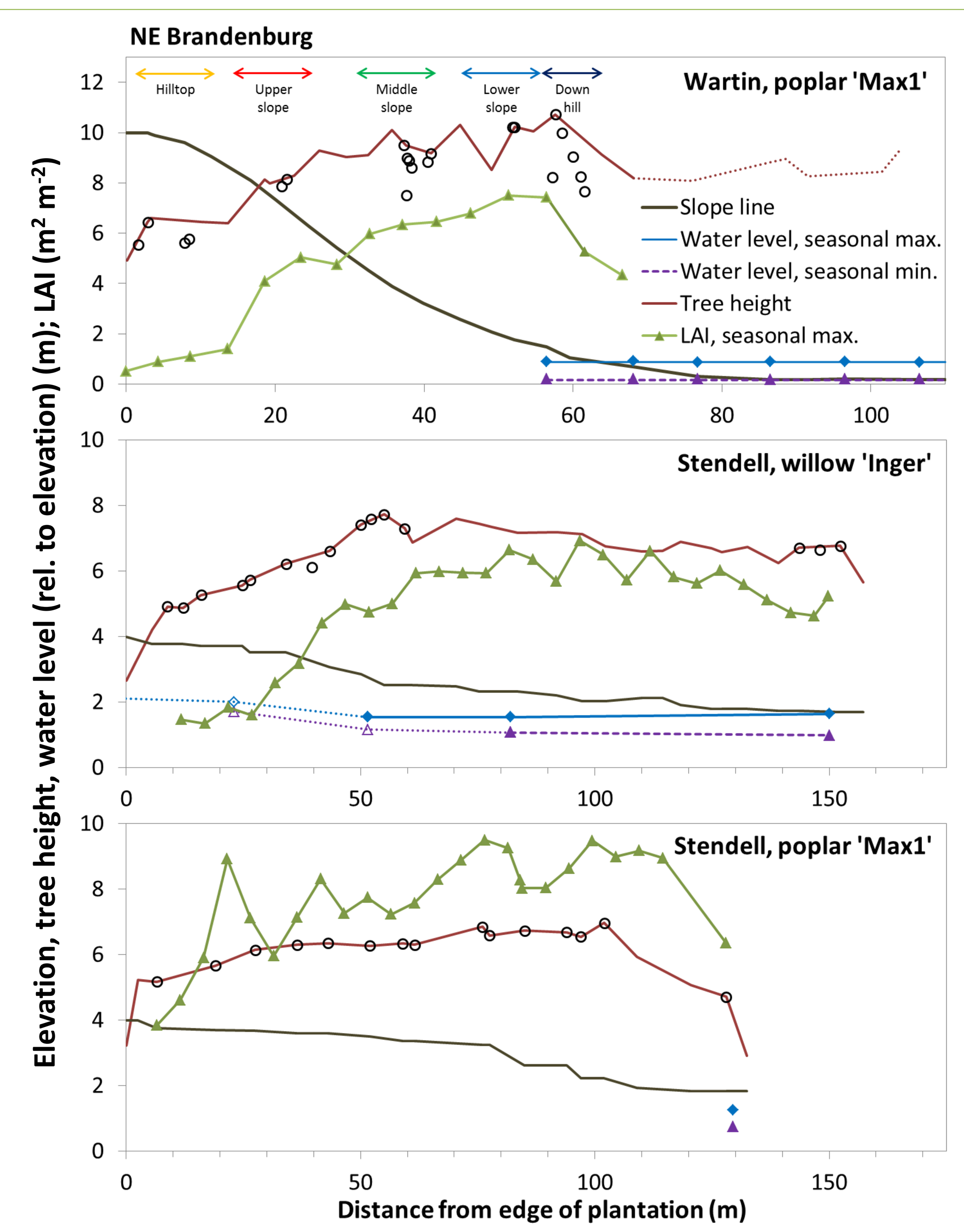

Figure 1: Overview of the experimental site Wartin (top) and Stendell (poplar: middle; willow: bottom).
Circles represent trees equipped with xylem sap flow probes and the trees' respective height. Open symbols for the water level are interpolations. For poplar at Stendell groundwater level was always deeper than 1.8 m (max. depth of observation well).

Conclusions

Tree water use, productivity and water use efficiency varied widely, depending on water availability and stand structure. Water use efficiency of the poplar clone 'Max1' tended to decrease under water surplus conditions and in denser canopies, compared to trees on drier sites or where leaf area index was lower. Such behaviour would be indicative of a loose stomatal control of water use.

As fast growing tree species suitable for SRC usually are often also shade intolerant, stand structure should be an important determinant of water use and water use efficiency in SRC plantations in general. Thus planting density should reflect the site conditions (water supply) and the intended coppicing interval to minimise luxurious water consumption and shading where optimisation of water use and productivity is required or desired.

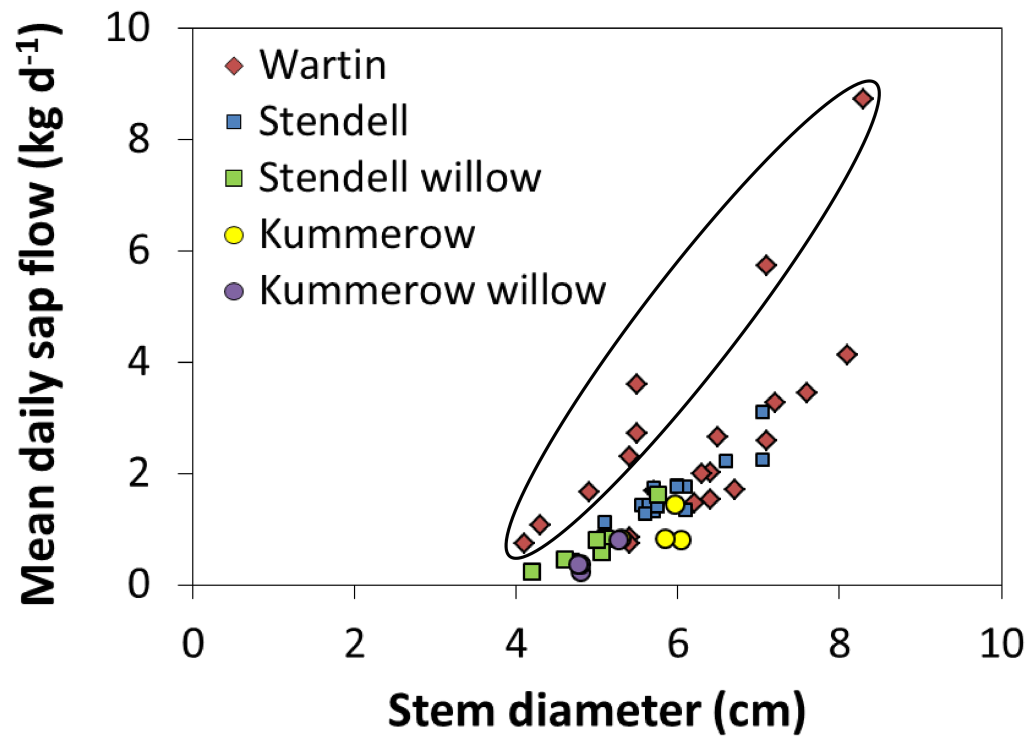

Figure 2: Seasonal mean daily sap flow (kg of water per tree and day) for poplar 'Max1' and willow 'Inger' vs stem diameter for shoots from different SRC plantations aged 3 years (Stendell, Kummerow; Wartin: 5 years).

Daily water use of poplar and willow shoots averaged over the growing season was 0.4–8.7 and 0.2–3.1 kg d^{-1}, respectively, for trees aged 3–5 years (Fig. 2). Note the highlighted trees in Figure 2 from Wartin, growing either over shallow groundwater or where the leaf area index (LAI) and tree density were low (cf. Fig. 1).

Water use was reduced on drier sites during summer drought: Figure 3 shows for the site Wartin a decrease of sap flow relative to the vapour pressure deficit of the air (VPD), in hilltop and particularly in upper and middle slope trees already in August, while sap flow remained high until September in lower slope and downhill trees.

At the lower slope and downhill positions soil water content in 30 cm depth decreased by only 2–4 Vol.-% over the growing season due to the high water table while it decreased by > 10 Vol.-% higher up on the slope (not shown). LAI correspondingly decreased earlier in the season at the upper and middle slope compared to the lower slope and downhill, whereas LAI was very small (1 m^2 m^{-2}) throughout the season at the hilltop (Tab. 1, Fig. 1).

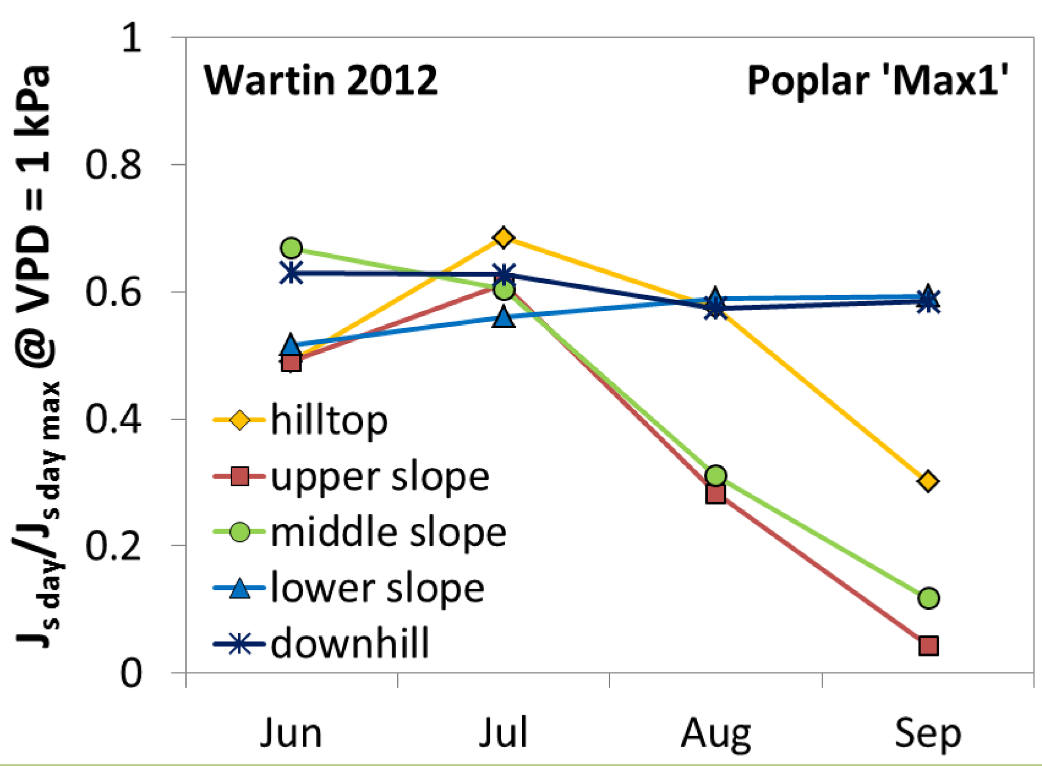

Figure 3: Seasonal course of sap flux density J_s relative to VPD for 5 representative trees along the slope transect in Wartin.
J_s is sap flow normalised with sapwood area. The daily sum of J_s ($J_{s\,day}$) is shown relative to the seasonal maximum ($J_{s\,day}/J_{sday\,max}$) at a reference maximum VPD of 1 kPa (based on regression equations of $J_{s\,day}/J_{sday\,max}$ with VPD_{max} for each month).

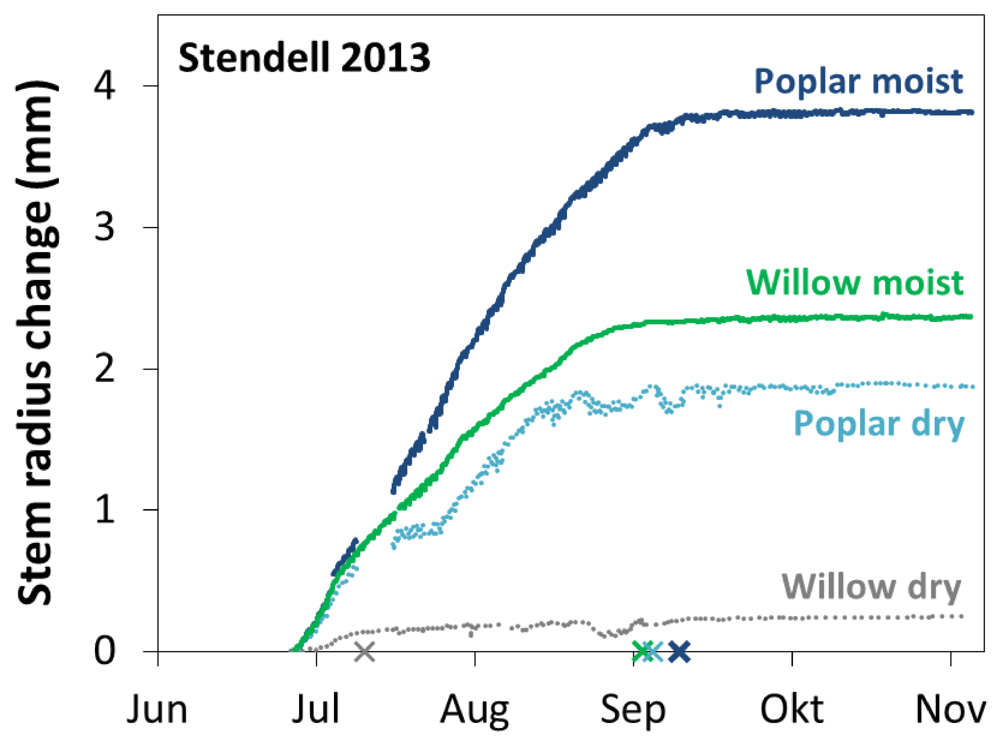

Figure 4: Stem radius change of two poplar and two willow trees with different distance to the water table ("moist" and "dry"). Cessation of radial growth is marked on the x-axis. Measurements started on June 26, 2013 (0 mm).

At the site Stendell, radial stem growth ceased more than 7 weeks earlier for a willow growing where the water table was at a depth >1.8 m compared to a willow at a water table level of c. 1.5 m (Fig. 4). In the poplars studied the difference in growth cessation was only marginal, and the water table was below 1.8 m soil depth (deeper than the observation wells). A drought spell at the end of August caused a pronounced stem shrinkage only in the "dry" willow and poplar.

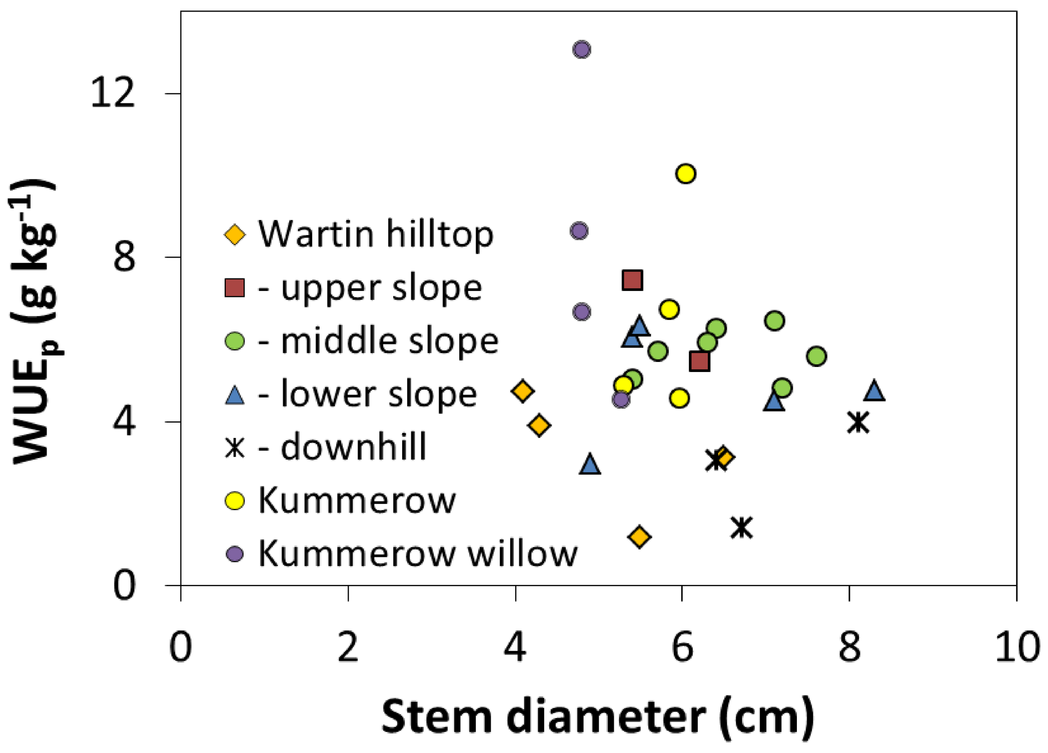

Figure 5: Water use efficiency (WUE_p) for poplar trees at the site Wartin and poplar or willow at the site Kummerow.
WUE_p is seasonal amount of woody aboveground biomass produced per kg of water used.

Preliminary results for the water use efficiency (WUE_p), the amount of woody aboveground biomass produced per kg of water used, range from 1.2 to 10 (poplar) and from 4 to 13 g kg-1 (willow shoots; Fig. 5).
Up to 7 kg of dry woody biomass were produced by a well water supplied tree in its fifth year (Tab. 1).

The variability of WUE_p within one site is rather large, presumably due to the differing soil water supply along the transect (Wartin) and varying stand structure (Wartin and Kummerow, cf. Tab. 1). The broad range of WUE_p is indicative of a loose control of water use by the plants as long as water supply is non-limiting (Wartin, lower slope and downhill) and/or points to a less efficient photosynthesis in denser parts of the canopy due to increased (self-) shading at high leaf area index (cf. Fig. 1).

References: Granier A (1985) Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. Annales des Sciences Forestières 42: 193–200.

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