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Research paper

Sensitivity of short rotation poplar coppice biomass productivity to the throughfall reduction – Estimating future drought impacts

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ABSTRACT

We examined the effect of throughfall exclusion on aboveground woody biomass (AGB) productivity in a short-rotation woody coppice plantation. This study was carried out between the 3rd and 7th year (2011–2015) of the second rotation cycle in hybrid poplar plantation (*Populus nigra* × *P. maximowiczii*) in the Czech Republic. A partial-throughfall exclusion (R) treatment and a control (C) treatment were applied. Throughfall exclusion was set to 40% in 2011–2012 and increased to 70% thereafter. The annual mean (standard error) AGB productivity for C and R during 2012–2015 were 11.2 (0.84) and 10.1 (0.89) Mg ha^{-1} y^{-1} of dry matter (DM), respectively. The lowest AGB productivity and most pronounced reduction (18.8%) in the annual AGB productivity by the R treatment occurred in 2014 - a year with the driest spring. The observed inter-annual variability in AGB productivity was not explained by precipitation nor by precipitation-treatment interaction. However, the annual AGB productivity variation depended ($p = 0.002$) on the throughfall totals during period May–July. The total harvestable biomass in 2015 reached 81.9 (7.2) and 75.0 (6.2) Mg ha^{-1} DM for the C and R treatments, respectively. Despite the non-negligible mean treatment difference (5.7 Mg ha^{-1} DM, i.e. 7.6%), the large between-plot variance and shifts in stand structure resulted in the nonsignificant differences. We suggest that once the root system is established, hybrid poplar plantations are relatively resilient to drought and might act as an income-stabilizing factor when traditional agricultural crops fail to deliver viable yields in drier climate.

1. Introduction

The productivity of poplar and willow short rotation woody coppice (SRWC) is largely dependent on the environment in terms of soil characteristics and climatic conditions [1,2]. While increased poplar productivity during the 20th century in the Czech Republic has been reported [3], it is clear that more frequent drought occurrences could potentially have direct economic consequences. One of the consequences of climate change is the increasing frequency and duration of heat waves throughout Europe. Higher air temperatures increase evaporation and thus affect droughts increasing their frequency, intensity and duration [4,5]. Droughts have been starting earlier and lasting longer [6,7]. King et al. [8], suggested that widespread bioenergy production will be especially sensitive to future water availability and will potentially compete with other demands for water, a situation that is likely to be exacerbated in many regions because of climate change. In the Czech Republic, increased global radiation and air temperature together with decreased relative humidity have led to increases in the evaporative demand of the atmosphere in all months of the growing season; this trend is particularly evident in April, May, and August, when more than 80% of the territory shows an increased demand for soil water [9]. Fischer et al. [10], reported that the actual evapotranspiration of a poplar-based SRWC was very similar with that of grassy surface under the same climatic conditions and reached approximately 80% of the annual sum of reference evapotranspiration (ET_o). However, in areas where the long-term ET_o exceeds precipitation, the biomass productivity can be limited, particularly when the temporal distribution of precipitation is uneven [11]. This phenomenon also applies to our study site, where total ET_o was 20% higher than total rainfall during the period of 2010–2015. Given that establishing a SRWC plantation requires considerable investment and a projected lifespan of SRWC plantation is approximately 20–25 years [12], the consequences of climate change need to be considered [3].

Therefore, we sought to answer fundamental questions relevant to SRWC systems and their productivity in light of predicted changes in climate: (1) what is the impact of long-term decreases in site water availability on stand level production and (2) what is the nature of the response to long-term decreases in site water availability in terms of stand structure changes and stump mortality? For that purpose, long-term throughfall exclusion experiment within an operational SRWC

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Table 1
Courses of mean air temperature and precipitation at the Domanínek site during selected periods.

	Mean air temperature (°C)			Precipitation (mm)		
	Jan.–Dec.	Apr.–Oct.	May–July	Jan.–Dec.	Apr.–Oct.	May–July
1961–1990	6.6	12.0	13.9	578.1	392.9	210.7
1971–2000	6.9	12.1	14.1	586.8	393.6	205.5
1981–2010	7.2	12.7	14.8	612.5	407.8	213.4
2001–2015	7.6	13.1	15.4	605.9	411.6	215.7
2011–2015	7.7	13.0	15.1	533.7	384.5	194.9

plantation was established where we attempted to alter site water availability by significant throughfall reduction. We hypothesized, that the throughfall reduction will lead to proportional decrease of soil water availability and consequently to proportional reduction of the biomass production.

2. Materials and methods

2.1. Study site

This study was carried out from June 2011 to October 2015 at the Domanínek research site (Czech Republic, 49°521′N; 16°235′E, at an altitude of 578 m a.s.l.). The site is located in the eastern part of Bohemian-Moravian Highlands. The site belongs to a rainfed area, with mean annual precipitation of 609.3 mm and a mean annual temperature of 7.2 °C. The mean length of the growing season (daily mean air temperature above 5 °C) is 217 days from April 1st to October 30th [10]. The soil is characterized as a relatively shallow (0.3–0.5 m) luvic cambisol influenced by gleyic processes, and stones are present in the profile. The mean air temperature and precipitation totals during the selected periods are depicted in Table 1, while Table 2 extends this overview with throughfall-related totals and reference evapotranspiration (ET_o) [13].

2.2. Plantation

In April 2001, a high-density multi-clone poplar plantation that consisted of approximately 3 ha was established near town Bystřice nad Pernštejnem (49°521′N, 16°235′E). This plantation was described in detail in Fischer et al. [10], where it was mentioned as “SRC2”. The most important plantation part was based on the hybrid poplar clone J-105 (*P. nigra* × *P. maximowiczii*), which has a quadrate shape, and the total area of this part was 1 ha. The plantation is situated on a slope of 8° on east-facing land that was formerly cropped with potato and cereals. Hardwood cuttings were planted in a double-row design. The inter-row distances were 2.6 m, and the spacing within rows was 0.7 m; this setup accommodated areal number density of 9216 ha^{-1}. The first rotation cycle length was set at 8 years due to strong weed competition that slowed down the canopy closure the first two years after planting. In the late fall of 2008, all stems from the first rotation were harvested. During the resprouting in 2009, many new shoots developed from each stump, however, in 2015, due to 7 years of self-thinning, each stump typically carried one to four living stems. This study covers five growing seasons between the 3rd and 7th years of the 2nd rotation cycle (2011–2015).

Table 2
Overview of precipitation, reference evapotranspiration (ET_o), throughfall, throughfall exclusion and throughfall reduction during selected periods of years 2011–2015.

		2011	2012	2013	2014	2015
April–October	Precipitation (mm)	408.3	325.4	375.8	417.8	290.5
	ET_o (mm)	545.4	576.5	520.8	488.4	560.4
	Throughfall at C (mm)	359.7	286.7	331.1	368.1	255.9
	Throughfall at R (mm)	258.0	172.0	173.1	110.4	76.8
	Throughfall reduction (mm)	101.7	114.7	158.0	257.7	179.2
	Throughfall reduction (%)	28.3	40.0	47.7	70.0	70.0
April–July	Precipitation (mm)	313.6	236.0	258.2	310.4	230.1
	ET_o (mm)	444.4	484.5	445.5	426.8	485.2
	Throughfall at C (mm)	276.3	207.9	227.5	273.5	202.7
	Throughfall at R (mm)	207.9	124.7	142.0	82.0	60.8
	Throughfall reduction (mm)	68.4	83.2	85.5	191.4	141.9
	Throughfall reduction (%)	24.7	40.0	37.6	70.0	70.0
May–July	Precipitation (mm)	229.4	182.4	173.6	115.8	112.3
	ET_o (mm)	284.5	309.3	264.1	294.1	313.0
	Throughfall at C (mm)	202.1	160.7	152.9	102.0	98.9
	Throughfall at R (mm)	155.3	96.4	75.1	30.6	29.7
	Throughfall reduction (mm)	46.8	64.3	77.8	71.4	69.3
	Throughfall reduction (%)	23.2	40.0	50.9	70.0	70.0

2.3. Throughfall exclusion experimental design

The throughfall exclusion experiment was established in mid-June 2011 (Fig. 1). This experiment consisted of a pair of adjacent square-shaped plots (25 m^2): the “throughfall exclusion treatment” (R) and the “control treatment” (C). Each plot contained 20 stumps with multiple shoots. The original hypothesis aimed to induce moderate drought stress that might be expected from climate change and to not threaten the trees with severe drought stress. Therefore, throughfall rainwater reduction of 40% was chosen for the first step. To cover natural variability in soil moisture patterns, three blocks were set up in different parts of the plantation, where each block accommodated one C and one R treatment. The blocks were established at least 15 m from the edges of the plantation to eliminate any edge effects. The R treatment was equipped with a horizontally inclined wooden construction approximately 0.5–1.0 m above the ground; this construction carried narrow roof strips made of transparent plastic. The roofs covered the inter-row space on both sides of the inner tree double row. Beginning in June 2011, the roof strips covered 40% of the projected area of each R plot. In addition, two 8.0-m-long gutters were installed diagonally across each R and C plot at a height of 0.4 m above the ground (between the roof and the ground surface in the case of R plots), and a 50-L collection barrel was located at the downstream end of each gutter. The amount of actual throughfall water entering each C and R treatment was determined weekly by comparing the quantity of the water collected in barrels at each treatment. The water collected by roofs was diverted 10 m downstream from the experiment using plastic pipes. Since June 2012, a 0.5–0.8 m deep ditch surrounded the R treatment. The ditches were insulated with geofoil to prevent roots from growing outside the plot and prevent water from percolating into the R plots. As the plants in the R treatment adjusted to drought, the throughfall exclusion was increased from 40 to 70% by adding additional roof strips to the existing construction (Fig. 1 and Table 2) to enhance the treatment effect.

2.4. Aboveground biomass productivity and stump mortality

The dry matter (DM) biomass (stems and branches) was related to the stem diameter at breast height (DBH) (130 cm) using the power