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Research paper

Potential and limitations of local tree ring records in estimating *a priori* the growth performance of short-rotation coppice plantations

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A B S T R A C T

As bioenergy plantations are a relatively new phenomenon, long-term experimental data on their productivity and tolerance to environmental stress that provides a robust framework for site selection and potential productivity assessment is still lacking. To address this need, we developed a method to correlate the productivity of bioenergy plantations with local climate using tree-ring chronologies. Tree-ring width from 37 *Populus nigra* (age > 115 y) and 368 poplar hybrid (*Populus nigra* × *Populus maximowiczii*) (9–12 y) individuals were collected and analyzed at demonstration sites in the Czech Republic. The growth of mature, naturally grown solitary native trees and young congeneric hybrids grown in high density (~10,000 ha^{-1}) showed statistically significant correlations ($r = 0.71$, $p < 0.05$). Further, we found significant ($p < 0.05$) and consistent growth responses to changes in key seasonal climatic parameters (e.g., mean air temperature, number of dry days or cumulative heat sum (degree-days) during the growing season) for both natives and their hybrids. The analysis of climate conditions and the tree-ring records revealed a gradual change of climatic conditions since the 1930s, positively affecting poplar growth and indicated that longer rather than shorter harvest cycles are preferable to ensure stable yields at our experimental site.

1. Introduction

The cultivation of woody biomass crops represents one of many alternative sources of renewable energy. Although estimates suggest that the land available in Europe for bioenergy production is decreasing, there is potential that lignocellulosic woody crops will provide a more significant share of bioenergy in the future [1]. Of the potential "second-generation" bioenergy crops, poplars and willows growing in short-rotation coppice (SRC) may provide stable production of high-quality woody biomass in many regions [2–4]. These SRC bioenergy production systems are environmentally robust and provide additional ecosystem services [5,6]. The search for alternative energy sources has recently intensified due to a perceived need to decrease carbon emissions to mitigate climate change [7]; however, climate change itself may pose interesting challenges for this source of renewable energy [8,9]. According to recent studies [10–12], the Central European climate has undergone significant changes, and trends suggest that temperatures are likely to increase and that the available water supply is likely to decrease in the next few decades [13,14]. These changes create challenges to estimating the productivity of recently planted or planned bioenergy plantations (given their 25–30-year life expectancy). It is therefore even more important to understand the relationship among climate, extreme weather events, and bioenergy crop production.

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Despite its relevance, long-term empirical studies addressing the physiology and productivity of SRC and their response to climatic conditions and weather extremes, which would allow large scale upscaling and reliable mapping of the potential production, are still lacking [15]. An alternative to long-term experiments might be application of process-based models [2,16,17]. However, since the models generally require detailed (and not trivial) parameterization, they are not practically applicable for other than research purposes at the current stage. In addition, to make models a reliable tool they need to be properly validated across a broad range of soil-climate conditions, again indicating the need for a long-term empirical, experimental database [15]. Studies required for the above-mentioned purposes are hindered by the relatively long-term harvest cycle of SRC systems and by their size. Whereas plot sizes from 10 to 30 m^2 are considered sufficient for traditional agricultural crops experiments, plot sizes should be at least ten times larger for tree-based experiments [18]. The harvest cycle of poplar plantations is usually between two and seven years (compared to a single year in the case of field crops), which prolongs the length of most experiments. Farmers and agronomists are used to having a wealth of available experimental data available to estimate potential agro-climatic risks and can use climate/soil suitability for traditional crops to aid in decision-making. However, as bioenergy production systems are relatively new (e.g., they have only been present in Central Europe since the end of the 1990s [19]), data on SRC productivity-climate relationships are severely lacking, although progress has been made [20–23]. Filling this gap would enable better decision making in selecting suitable energy crops species/genotypes for specific soil and climatic conditions, especially in the situation where reliable model upscaling has been not yet been realized. We suggest that finding widely grown trees of native species with the best correlation with the growth of SRC systems can be a useful way to evaluate the potential viability of SRC plantation productivity at given site.

In this conceptual study, we hypothesized that the growth of trees of native species correlates well with the growth of congeneric hybrids in SRC, and that inter-annual growth variability can be used as a metric useful for site selection. Although the effect of growing season length cannot be controlled for, quantifying its effect on the growth response is informative since it can suggest the potential variation in yield possible. In contrast, if a native species shows high growth variability during years with similar growing season length but differences in precipitation, it suggests that water is a main constraint and the biomass productivity and plantation vitality may be at risk.

To demonstrate the viability of our concept, we used over 100 years of tree-ring data from *Populus nigra* specimens that are relatively common across the European landscape. We first investigated a potential link between the responses of a bioenergy poplar hybrid (*Populus nigra* × *Populus maximowiczii*) SRC grown at high-density and mature solitary *P. nigra* trees grown under natural conditions at the same location. We show how the tree-ring response of the mature *P. nigra* trees to climate can be used to assess the likelihood of adverse climate events negatively affecting growth and productivity of the bioenergy plantation. Although different species might be used to relate to growth of the SRC, we reasoned that the close genetics ensured more similar resource requirements and seasonal growth patterns.

2. Materials and methods

2.1. Site characteristics

The study was conducted in a typical rain-fed agricultural area of the Bohemian-Moravian Highlands (Fig. 1) near the Domanínek research station (49° 31′ N, 16° 14′ E; 530 m a.s.l.). The long-term mean (1981–2010) annual temperature is 7.2 °C, the mean annual precipitation is 609.3 mm, and the mean annual reference evapotranspiration [24] is 650 mm. The mean length of the growing season (daily mean air temperature above 5 °C) is 217 days, from March 30 to November 1. These data are based on daily weather variables obtained from the meteorological station at Bystřice nad

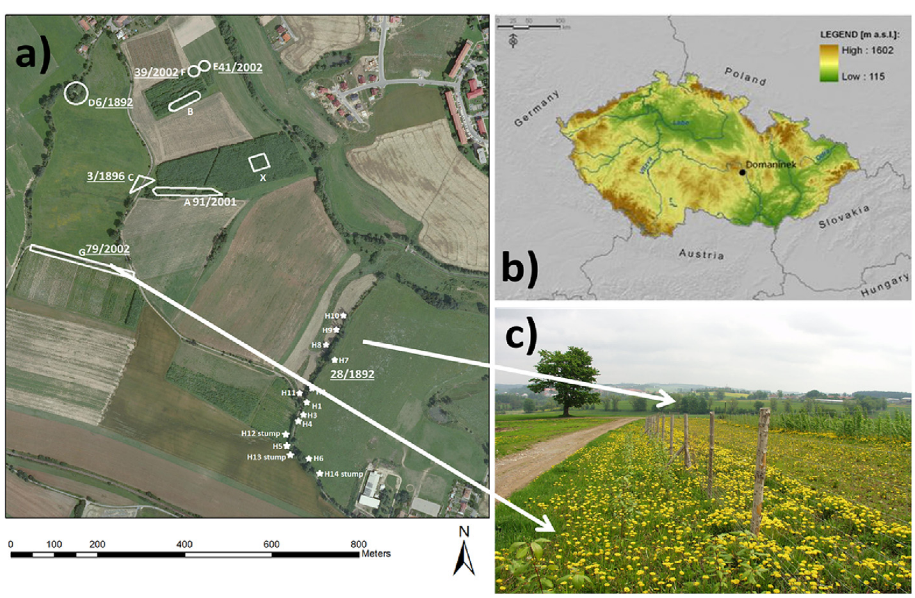

Fig. 1. a) The spatial distribution of the sampling sites within the sampling area. Letter identifies individual sampling sets. A,G represent "dry" while B,E.F "wet" SRC sites while D,C and H indicate *Populus nigra* site. The first number identifies the number of specimens within the sampling while the year stands for the oldest identified tree ring at the given sampling site. The "X" site shows were the continuous growth increment measurements used in Fig. 2a took place. The arrows indicate the position of the sampling sites G and H. b) The location of the case study site. c) An image of the G (*Populus nigra* × *P. maximowiczii)* sampling site in 2003 (two years after planting) with the H (*Populus nigra*) site in the distance. *Note: The marking A-H for tree ring sampling sites was determined based on the order of collection of the samples on the collecting day and was retained for the study. No tree-rings were collected at the „X" site.*