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Petiole and leaf traits of poplar in relation to parentage and biomass yield

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ABSTRACT

Poplars grown under a short-rotation coppice (SRC) regime for biomass production offer a promising alternative source of renewable energy to fossil fuels. We examined the potential of leaf and petiole traits of 12 different poplar genotypes as early selection criteria for breeding and selection programmes. Petiole traits included theoretical hydraulic conductivity of the petiole, petiole xylem area and the number of vessels in each petiole. The different genotypes clustered largely according to their breeding programmes and to their parentage. Leaf and petiole traits showed strong correlations, which enabled the prediction of difficult-to-measure petiole traits as xylem area, total vessel lumen area and number of vessels based on the more common and easily measurable leaf dry mass. We found significant correlations between above-ground woody biomass and nine leaf and petiole traits. We developed three predictive correlative models based on the easy-to-measure petiole and leaf traits (petiole cross-section area, petiole thickness and leaf dry mass). These simple models can be used as early selection criteria for biomass yield in poplar breeding programmes. The usefulness of the easy-to-measure petiole thickness for biomass prediction should be further tested on other poplar genotypes.

1. Introduction

The culture of fast-growing trees under a short-rotation coppice (SRC) regime for biomass production offers one of the most promising alternatives to fossil fuels in the search for renewable energy sources (Foster, 1993). The concept of SRC is defined as carefully tended, high-density plantations of fast-growing perennial crops with rotations shorter than eight years (Herrick and Brown, 1967). Poplar (*Populus* spp.) and willow (*Salix* spp.) are the most commonly used species for SRC in Europe (Kauter et al., 2003; Aylott et al., 2008). Poplar is particularly suitable for SRC cultures in temperate regions because of its high growth rate and biomass yield, its easy vegetative propagation from cuttings and high coppice ability (Dillen et al., 2010). Since the early 1950s, intensive selection and breeding programmes for poplar have resulted in a wide range of highly productive genotypes. Several aspects of genotypic differences have already been examined and documented over the past decade: the importance of species and genotypes used in SRC (Willebrand et al., 1993; Dillen et al., 2011); the impact of coppicing (Herve and Ceulemans, 1996); the length of the coppice rotation cycle (Al Afas et al., 2008); and the interactions between soil type and genotype (Dillen et al., 2010).

Several studies have identified poplar traits that facilitate the poplar breeding process, as this remains a necessary and continuous requirement for SRC (Rae et al., 2004; Verlinden et al., 2013). A negative correlation between growth rate and wood density was shown in some studies (Pliura et al., 2007; Zhang et al., 2012), while others reported that there was no correlation (DeBell et al., 2002; Zhang et al., 2003). The reason for these conflicting observations could be that wood density changed with tree age in the study of DeBell et al. (2002); density increased after five years of growth in three poplar genotypes. So, the efficient selection of genotypes based on wood properties may require a standardised sampling at more than one height (DeBell et al., 2002; De Boever et al., 2007). On the other hand, individual leaf area and leaf area index were found to be very promising traits for early selection criteria, as they positively correlated with biomass (Barigah et al., 1994; Harrington et al., 1997; Verlinden et al., 2013). The petiole is an important part of the leaf. It plays a dual function in leaves, i.e. providing mechanical support, and also serving as a pathway for water and nutrients, as well as for retranslocation of photosynthates (Rost et al., 2006). There is evidence for allometric relationships between leaf and petiole traits (Niinemets et al., 2004; Al

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Afas et al., 2005). For example, a positive correlation between individual leaf area and petiole diameter was observed for 12 different poplar genotypes (Al Afas et al., 2005). As there are allometric relationships between leaf area characteristics and biomass, and as the petiole is a crucial part of the leaf, one might assume that there are correlative relationships between the easy-to-measure petiole thickness and biomass. The petiole thickness is therefore an interesting candidate for early selection criteria in poplar breeding programmes.

This study was performed on a large-scale operational SRC plantation as part of an ambitious multidisciplinary bio-energy project (POPFULL, 2015). Twelve different poplar genotypes were planted at the POPFULL plantation which enabled us to measure their responses in a common environment to quantify the degree of genotypic variation, in particular in leaf and petiole traits. Our objective was to identify leaf and petiole traits that could be used as early selection criteria in future breeding and selection programmes. We hypothesised that: (1) leaf and petiole traits are reliable indicators of biomass yield; and (2) leaf and petiole traits are determined by parentage. If these hypotheses were validated, it would allow us to construct a simple model to calculate difficult-to-measure leaf and petiole traits from easier ones based on their correlation.

2. Materials and methods

2.1. Site description

The POPFULL field site is located in Lochristi, province East-Flanders, Belgium (51°06′44″N, 3°51′02″E). The region has a temperate oceanic climate with a long-term average annual temperature and precipitation rate of 9.5 °C and 726 mm, respectively (Royal Meteorological Institute of Belgium). According to Belgian soil classification data, the area forms part of a sandy region with poor natural drainage. The 18.4 ha site was formerly used for agricultural purposes consisting of croplands (62%; with corn being the most recent cultivated crop) and extensively grazed pasture (38%). On 7–10 April 2010, an area of 14.5 ha (excluding the headlands) was planted with 12 selected poplar (*Populus*) and three selected willow (*Salix*) genotypes, representing different pure native species and genotypes of *Populus deltoides*, *P. maximowiczii*, *P. nigra*, *P. trichocarpa, Salix viminalis*, *S. dasyclados*, *S. alba* and *S. schwerinii.* The present study focuses on the 12 poplar genotypes only (Table 1). Half of the genotypes were sourced from and bred by the Institute for Nature and Forestry Research in Geraardsbergen (Belgium) and half were bred by the ''De Dorschkamp'' Research Institute for Forestry and Landscape Planning in Wageningen (The Netherlands; Table 1). Dormant and unrooted cuttings were planted in a double-row system with alternating distances of 0.75 m and 1.50 m between rows and an average 1.10 m between trees within the rows (i.e. 8000 plants ha^{-1}). After the first two-year rotation, the plantation was harvested on 2–3 February 2012 (Berhongaray et al., 2013). The second harvest took place after the second two-year rotation on 18–20 February, 2014 (Vanbeveren et al., 2015). Plantation management was extensive, without fertilisation or irrigation. Only a minor influence of former land-use on the biomass production was observed during the first growing season, and it disappeared during the second growing season (Broeckx et al., 2012). The absence of an influence of former land-use was explained by the sufficient nutrient conditions and optimal site conditions in terms of soil quality for both former cropland and pasture. Thus, former land-use was not accounted for in the present study. More details on site conditions, on planting material and on plantation layout have been previously reported (Broeckx et al., 2012).

Table 1
Breeding institution, place of origin, botanical and parental characteristics of the twelve poplar (*Populus*) genotypes studied. Adapted from Broeckx et al. (2012).

Genotype	Parentage	Section	Breeding Institution	Place of origin	Gender	Year of cross/commercialisation
Bakan	T × M	Tacamahaca	Institute for Nature and Forestry Research (Belgium)	(Washington USA × Oregon US) × Japan	Male	1975/2005
Skado	T × M	Tacamahaca	Institute for Nature and Forestry Research (Belgium)	(Washington USA × Oregon US) × Japan	Female	1975/2005
Muur	D × N	Aigeiros	Institute for Nature and Forestry Research (Belgium)	(Iowa USA × Illinois USA) × (Italy × Belgium)	Male	1978/1999
Oudenberg	D × N	Aigeiros	Institute for Nature and Forestry Research (Belgium)	(Iowa USA × Illinois USA) × (Italy × Belgium)	Female	1978/2000
Vesten	D × N	Aigeiros	Institute for Nature and Forestry Research (Belgium)	(Iowa USA × Illinois USA) × (Italy × Belgium)	Female	1978/2001
Ellert	D × N	Aigeiros	Research Institute for Forestry and Landscape Planning (The Netherlands)	Michigan USA × France	Male	1969/1989
Hees	D × N	Aigeiros	Research Institute for Forestry and Landscape Planning (The Netherlands)	Michigan USA × France	Female	1969/1990
Koster	D × N	Aigeiros	Research Institute for Forestry and Landscape Planning (The Netherlands)	Michigan USA × The Netherlands	Male	1966/1988
Robusta	D × N	Aigeiros	The nursery Simon-Louis Frères (France)	Eastern USA × Europe	Male	1885–1890/1895
Grimminge	D × (T × D)	Aigeiros × (Tacamahaca × Aigeiros)	Institute for Nature and Forestry Research (Belgium)	(Michigan USA × Connecticut USA) × (Washington USA × (Iowa USA × Missouri USA)	Male	1976/1999
Brandaris	N	Aigeiros	Research Institute for Forestry and Landscape Planning (The Netherlands)	The Netherlands × Italy	Male	1964/1976
Wolterson	N	Aigeiros	Research Institute for Forestry and Landscape Planning (The Netherlands)	The Netherlands	Female	1960/1976

D = *Populus deltoides*, M = *Populus maximowiczii*, N = *Populus nigra*, T = *Populus trichocarpa.*