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Evaluation of biomass production potential and heating value of hybrid poplar genotypes in a short-rotation culture in Italy

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ABSTRACT

Ensuring increased and sustainable biomass production is critical for European countries. Short-rotation coppice (SRC) plantations on agricultural lands have a great potential to increase biomass supply for biofuels, bioenergy, and bioproducts. In Italy, SRC is based on the use of fast growing species, high planting density, and short harvesting cycles. In this study, the performance of new genotypes to be used in SRC plantations for biomass production was evaluated after three biennial rotations. At the trial plantation in Mira (Northern Italy), six different poplar (*Populus*) genotypes, belonging to different interspecific hybrids were studied. This plantation provided the opportunity to study the relationships between survival, biomass production and other growth parameters over multiple rotations and for a wide genotypic range. Biomass production differed significantly among rotations starting from 16 Mg ha^{-1} $year^{-1}$ in the first, peaking at 20 Mg ha^{-1} $year^{-1}$ in the second, and decreasing to 17 Mg ha^{-1} $year^{-1}$ in the third rotation. At the end of each rotation, significant differences among genotypes were observed in number of shoots per stool and per ha, stem diameter, tree height, and biomass production. Mean survival rates became significantly different from the other rotations only in the third rotation during which survival rate ranged from 95% for (*P.* × *generosa*) × *P. nigra* 'Monviso' to 75% for (*P.* × *generosa*) × *P. nigra* 'AF6', but non-significant difference was observed among genotypes. Skewness and inequality of shoot size distributions were genotype-dependent and increased with rotations. Highest biomass production was found for genotypes *P.* × *canadensis* '83.148.041', 'Monviso' and (*P.* × *generosa*) × *P. trichocarpa* 'AF8' with mean annual dry mass production of 21.7, 19.5 and 19.3 Mg ha^{-1} $year^{-1}$, respectively. Genotype × rotation interactions were significant on shoot size, diameter and number, but not on survival and biomass production highlighting that genotypes behaved differently over rotations. Moisture and ash content, wood specific gravity, and higher heating value were determined at the end of the third biennial rotation, and significant differences among genotypes were found. This study is critical for investigating the behavior of novel poplar genotypes with potential for commercial biomass production over multiple coppice rotations.

1. Introduction

The European Union (EU) is in need of alternative energy sources to reduce the consumption of non-renewable fuels and rely mostly on renewable energy. With today's high energy prices and urgent need for substantive CO_2 emission reduction, the development of an alternative energy industry from forest biomass will help reduce energy prices and mitigate global climate change. Bioenergy will play a key role in the EU long term energy strategy for all applications and especially the transport sector, contributing up to 14% of the EU energy mix and up to 10% of energy demand for transportation in 2020 (Commission of the European Communities, 2006).

Tree plantations have been recognized by the United Nations Framework Convention on Climate Change in the Kyoto protocol as a means to mitigate greenhouse gas emissions and to monitor, preserve, and enhance terrestrial carbon stocks (Updegraff et al., 2004). Forest trees serve as feedstocks for the paper and

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pulp industry but also can be cultivated specifically to address the feedstock needs for the bioenergy or biofuels industry. These purpose-grown trees will be part of the bioenergy solution in Europe, especially in Italy, which is rich in forest genetic resources. Fast growing broadleaved tree species with high sprouting ability are used in short rotation coppice (SRC) plantations to produce woody biomass (Hansen, 1991; Deraedt and Ceulemans, 1998). SRC is an old concept in which cutting a tree at the base of its trunk mimics natural disturbance processes like flooding or fire, and results in the regeneration of new shoots from the stump and/or roots (Blake, 1983). It has been long known that coppicing is a cheap alternative for replanting and results in increased final biomass production (Sennerby-Forsse et al., 1992; Verwijst, 1996). SRC systems have several socio-economic as well as ecological benefits (Hauk et al., 2014). They are very attractive due to several factors: they can be grown on agricultural land (Ranney et al., 1987) as feedstock for energy and industry (Hansen, 1991), as a means to sequester carbon dioxide (Hall and House, 1994) and, as a means for phytoremediation (Zacchini et al., 2009; Tognetti et al., 2013). Furthermore, SRC systems will likely help to enhance biodiversity, nutrient capture and carbon circulation in the soil-plant-atmosphere system, especially on former agricultural land, and they protect the soil from water and wind erosion (Perttu, 1995; Isebrands and Karnosky, 2001; Immerzeel et al., 2014). Additionally, SRC systems of woody crops have the potential to at least partially counterbalance the ever increasing global demand from wood and wood products (Abbot and Lowore, 1999). In the context of the search for alternatives and sustainable energy sources in Sub-Saharan Africa, SRC has been shown to be a promising option to increase firewood supply on agricultural (Abbot and Lowore, 1999; Shackleton, 2001) and fallow lands (Avohou et al., 2011). SRC management has the objectives to obtain a maximum output (i.e. woody biomass) with a minimum input (i.e. fertilization, site preparation, etc.) (Ledin and Willebrand, 1996). Poplar is one of the most widely cultivated tree species and promising candidate for short rotation plantation due to its fast growth, easy asexual (or vegetative) propagation, and wide interspecific crossability (Dickmann and Stuart, 1983; Eckenwalder, 1996; Bradshaw et al., 2000). Yet, higher biomass production can still be achieved by optimizing plant genotype to site and cultural management (Hansen, 1991; Guo and Zhang, 2010; Paris et al., 2011; Sixto et al., 2013). When grown under short-rotation silvicultural practices, hybrid poplars have generally shown biomass production ranging between 10 and 15 Mg dry matter of wood per hectare per year (Mg ha^{-1} year^{-1}) (Vande Walle et al., 2007; Di Matteo et al., 2012). Seeking a better fibre-to-bark ratio, many farmers in southern Europe resort to the biennial or triennial system, where the plantation is harvested at 2–3-years interval. Cuttings are planted in single rows, with a spacing of about 3.0 m between the rows and 0.5–0.7 m along the rows. This results in a stool density of 6–7000 units ha^{-1} (Spinelli et al., 2009).

Six poplar (*Populus*) genotypes, of which four recently commercialized, were planted in an SRC culture for the production of biomass for bioenergy. These genotypes were previously studied by Paris et al. (2011), but the results reported have targeted a limited number of traits over only two rotations and lacked the analysis of the genotype × rotation (G × R) interactions. Maximizing poplar biomass production over coppice rotation cycles depends on understanding G × R interactions. Thus, a G × R interactions analysis will help to determine how different poplar genotypes behave differently over rotations. Here, we sought to investigate important traits such as mean shoot number per stool, shoot diameter, shoot height, and biomass production at stool level over three biennial rotations. Additionally, higher heating value of wood was determined on a clonal basis at the end of the third rotation. This study is then valuable for determining traits with high relevance for biomass production for maximum bioenergy yield over numerous rotation cycles in SRC. The objectives of the study were: (i) to analyze the dynamics of biomass production in a poplar SRC system after three biennial rotations; (ii) to study genotype × rotation (G × R) interactions and to define important determinants to select the best performing genotypes over multiple rotations; and (iii) to assess the biomass production potential and its higher heating value (HHV) for this type of eco-agricultural forest plantation for providing woody biomass as a feedstock for the bioenergy industry.

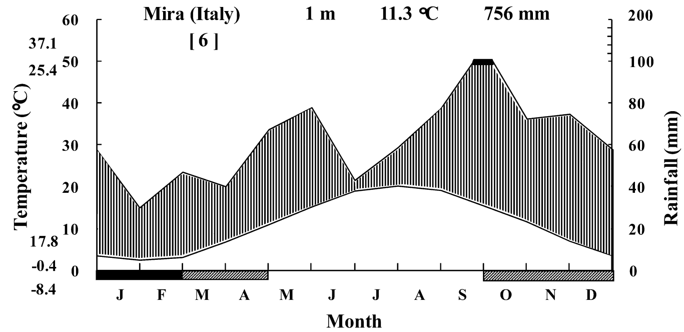

Fig. 1. Walter–Lieth climate diagram based upon monthly averages for temperature and precipitation for the Mira site, Italy, over the three biennial rotations. Vertical black shading where the precipitation curve supersedes the temperature curve indicates a moist period. The top black area indicates monthly precipitations that exceed 100 mm as reported in logarithmic scale. Bold numbers close to the left axis correspond to (from top to bottom): (1) annual absolute maximum temperature, (2) average daily maximum temperature of the warmest month, (3) annual thermal excursion, (4) average daily minimum temperature of the coldest month, (5) annual absolute minimum temperature. Dashed bars below the horizontal line indicate a possibility of frost but average daily minimum temperature above 0 °C. A black bar below the horizontal line indicates average daily minimum temperature below 0 °C. [6] is the number of years; 1 m is the height a.s.l.; 11.3 °C is the annual average temperature; 756 mm is the annual average precipitation.

2. Material and methods

2.1. Site description and climatic conditions

The study site was located at Mira (VE) in north eastern Italy (45°22′53″N, 12°09′44″E, 1 m a.s.l.) in close proximity to the coast of the Adriatic Sea with a permanent near-surface water table. Experiments were conducted on a 0.8 ha flat agricultural site with a highly productive soil, which was formerly used for maize cultivation. The soil is sandy-loam, well-drained, and has a near-neutral pH with good physical and chemical properties (Paris et al., 2011).

Climatic features of the site were characterized by 756 mm annual average rainfall, 11.3 °C annual mean temperature and the absence of a summer drought period during the three biennial rotations (Fig. 1). Rainfall was regularly distributed throughout the year. Precipitation reached a minimum monthly mean during June (43 mm) and a peak during September (107 mm). Daily temperatures were mild in the winter months except for January and February, when a monthly mean of the minimum daily temperatures (T_{min}) was slightly below 0 °C. January was the coldest month (T_{min} = −0.4 °C), whilst July was the warmest, with a monthly mean of the maximum daily temperatures (T_{max}) of 25.4 °C. Extreme maximum and minimum temperatures occurred in August 2003 (37.1 °C) and in January 2006 (−8.4 °C).

2.2. Experimental design and plant material

The plantation was realized in 2003 and followed a randomized block design with each block replicated four times. The different genotypes, organized as experimental units of 5 × 14 trees of the same genotype, were randomly distributed within each block