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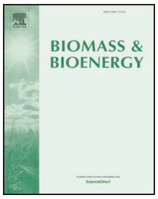

Research paper

Genotypic differences in biomass production during three rotations of short-rotation coppice

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ABSTRACT

Short-rotation coppice (SRC) will play a major role in meeting the predicted demands for woody biomass, but data on genotype-specific biomass productivity and growth parameters are still largely missing. These data are, however, important for assessing the expected revenue, but also for predicting the choice of harvester. Therefore, an operational SRC with 12 *Populus* genotypes was yearly monitored over its first seven years (three rotations). Inventories of shoot diameters at 22 cm above the ground, of number of shoots per stump and stump mortality were converted to above-ground woody biomass (AGWB) with allometric relations. The dataset was based on 23,656 sampled stumps for determining the number of shoots per stump, while 36,792 shoots were measured to determine their diameter. An AGWB productivity of 3.43, 11.13, and 16.49 Mg ha^{-1} y^{-1} was reached in the first (two-year), second (two-year), and third (three-year) rotation, respectively. Within each rotation, the AGWB productivity increased yearly, while rotations (after the establishment rotation) reached comparable AGWB productivities over the same (two-year) duration. Significant genotypic and spatial variation in shoot diameters, number of shoots per stump and AGWB were found within and among the seven sampled years. Additionally, repeated sampling at breast height in the second and third year of the third rotation was comparable to sampling at 22 cm above the soil. Lastly, a shoot diameter measurement accuracy of 0.01 mm proved exagerrated for biomass assessments and could be limited to an accuracy of 1 mm.

1. Introduction

According to the Paris Agreement, global warming should be limited to well below 2 °C if we want to cope with climate change effects, and therefore, the atmospheric CO_2 concentration has to be lowered [1]. Apart from an increased fuel conversion efficiency, fossil fuels will have to be replaced with renewable energy sources [2], with a major contribution from second generation bio-energy (i.e. energy from lignocellulosic, non-edible biomass) [3,4]. This biomass can partly be sourced from forest residues or organic waste cycles, but will have to be complemented by dedicated short-rotation coppices (SRCs) to meet the predicted demand for bio-based materials [5,6].

Despite the vast amount of research conducted on SRC, many uncertainties still remain, keeping farmers from establishing SRC: farmers' lack of experience with trees, the unavailability of harvesting machinery, price volatility, and missing information on (long-term) biomass productivity [7,8]. Information on the evolution of realised biomass productivity is important for predicting the expected revenue, but also to validate remotely sensed data on biomass productivity [9]. Because field inventories are tedious and time consuming, limited information is, however, available over the long term [10].

Productivity of an SRC is usually predicted from field inventories of the number of shoots per stump, shoot diameters and stump mortality, which are then extrapolated to woody biomass with allometric equations. This information is equally important for anticipating the choice of harvesting machinery, as each machine is not only constrained by weather and field conditions, but also by several feedstock characteristics (e.g. shoot height, maximum harvestable shoot diameter and shoot density) [11,12]. In order to allow SRC managers to correctly assess the planning of the harvests and expected revenues, more genotype-specific data on the evolution of biomass productivity and shoot dynamics of SRC are needed [13].

Different species and genotypes display very different growth habits, biomass productivities and responses to a regular coppicing regime [14,15]. An average productivity of 8.5 Mg ha^{-1} y^{-1}, ranging from roughly 2–20 Mg ha^{-1} y^{-1} is reported for poplar SRC in temperate regions [16–20]. Because species-specific information is limited available for SRC and because genetically diverse SRCs are generally more resilient to pests, diseases and other hazards, combining multiple genotypes at an SRC is advisable. The trade-off that arises with genetic

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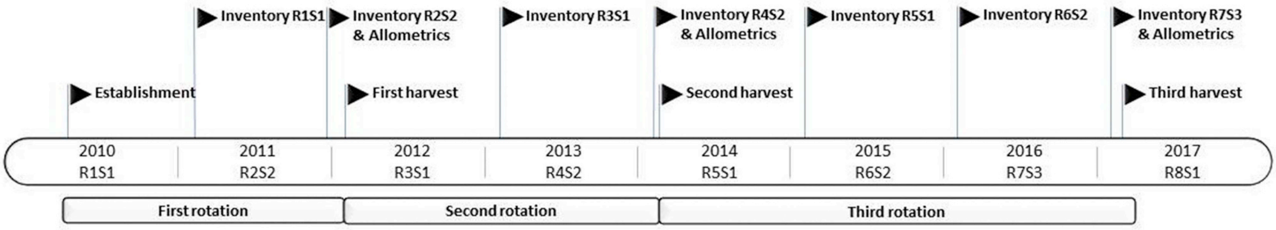

Fig. 1. Timeline of the POPFULL short-rotation coppice plantation. R#S# stands for root and shoot age (in years), respectively.

diversity is the increased feedstock heterogeneity due to an increasing variablity in shoot dynamics [21–23]. This heterogeneity makes it harder to match a suitable harvesting machine to the large feedstock variability [24,25]. This is important to keep in mind, as harvesting is the largest cost over the lifetime of an SRC (if no fertilization is applied) [26].

The main objective of this research was to compare the biomass productivity and related growth parameters (stump mortality, shoot diameter and the number of shoots per stump) among 12 poplar genotypes grown as SRC over the first three rotations (2 + 2 + 3 years). Information on stump and shoot dynamics intensively measured during seven years is scarce, emphasizing the importance of making these data available. As a secondary objective, the experimental sampling design (including non-repetitively measured stumps and shoots or not) was evaluated. Furthermore, two ways of sampling optimisation were investigated: measuring at breast height instead of at 22 cm above-ground level, and limiting the measurement accuracy from 0.01 mm to 1 mm.

2. Materials and methods

2.1. Site description, plantation management and plant materials

All measurements were done at an existing operational SRC site in Lochristi, Belgium (51°06′44″ N, 3°51′02″ E [27]). The site has a flat topography at an altitude of 6 m a.s.l., a sandy soil with poor drainage, which was formerly fertilised [28]. It is characterised by a temperate oceanic climate with 953 mm (in 2010), 660 mm (in 2011), 1046 mm (in 2012), 851 mm (in 2013), 852 mm (in 2014), 805 mm (in 2015), and 873 mm (in 2016) annual precipitation [28]. The former land use consisted of fertilised pastures and cropland (mainly maize). The SRC was established within the framework of the POPFULL research project (http://uahost.uantwerpen.be/popfull/) in April 2010 (Fig. 1) by planting 14.5 ha on a total land surface of 18.4 ha (Fig. 2). The main planting material consisted of 12 commercially available poplar (*Populus*) genotypes, both pure species and hybrids of *P. deltoides*, *P. maximowiczii*, *P. nigra* and *P. trichocarpa* (Table 1). A small part of the planting material was made up of willow (*Salix*) genotypes, but these were not taken into account in this study. Unrooted cuttings of 0.25 m were planted as mono-genotypic blocks in a double-row design at a density of 8000 ha^{-1} (alternating 0.75 m and 1.50 m between the rows, and 1.10 m within the row). Further details about the establishment and the lay-out of the plantation and about the planted genotypes were previously published [15,28].

The SRC was extensively managed: during the entire duration of this study neither fertilisation nor irrigation was applied; manual, mechanical and chemical weeding were performed at the onset of every growing season following establishment or harvesting. Due to mortality at the end of the first growing season after establishment (i.e. R1S1: 1-year old roots, 1-year old shoots), the largest gaps were re-planted with one-year old unrooted cuttings. The SRC was harvested for the first time in February 2012 after a two-year rotation [29], a second time in February 2014 after another two-year rotation [30], and a third time in February 2017 after a three-year rotation [31] (Fig. 1). After the second harvest part of the SRC was converted to cropland (black boxed areas in Fig. 2), thereby reducing the total area to 11.0 ha and the planted area (only poplar) to 8.3 ha.

2.2. Diameter inventories and data analysis

Inventories of shoot diameters were made to monitor the yearly growth performance (Fig. 1). Measurements were always done in winter (between late December and early February), i.e. the dormant season of the poplar trees, after all leaves had fallen. Each year diameter measurements were made within one and the same week. Per mono-genotypic block the same row was inventoried every year by counting the number of shoots per stump (SS) at 22 cm above-ground level [23]. The only exception was the inventory after R5S1 when a random row was inventoried in each mono-genotypic block. From one fifth of those stumps, all shoot diameters (D) exceeding 5 mm were measured at 22 cm above-ground level with a digital calliper (Mitutoyo, CD-15DC, UK; 0.01 mm precision) as shown in Refs. [23,32]. Measurements were made on additional rows when the sample size for genotypes Brandaris (2 rows of mono-genotypic block 4), Ellert (2 rows of mono-genotypic block 3), Hees (2 rows of mono-genotypic block 12), Robusta (3 rows of mono-genotypic block 1) and Wolterson (3 rows of mono-genotypic block 2) became too small after the reduction in planted area early 2014. The mortality was calculated as the ratio of dead over alive stumps.

Allometric relationships between D and above-ground woody biomass (AGWB; in Mg dry matter) were established per genotype at the end of each rotation. Ten shoots per genotype were selected before each harvest, covering the widest possible diameter range (based on the diameter inventory of that year). These shoots were manually harvested at 15 cm above-ground level, their D and diameter at breast height (DBH, i.e. at 1.30 m) were measured and they were oven-dried at 70 °C until constant dry weight. Per rotation, a power function ($AGWB = a * D^b$) per genotype was fitted to all shoot diameters measured in the preceding rotation [as done in Refs. [15,33]. The AGWB per stump was calculated by summing the AGWB of all its shoots. Per year and per genotype the average AGWB per stump was calculated. Multiplying the average AGWB per stump with the surviving density provided the field stocking (in Mg ha^{-1}) for each year and for each genotype at the (potential) harvesting time each year. By multiplying each genotype's field stocking with the planted area of that genotype, the standing biomass (in Mg) was obtained.

With the above mentioned shoot diameter data of the first three rotations (i.e. seven years) two databases were constructed:

A. Database A was the largest database and it contained all data on SS, D and AGWB that were yearly gathered. The advantage of this database is the magnitude of the sample size: the SS of 36,316 stumps was counted and the D of 59,594 shoots was measured. The disadvantages are: (i) data were statistically not continuous because a random row per mono-genotypic block was measured after R5S1, (ii) rows in mono-genotypic blocks that were converted after the second rotation were only available for the first two rotations, and (iii) additionally measured rows in the third rotation were not measured in the first two rotations.