Biomass and Bioenergy 111 (2018) 46–51

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: www.elsevier.com/locate/biombioe

Research paper

Productivity and biomass characteristics of selected poplar (*Populus* spp.) cultivars under the climatic conditions of northern Poland

Marzena Niemczyk[a,*], Adam Kaliszewski[b], Marcin Jewiarz[c], Marek Wróbel[c], Krzysztof Mudryk[c]

[a] Department of Silviculture and Forest Tree Genetics, Forest Research Institute, Sękocin Stary, Braci Leśnej Street No 3, Poland
[b] Department of Forest Resources Management, Forest Research Institute, Sękocin Stary, Braci Leśnej Street No 3, Poland
[c] Laboratory of Technology for Production and Quality Assessment of Biofuels, Faculty of Production and Power Engineering, University of Agriculture in Krakow, Poland

ARTICLE INFO

Keywords:
NE-42'
'Fritzi Pauley'
Short-rotation coppice
Biomass productivity
Poplar cultivar
Wood properties

ABSTRACT

This study aimed to determine the productivity and energy values of 10 poplar cultivars for use as potential fuel sources in Poland. The study was conducted over a seven-year cycle in northern Poland. The cultivars belonged to clones traditionally used for timber production, as well as new clones specific to short-rotation coppice (SRC) practices. Biomass production and biomass properties were measured, including elemental composition, the gross and net calorific values (heating value) of wood, and envelope density. For each cultivar, the synthetic fuel value index (FVI) was calculated. Biomass dry matter (DM) production differed noticeably between cultivars, and it was the highest for traditional cultivars ('NE-42' and 'Fritzi Pauley', amounting to 8 $Mg\ ha^{-1}\ yr^{-1}$), and the lowest for new cultivars (DM was one-third that of the cultivars with the highest production). Two traditional cultivars ('NE-42' and 'Fritzi Pauley') had the highest FVI, representing potential biofuels, whereas two new SRC cultivars ('AF-8' and 'AF-2') had the lowest indexes. Overall, poplar plantations with short rotations could be considered as a potential additional source of renewable energy in Poland. However, the key factor is selection of appropriate genotypes for the specific climatic conditions. In conclusion, our study demonstrated the importance of testing cultivars under local climatic conditions before using them at a commercial scale.

1. Introduction

Short rotation plantations, including poplar plantations, are considered a very promising alternative towards realising a more sustainable energy supply, as they provide a substitute for fossil fuels [1–7], and hence contribute to conserving fossil fuels, reducing CO_2, wastes and hazardous emissions (CH_4, NO_X, SO_X, toxic trace elements), and capturing and storing toxic components in the ash [8].

The natural range of poplar (*Populus* spp.) extends over very wide ecological conditions across the northern hemisphere [9]. The genus *Populus* is divided into six sections and consists of a large number of subspecies and transient forms due to intra- and inter-specific hybridisation [10]. As a consequence of the huge genetic diversity of the natural population, the genetic resources of poplars are managed at multiple levels to breed commercial cultivars for, among others, wood-based commodities and energy feedstock [9].

The productivity of biomass for various poplar cultivars has been evaluated by many studies in North America and Europe. However, it still remains poorly documented with respect to the climatic conditions of Poland [11,12]. According to Zajączkowski [13], the yield of poplars in Poland is potentially higher than that of other fast-growing species under short-rotation coppice (SRC) regimes. In Poland, such plantations are managed on cycles usually lasting 1–10 years [13].

To date, several poplar hybrids were selected in Poland (in the years 1956–1982, 1996) to test their productivity and resistance to abiotic and biotic stress in long rotations (over 40 years) [13]. These hybrids mainly belonged to one of two sections, either the *Aigeiros* section (black poplars: *P.* × *canadensis* 'Blac du Poitou', *P.* × *canadensis* 'Flachslanden') or the *Tacamahaca* section (balsam poplars: *P. maximowiczii* × *P. trichocarpa* 'NE-42', *P. trichocarpa* 'Fritzi Pauley', *P. maximowiczii* × *P. trichocarpa* 'Androscoggin', *P. maximowiczii* × *P. berolinensis* 'Oxford', *P. maximowiczii* × *P. berolinensis* 'Geneva') [13,14]. However, these hybrids have never been tested in SRC under the climatic conditions of Poland. It should also be pointed out that currently there is no breeding programme for poplars in Poland. Consequently, the nation is dependent on imported cultivars that are often bred in, and adapted to, different climatic conditions. Over time, several new clones of hybrid poplars specific to SRC have been selected in Europe by both private companies and public research institutions. Many studies have already shown that the growth and biomass

* Corresponding author.
E-mail address: M.Niemczyk@ibles.waw.pl (M. Niemczyk).

https://doi.org/10.1016/j.biombioe.2018.02.002
Received 6 November 2017; Received in revised form 30 January 2018; Accepted 2 February 2018
Available online 08 February 2018

production in short-rotation poplar field trials vary greatly, depending on the cultivars, environmental conditions, and cultural regimes [15–21]. Annual biomass production obtained by different interspecific hybrids from Section *Aigeiros* and/or *Tacamahaca,* and using intensive fertilisation and irrigation of around 20 Mg ha^{-1} yr^{-1} was reported from trials in the Pacific Northwest, USA [22–24], and from coppice cultures in southern Europe [25–27]. The yield obtained in Scandinavia is, however, lower at approximately 3–9 Mg ha^{-1} yr^{-1}, depending on, among other factors, cultivars and geographical location [28]. Therefore, it is important to select cultivars with confirmed productivity [29].

The use of wood for energy production, especially with respect to fast growing species, should also be assessed based on the elemental composition and the gross and net calorific values (heating value) of woody biomass.

Compositional information is obtained from proximate and ultimate analyses [30]. Proximate analysis is important for developing the thermochemical conversion processes of biomass. It provides information about the proportion of various products obtained by wood combustion under controlled conditions. These products include water, volatile matter, fixed carbon, and ash mass fractions. In comparison, ultimate analysis provides information on the major elemental composition of biomass on a gravimetric basis, such as carbon, hydrogen, sulphur, water, and ash mass fractions [30].

The heating value is one of the most important quality characteristics of biomass for energy production [26,31]. This value depends on the type and quantity of flammable components in fuel, along with the moisture mass fraction [32], which has a large effect on the quantity of all parameters. Other parameters must also be estimated when considering the logistics and preparation of wood for further processing, including bulk and envelope (particle) density (the ratio of the mass of a substance to the envelope volume, which is the volume of particles, including internal pores). These parameters are important determinants of transport costs, and the size of fuel storage and handling equipment [30].

Both the productivity and the biomass properties of poplar cultivars under specific climatic conditions are important in selecting cultivars for cultivation at a commercial scale. Our study aimed to: (1) determine the productivity of various poplar cultivars belonging to clones traditionally used for timber production, as well as new clones specific to SRC, under the climatic conditions of northern Poland and (2) characterise the biomass of these clones in terms of elemental composition and energy value, to identify clones of potential use for commercial biofuel production.

2. Material and methods

2.1. Experimental location, soil and climatic condition

The experimental area of the study was established in northern Poland (N 54° 4′ 26″, E 20° 30′ 4″) in April 2010, on post-agricultural land. This location was selected because of the potentially high supply of post-agricultural lands suitable for afforestation and establishing plantations in that region [33]. The main soil type was Cambisol. Average annual temperature and annual precipitation in each year from 2010 to 2016, as well as long-term data (since 1971), are shown in Table 1.

One-year-old poplar saplings were planted with a spacing of 2.5 × 3 m, resulting in a planting density of 1333 ha^{-1}.

2.2. Planting material

Planting material was produced from the woody cuttings of 10 cultivars (Table 2). The 'NE-42' and 'Fritzi Pauley' cultivars are old hybrids that were introduced to Poland in 1938 and 1959, respectively [34]. The utility of both cultivars for long rotation forestry (for timber production) was previously tested and confirmed in Poland [13]. Four *P.* × *canadensis* cultivars ('Degrosso', 'Albelo', 'Polargo', and 'Koster') produced by Luis Poloni (France) were recently released and show broad adaptability in tests throughout Europe [9]. The Alasia Franco (AF) cultivars are new SRC clones and have been frequently used in commercial energy plantations in Poland in recent years.

2.3. Study design

The study layout was a randomised complete block design (RCB) with three block replicates. The experimental area was divided into three blocks, with each block being further divided into 10 units equal to the number of cultivars. Within each block, the cultivars were assigned at random, and each cultivar was allocated in one unit. As a result, every cultivar was assigned once to each block. One hundred saplings of a given poplar cultivar were planted within each unit. Bordering rows were planted around the experimental area. The area was fenced to prevent browsing by wild animals. During the first two years, the plantation was weeded mechanically once per year (in June). In our study, irrigation and fertilisation were not applied.

2.4. Measurement of tree characteristics

After seven years of growth, the diameter at breast height (DBH; measured at a height of 1.3 m) of all trees was measured, and the basal area for each tree was calculated based on its DBH. Height was recorded for 20 trees in each unit. Tree volume was calculated based on the relationship between diameter, height, and form factor, as:

$$v = \frac{\pi}{40000} d^2 * h * f_{1,3}$$

where V is the individual tree stem volume, h is tree height, d is breast height diameter, and f is form factor. The form factor was derived by Niemczyk and Bruchwald [35] from the following empirical equation:

$$f_{1,3} = 0{,}5608 - 0{,}0127 * d + 0{,}0360 * \frac{h}{d}$$

According to Christersson [18], total above ground tree volume can be estimated by applying an expansion factor of 1.25 for poplars to the estimated stem volumes. Thus, the total above ground volume was calculated as 1.25 × V, taking into account survival rates. The survival rate was assessed based on the number of living trees. In early spring (between 27 February and 3 March 2017), 20% of the total number of trees (from each cultivar) were harvested. This period is when poplars are typically harvested in Poland. The fresh-weight biomass of each tree was recorded (to the nearest 1 g) in the field, immediately after a tree was cut. The basal area of all trees was used to identify an 'average tree' for each cultivar in a given block (replicate). The 'average trees' were used to evaluate moisture mass fraction, chemical composition, particle density, and the heating value for all cultivars. From each 'average tree', 40 cm-long samples were taken at the middle of every 2 m section, beginning from the stem base to the tree top. Samples were weighed in the field. The total fresh dendromass of the samples ranged from 6284 to 7004 g, depending on the thickness and height of the trees, which represented about 10% of the total fresh dendromass of each tree. All samples were numbered and transferred in paper bags to the laboratory immediately after collecting and weighing. In the laboratory, samples were dried at 105 °C until their weights stabilised. The moisture mass fraction, M_{ar}, was determined based on the difference in sample weight before (fresh biomass) and after drying (dry mass), according to the ISO 18 134–1:2015 procedure (for each tree separately). For this purpose, an AS 160.R2 analytical balance with readability 0.1 mg, produced by Radwag, Radom, Poland, was used. Total DM yields for cultivars per unit area were determined from the weight of harvested fresh biomass obtained from a given replicate, reduced by the appropriate value for moisture mass fraction, and calculated for a given unit area per year, taking plant survival rate into account.