Biomass and Bioenergy 119 (2018) 109–120

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

Short rotation coppices, grasses and other herbaceous crops: Productivity and yield energy value versus 26 genotypes

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ARTICLE INFO

Keywords:
Salix
Populus
Miscanthus
Helianthus
Sida
Silphium

ABSTRACT

The diversity of perennial plants requires the proper selection of species and cultivars with high resistance to weather and habitat conditions and high productivity and yield energy value. Therefore, this study analysed the resistance to environmental conditions, survival rate and morphological features, yield and energy value of the yield of 26 genotypes of perennial plants in three annual harvest cycles. The study was carried out in north-eastern Poland and included 15 genotypes of short rotation woody crops, six genotypes of herbaceous plants and five genotypes of grasses.

Short rotation woody crops where the most resistant to environmental conditions, whereas grasses and some herbaceous genotypes were the most prone to lodging. The three willow varieties (Ekotur, Żubr and Start) gave the highest average yield (over 15 Mg ha^{-1} y^{-1} d.m.) and they yielded over 20 Mg ha^{-1} y^{-1} d.m. in 2013, which in terms of energy was equivalent to 350 GJ ha^{-1} y^{-1}. Poplars gave more than three times and black locust up to five times lower yield compared to the highest-yielding willows. The highest yield among herbaceous plants was obtained from *Helianthus salicifolius*, and among grasses – from *Miscanthus sacchariflorus* (on average 9 Mg ha^{-1} y^{-1} d.m.). The yield energy value of these genotypes was approx. twice lower compared to the best willow varieties. It was found that of the 26 genotypes of perennial plants, new willow varieties proved the most valuable in terms of yield and energy in the initial three years under the environmental conditions of north-eastern Poland.

1. Introduction

The application of biomass for energy generation and in industry is important and brings many benefits regarding: (i) increasing energy independence, (ii) environmental protection, (iii) economy, (iv) society [1–3]. It is noteworthy that there are an estimated 8 100 000 direct and indirect workplaces in the renewable energy sector worldwide, including ca. 2 900 000 jobs in bioenergy (biomass, biofuels, biogas) [4]. In the EU–28, the bioenergy generating sector is also a leading employer in the renewable field (in 2014, ca. 500 000) [5]. This large number of jobs in the bioenergy sector compared to other RES can be easily explained by the fact that, being an energy feedstock, biomass requires the involvement of many “market actors” to organise the entire logistics chain from production and acquisition of biomass, through its storage, warehousing, transport, preparation for technological processes, conversion and final use.

It must be stressed, however, that biomass is highly diverse, depending on the species, weather conditions and its origin. Solid biomass is usually derived from forests, the wood processing industry, from maintenance work on roads and urban vegetation, as well as from sorted organic waste. Agriculture is also an important source of biomass, including agricultural residues and plantations of perennial plants [6–8]. Perennial energy crops and industrial crops include three groups of plants: (i) fast growing bush and trees, which provide woody biomass, such as willow, poplar, black locust; (ii) perennial plants which yield semi-woody biomass, such as Virginia mallow, willowleaf sunflower and cup plant; (iii) grasses which yield biomass as straw, such as giant miscanthus, prairie cordgrass and giant cane [9–11]. The diversity of perennial plants requires proper selection of species and cultivars with high resistance to weather and habitat conditions and high productivity and energy value of the yield, which will affect the profitability of their production. To date, although many studies have been carried out on the productivity and energy value of a wide variety of perennial species, those studies were conducted in diverse regions of the world (under varied habitat and climatic conditions) and focused mainly on selected plants. On the other hand, there have been few

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https://doi.org/10.1016/j.biombioe.2018.09.014
Received 27 March 2018; Received in revised form 3 September 2018; Accepted 19 September 2018
0961-9534/

studies that directly compared (under the same soil and climatic conditions) the productivity of varied groups of perennial crops. It should be stressed that the biomass yield is one of the most important parameters in evaluating the productivity of a wide variety of crops. However, this indicator is strictly determined by environmental conditions and this is why direct comparison analyses are required to identify the most desired crops under given conditions [9]. Multi-species comparative experiments and their monitoring under given environmental and soil conditions are very useful to be able to obtain reliable characteristics of yielding potential and energy efficiency of the production of a wide variety of crops [11]. Developing a perennial crop ranking through direct comparison of short rotation woody crops, herbaceous plants and grasses is crucial for the identification and promotion of a cultivation system which can provide the highest yields and energy efficiency under given environmental conditions.

Therefore, it should be pointed out that the novel character of the current study consists in the direct comparison (under the same soil and climatic conditions) of many varied perennial species belonging to three groups (short rotation woody crops, herbaceous plants and grasses) cultivated under one experiment, in subsequent one-year harvest cycles. Therefore, the aims of this study included an assessment of: (i) resistance to environmental conditions, (ii) survival rate and morphological features, (iii) yield and (iv) energy value of the yield of 26 genotypes of perennial plants harvested in three successive annual harvest cycles.

2. Materials and methods

2.1. Location and factors of the field experiment

The study was conducted as a multi-year field experiment located at the Didactic and Research Station in Bałdy (53°35′41 N, 20°36′17 E) owned by the University of Warmia and Mazury in Olsztyn. Bałdy is situated in the Olsztyn Lakeland, in the western part of the Mazurian Lakeland, approx. 25 km south of Olsztyn, which is the major city in the north-eastern Poland. A field experiment was set up in spring 2011 on proper brown gley soil, formed from sandy loam-based light loam. The soil contained 3.3% organic matter and the pH in KCl was 6.7. The content of phosphorus, potassium and magnesium was: 87.1; 84.7 and 62.0 mg kg^{-1} of soil, respectively. The water table was below the level of 100 cm. Detailed data on soil texture and physico-chemical parameters are presented in Table 1. The first year after the experiment was set up (2011) was regarded as the initial year, in which the plants took root; therefore, no data from this growing period is provided in this paper. The exact experiment presented in this paper was carried out in 2012–2015.

The constant and grouping factor were twenty-six species/genotypes of perennial plants, which yielded biomass classified as woody (15 genotypes of short rotation woody crops), semi-woody (6 genotypes of herbaceous plants) and straw biomass (5 genotypes of grasses). For uniformity of nomenclature of species, cultivars, clones, etc., the term "genotype" is used throughout the paper. Genotypes that yielded woody biomass included: *Populus balsamifera* L., clone UWM 2; *P. balsamifera* L., clone UWM 3; *P. nigra* × *P. maximowiczii* Henry cv. Max-5; *Robinia pseudoacacia* L.; *Salix viminalis* L., variety Start; *S. viminalis* L., variety Tur; *S. viminalis* L., variety Turbo; *S. viminalis* L., variety Ekotur; *S. viminalis* L., variety Żubr; *S. viminalis* L., clone UWM 195C; *S. viminalis* L., clone UWM 263C; *S. viminalis* L., clone UWM 337C; *S. dasyclados* Willd, clone UWM 155; *S. pentandra* L., clone UWM 035; *S. alba* L., clone UWM 095. The species which yield semi-wood biomass include: *Helianthus salicifolius* A.Dietr; *Sida hermaphrodita* Rusby L.; *Silphium perfoliatum* L.; *Reynoutria sachalinensis* Nakai; *R. japonica* Houtt.; *Helianthus tuberosus* L. Genotypes yielding grass biomass included: *Miscanthus* × *giganteus* J.M. Greef & M. Deuter; *M. sacchariflorus* ((Maxim.) Hack.); *M. sinensis* ((Thunb.) Andersson); *Spartina pectinata* Bosc ex Link and *Arundo donax* L.

The following three successive years of the experiment were the factor of repeated measures: 2012; 2013; 2014. The harvest was carried out and the biomass yield was determined in early spring next year. This means that the yield harvested in March 2013, 2014 and 2015 was the yield obtained for the growing season of: 2012, 2013 and 2014, respectively.

The field experiment was established in a random block system, in three replications, on 78 plots, where genotypes of the particular crops were nested in blocks. The area of one plot was 20 m^2 (width 4 m, length 5 m). The whole field experiment with access roads occupied the area of 0.26 ha. There were four rows of plants in each plot.

Planting material for the majority of genotypes originated from own field experiments conducted in the Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn. Only *A. donax* was received from Greece under cooperation with the Centre for Renewable Energy Sources and Saving (CRES). The planting material of *Salix* spp., *Populus* spp., *R. pseudoacacia* constituted 20-cm ligneous cuttings obtained from one-year old shoots, the planting stock of *H. tuberosus* were tubers, while for the other genotypes underground rhizomes were used. *Salix* spp. *Populus* spp., *R. pseudoacacia*, *S. hermaphrodita*, *H. salicifolius* and *H. tuberosus* were planted at the density of 20 000 ha^{-1}. Planting materials were planted manually in strips, with twin rows in a strip spaced every 75 cm, then 90 cm of space separating the next two rows in a strip with 75 cm space between them, etc. Planting material in each row were spaced every 60 cm. *R. sachalinensis*, *R. japonica*, *S. perfoliatum* and all the grass genotypes were planted manually at a density of 10 000 ha^{-1}. The inter-row space and the distance between plants in a row was 100 cm.

Table 1
Soil texture and physico-chemical parameters.

Parameter	Unit	Horizon (cm)		
		A (0–32)	B (32–64)	C (64–150)
Soil texture		light loam	light loam	sandy loam
Clay < 0.002 mm	%	10	22	6
Silt 0.002–0.05 mm	%	29	17	20
Sand 0.05–2.0 mm	%	61	61	74
Specific density		2.67	2.67	2.72
pH (KCl)	–	6.7	6.1	7.6
Organic matter	%	3.31		
C: N	–	10.58		
P	mg kg^{-1}	87.1	8.4	4.4
K	mg kg^{-1}	84.7	59.8	40.7
Mg	mg kg^{-1}	62.0	59.0	65.0

2.2. Preparation of the site and conducting the experiment

Triticale was sown as a forecrop for perennial plants. Roundup 360 SL at 5 dm^3 ha^{-1} was applied before the experiment was set up, in mid-September 2010, in order to destroy weeds. Winter ploughing at the depth of 30 cm was performed in mid-October 2010. The field was harrowed twice in early spring of the year of establishing the experiment (2011). Planting material of each genotype was planted manually.

Mechanical or manual weeding was carried out during the experiment, depending on the crops and weed growth. No pesticides or fungicides were applied in the experiment. In the successive years of the study (2012–2014), in spring before the growing season started, a one-off dose of identical mineral fertilisation was applied to all genotypes at the rate of: N 90 kg ha^{-1}, P_2O_5 30 kg ha^{-1}, K_2O 60 kg ha^{-1}. Nitrogen, phosphorus and potassium were applied as ammonium nitrate, superphosphate and potassium salt, respectively.