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Short rotation coppices, grasses and other herbaceous crops: Biomass properties versus 26 genotypes and harvest time

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ABSTRACT

Plant biomass is a highly diverse material whose properties depend on its origin, plant species and weather conditions. Since perennial plants biomass features are so diverse, their usability as feedstock for energy generation, for industry or for integrated biorefineries can vary. The literature provides only scarce data regarding a comparison, in the same soil and climate conditions, of the quality of biomass of various genotypes of perennial plants. Therefore, the aim of this study was to assess the thermophysical properties and elemental composition of 26 perennial plant genotypes (15 short rotation woody crops, 6 herbaceous plants and 5 grasses) obtained at three different dates (November, January, March) in three consecutive harvest cycles.

The harvest date of short rotation woody crops did not have a significant effect on the moisture content in the harvested biomass, which was on a high, constant level. However, harvesting biomass of semi-woody (herbaceous) and straw (grasses) crops at a later date had a significant, beneficial effect on a decrease in the moisture content and increase the lower heating value. Short rotation woody crops biomass contained less ash and more carbon and hydrogen compared to herbaceous and grasses. Furthermore, the content of sulphur and ash in the biomass of semi-woody and straw crops decreased as the harvest date became later.

1. Introduction

Plant biomass is a highly diverse material whose properties depend on its origin, plant species and weather conditions. It is mainly obtained from forests and the wood processing industry, as waste from roadside and urban green care procedures as well as from municipal services (sorted organic waste). Considerable amounts of biomass are obtained from agriculture; this includes annual plants (cereals, oil and root crops, legumes) and perennial plants (grasses, clovers, orchards), agricultural residues (Parajuli et al., 2015a) and plantations of perennial plants established to use their biomass as energy and industrial feedstock (Christian et al., 2008; Matyka and Kuś, 2016; Monti et al., 2015; Sabatti et al., 2014; Stolarski et al., 2013a). Such plantations of perennial crops include three groups of plants. (i) Fast growing bush and trees, which provide woody biomass (short rotation coppice), such as willow, poplar, black locust. (ii) Perennial plants which yield semi-woody biomass (herbaceous crops), such as Virginia mallow, willowleaf sunflower, cup plant. (iii) The third group includes grasses, which yield straw biomass, such as giant miscanthus, prairie cordgrass and giant cane (Ceotto et al., 2015, 2016; Stolarski et al., 2014, 2017).

Since genotypes of perennial plants are so diverse, their usability as feedstock for energy generation, for industry or for integrated biorefineries can vary. One of the studies which included a multi-criteria assessment of various substrates for biorefineries showed that willow biomass is more valuable compared to miscanthus or poplar (Parajuli et al., 2015a). It should be stressed that biomass of perennial plants can be important not only because of its significance as feedstock in production of solid, liquid and gaseous biofuels (Godin et al., 2013; Jankowski et al., 2016; Stolarski et al., 2015b) and in the generation of heat, electricity and cold (Scordia et al., 2016; Stolarski et al., 2013b), but also in the production of renewable bioproducts, including biochemicals (García et al., 2014; Klímek et al., 2016; Krzyżaniak et al., 2014; Parajuli et al., 2015a,b). However, in order to determine the usability of various types of biomass of perennial crops for thermochemical, thermo-physical, biological, biochemical conversion or as feedstock in integrated biorefineries, one has to first determine its properties.

The literature reports published so far have usually presented information on the quality of biomass of various species grown and acquired in various regions or countries around the world (in various site

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and weather conditions). They concern the quality of biomass of a selected species, which also emphasize its great diversity, depending on the factors under analysis. For example, *Miscanthus* grown with no nitrogen fertilization was shown to have better fuel quality than with other treatments, resulting in a fuel with lower N, ash content, and a lower fouling properties and higher C concentrations (Baxter et al., 2014). On the other hand, a study of poplar showed its biomass could be considered a suitable solid biofuel due to its appropriate ash melting behaviour and its low content of nitrogen, sulphur and chlorine. However, the effect of additional fertilization on the poplar quality was not found to be significant, although poplar quality varied as a function of root/stem age (Fernández et al., 2016). Furthermore, a significant effect of the genotype and the planting density on the poplar biomass properties has been observed in other studies (Monedero et al., 2016). Meanwhile, studies in which the quality of biomass of various perennial plants was compared used the results of experiments conducted at various geographic locations. Moreover, the analysis was not conducted on fresh biomass but rather on air-dry or completely dry biomass (Howaniec and Smoliński, 2011), or the information was gathered from various literature sources in review articles (Ge et al., 2016).

Therefore, it should be emphasized that this is a novel study as it directly compares (in the same soil and weather conditions) the quality of biomass (multiple parameters) of many perennial species grown at various periods at the same site and within one experiment. Therefore, the aim of this study was to assess ten parameters, including: (i) thermophysical properties, (ii) elemental composition of 26 perennial plants genotypes obtained at three different dates in three consecutive harvest cycles.

2. Materials and methods

2.1. Location and experiment factors

The study was based on a multi-year field experiment located at the Teaching and Research Station in Bałdy (53°35′41N, 20°36′17E) owned by the University of Warmia and Mazury in Olsztyn. The experiment was set up on proper brown gley soil, formed from sandy loam-based light loam.

The study presented in this paper was carried out in 2012–2015. An analysis was performed on 26 species/genotypes of perennial plants, which yielded biomass classified as woody (15 genotypes of short rotation coppice), semi-woody (6 genotypes of perennial plants) and straw biomass (5 genotypes of grasses). For uniformity of the nomenclature of species, varieties, 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.); *Miscanthus sinensis* ((Thunb.) Andersson); *Spartina pectinata* Bosc ex Link; and *Arundo donax* L.

Salix spp. *Populus* spp., *R. pseudoacacia*, *S. hermaphrodita*, *H. salicifolius* and *H. tuberosus* were planted at the density of 20 000 ha^{-1}. *R. sachalinensis*, *R. japonica*, *S. perfoliatum* and all the grass genotypes were planted at the density of 10 000 ha^{-1}. The field experiment was set up in the random block design in three replicates, on 78 plots altogether. Each plot had an area of 20 m^2.

Properties of the biomasses of these 26 genotypes were evaluated at three time points of sample taking, further in the paper regarded as crop harvests. Biomass was harvested on the last days of: (I) November in 2012, 2013, 2014, immediately after the end of the growing season in autumn; (II) January in 2013, 2014, 2015, in winter; (III) March in 2013, 2014, 2015, in early spring, just before a new growing season started.

2.2. Collecting and preparing biomass samples and laboratory analyses

Samples of biomass were collected three times in consecutive years of the study. Representative stems (ca. 0.5 kg) were taken manually with garden shears, collected into plastic bags and transported to the energy crop assessment laboratory. Subsequently, on the same day, stems of each genotype were cut up manually with garden shears, the chips were mixed and biomass moisture content was determined.

The moisture content in biomass was determined by the drying and weighing method as per EN ISO 18134-1:2015 with an FD BINDER laboratory dryer. To this end, biomass was dried at 105 °C until the sample weight was constant. After the moisture content was determined, dry biomass samples were ground in an analytic mill with a 1 mm mesh sieve (SM 200 Retsch cutting mill). After being ground, biomass samples were kept in a dryer at 105 °C and their thermophysical properties and elemental compositions were subsequently determined. The higher heating value (HHV) of biomass of each genotype was determined in an IKA C 2000 calorimeter by the dynamic method, as per ISO 1928:2009. The HHV and moisture content was used to calculate the lower heating value (LHV) of fresh biomass (Kopetz et al., 2007). The ash, volatile matter and fixed carbon content in biomass was determined in an automatic ELTRA TGA-THERMOSTEP analyser, as per ISO 18122:2015.

The study of the elemental composition of biomass included determination of the content of carbon (C), hydrogen (H) and sulphur (S) with an automatic ELTRA CHS 500 analyser (ISO 16948:2015 and 16994:2015). Moreover, nitrogen assay was conducted by Kjeldahl's method on a K-435 mineraliser and a B-324 BUCHI distilling device. All biomass analyses were conducted in triplicate in all the years and at all sampling time points.

2.3. Statistical analysis

A three-way analysis of variance was performed to examine the fixed effects of genotypes (factor A), harvest time (factor B), year (factor C) and their interactions. All statistical analyses were done with the STATISTICA software (StatSoft, Inc., 2014). The arithmetic mean and standard deviation were calculated for each of the analysed features. Homogeneous groups at the level of significance of $P < 0.05$ were identified with the Tukey significance test (HSD). Moreover, Pearson's r correlation coefficients between the features under study were determined.

3. Results and discussion

3.1. Thermophysical properties of biomass

Thermophysical properties (moisture content, ash content, HHV and LHV) were differentiated significantly by genotypes, biomass harvest time, years of study and the interactions between them (Table 1).

Nine homogeneous groups were identified for the average (from 3 harvest dates) moisture content of the genotypes under study. The significantly highest average moisture content was found in biomass of *A. donax* − 57.6% (Fig. 1). The same homogeneous group (g) also contained all the genotypes of poplar and willow *S. dasyclados* UWM 155. A second homogeneous group in regard to biomass moisture content (range 51.1–53.0%) included biomass of six genotypes of willow. Biomass of the other genotypes of *Salix* spp. was classified into the third homogeneous group (c); the lowest moisture content in this