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Thermochemical and physical evaluation of poplar genotypes as short rotation forestry crops for energy use

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ABSTRACT

Short rotation plantations of fast-growing species provide a promising way to produce heat and electricity from renewable sources. The thermo-chemical and physical properties of different genotypes of poplar in short rotation forestry crops grown at three locations with different climatic and edaphic characteristics as well as planting density, have been determined in order to characterize the most appropriate biomass in terms of energy potential. The planting density was 6666 or 13,333 trees/ha (depending on the location) in a rotation of three-four years and the analysis was carried out at the end of the first rotation. For all the genotypes, experimental tests to quantify the moisture content, particle size distribution, bulk density, heating value, ash content and composition as well as the volatile matter were performed. In addition, natural air drying of biomass (stem and branches) was studied in two locations with the aim of determining the humidity loss during raw storage. A significant effect of the genotype and the planting density on the biomass properties was observed. The results obtained indicate that 'Monviso' and 'Viriato' are the most suitable genotypes. No operational problems related to ash fouling and deposition in combustion devices are expected for any of the genotypes studied.

1. Introduction

In the current context of climate change and the need to develop a bio-based economy, it is important to promote the use of alternative and renewable energy sources such as woody biomass. Firewood provides a form of energy that is still used globally today as an alternative to fossil fuel [1]. In fact, the EU is stimulating the use of clean, renewable energy; lignocellulosic biomass being a highly promising alternative [2].

Short rotation forestry crops provide one of the most effective ways to produce lignocellulosic biomass [3]. The use of woody crops is considered a cost-effective and ecological option to produce electricity along with regional benefits [4]. The use of energy crops, in addition to environmental benefits, could also have a positive social impact through the creation of new jobs in rural areas that are suffering a decline in population [5].

In Europe, large amounts of woodchips are produced in plantations specifically dedicated to this purpose. Recently, the cultivation of lignocellulosic species has increased as several farms have diversified their production to include short rotation forestry crops [6]. The main forestry species cultivated in Europe are poplars (*Populus* spp.) [7], willows (*Salix* spp.) [8], and eucalyptus (*Eucalyptus* spp.) [9] and to a lesser extent black locust (*Robinia pseudoacacia*) [10]. Forestry species can be cultivated either using a high planting density, harvested every 1–4 years, or at a lower planting density, with harvesting ranging from 5 to 7 years [11]. Salicaceae family [12–15] grown in short rotation forestry systems provide a valuable source of woody fuel in areas with high water availability, such as sites located in Northern Europe.

It is well known that the whole process associated with the thermal utilization of solid biofuels (fuel supply, combustion performances, solid and gaseous emissions) is highly influenced by the type of biofuel, its physical characteristics (e.g. particle size, bulk density, moisture content) and its chemical properties (heating value, ash content and composition) [16]. This is why the utilization of poplar genotypes as biofuels for energy production cannot be discussed considering only agricultural aspects but also combustion properties.

High moisture content reduces the combustion temperature causing incomplete combustion and undesirable reaction products

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and it leads to flame instabilities in the burner. Drying the biomass prior to combustion can increase the boiler efficiency, lower emissions and improve boiler operation [17]. It has been shown that natural drying is a cost-effective method to enhance energy efficiency in wood based fuel products [18].

Understanding the thermochemical properties of each type of biomass allows the efficiency of the process and its environmental impact to be assessed. For example, C, H and O are the main components of solid biofuels and they are of particular importance in determining the higher and lower heating value. The fuel N content is responsible for NOx formation, the emission of NOx being one of the main environmental impacts associated with solid biofuel combustion. Cl and S are responsible for the formation of deposits as well as corrosion and they are therefore relevant as regards avoiding operational problems. Furthermore, they are responsible for HCl, PCDD/F and SOx emissions, hydrogen chlorine and sulfur oxides also being involved in the formation of aerosol. Ash content is negatively correlated to the energy value, and the choice of deposit removal technology and appropriate combustion operating conditions will depend on the percentage of ash. Moreover, fly ash emissions and corrosion could also depend on the biomass ash content and composition [19].

Although plenty of literature exists with regard to agricultural aspects of different energy crops, there is a lack of information related to the combustion properties of these biofuels. An appropriate fuel choice requires both these factors to be considered. Moreover, biomass properties may vary widely between species or genotypes of the same species [20]. The environmental conditions (such as water availability, temperature, soil type and characteristics among others) have an important influence on growth performance and production of genotypes in short rotation forestry crops [21–23]. Moreover, planting density of crops can affect the genotypes growth and thus, the biomass properties depending on site [24]. Although some information about the genotype effect in the physico-chemical properties has been reported before [25,26], little information exists with respect to the interaction between site (with different physiographic and climatic characteristics, soil properties and planting density) and physico-chemical properties of the genotypes. A better understanding of both factors (site and biomass type) is essential when checking the use of woody biomass as a potential energy source.

Taking into consideration the above-mentioned aspects, this study presents a complete thermochemical and physical characterization of biomass from different poplar genotypes under Mediterranean climatic conditions. The objective was to determine the most appropriate genotypes as well as to obtain general and practical trends regarding the effect of the site characteristics (environmental conditions and soil properties) and the planting density, considering not only growth performance but also the expected combustion behavior when used in energy generation devices. Natural air-drying after harvesting was also evaluated in order to quantify the improvement in combustion properties achieved by using a low-cost drying method.

2. Materials and methods

2.1. Plant material

Ten different genotypes belonging to different species or hybrids were used in this study. These were: *Populus* × *euramericana* (Dode) Guinier ('I-214', 'Vesten', 'AF2', 'Oudemberg', 'Ballotino', 'MC' and 'Dorskamp'), *Populus deltoides* ('Viriato'), *Populus* × *interamericana* Brockh. ('Grimminge'), *P.* × *interamericana* × *P. nigra* L. ('Monviso').

2.2. Locations

Three different commercial plantations located in Spain with different environmental conditions were evaluated. The soil, physiographic and climatic characteristics of each location are shown in Table 1. No fertilization was performed in any of the location studied. Immediately after the cuttings had been planted, oxifluorfen (4 L ha^{-1}) was applied over the whole area in order to control the weeds during the first months of growth until the plantations were established. Irrigation was applied according to the requirements at each site.

The genotypes planted at each location are shown in Table 2 as not all of the genotypes were grown at each location. Due to the latter aspect, accurate conclusions about the genotype-site characteristics interaction cannot be deduced although some general trends have been obtained by comparing the three sites.

2.3. Plantation design and management

Site preparation and plantation was carried out mechanically in spring 2011 (L1), 2009 (L2) and 2012 (L3) using unrooted cuttings. The density was 6666 trees ha^{-1} (spaced 3×0.5 m) in L1 and L3 and 13,333 trees ha^{-1} (spaced 2.5×0.3 m) in L2. The rotation was 4 years at L1 and 3 years at L2 and L3.

In order to sample in the different plantations, 4 randomized replications were used. Twenty-five trees per replication and genotype were used to estimate production. The fresh weight of the aboveground biomass (stem and branches) per plant was determined. Yield data (Table 2) was shown as dry weight after estimating the humidity content of a subsample from each plot, which was oven-dried to constant weight at 100 °C.

2.4. Biomass sampling

After the first rotation, sampling was performed at two different moments; the first sampling was to determine the moisture content and the thermochemical and physical properties of the genotypes and the second was to evaluate the natural air-drying of

Table 1
Biophysical factors at sites.

Factors and determination methods	Location 1	Location 2	Location 3
Latitude (°)	41.5996738	37.2516935	36.1839849
Longitude (°)	−4.1280864	−3.7002334	−5.75707350
Altitude (m, asl)	756	590	27
Annual mean temperature (°C)	12.1	15.9	17.8
Mean maximum temperature (°C)	25.4	29.3	23.9
Mean minimum temperature (°C)	−0.1	3.7	9
Absolute maximum temperature (°C)	36.7	40.3	31.6
Absolute minimum temperature (°C)	−7.7	−5.8	3.1
Annual precipitation (mm)	316	368	456
K (pmm) by atomic emission	219	76	246
Mg (meq/100 g) by atomic absorption	–	2.13	2.3
Organic Matter (%) by Walkey-Black	1.75	0.9	0.74
Electric conductivity (mS/cm) by 1:2.5	0.82	0.2	0.7
P (pmm) by Olsen	5.8	4.1	18.35
pH by 1:2.5	7.7	8.5	7.1
Active lime (%)	5.6	4.3	0.7
Clay (%) by ISSS	41.9	26.7	5.5
Lime (%) by ISSS	23.6	46.3	33
Sand (%) by ISSS	34.6	27.7	56.5