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Effect of waste organic amendments on *Populus sp* biomass production and thermal characteristics

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Energy crops and thermal conversion of the obtained biomass is a feasible route for the production of energy. In this work, dehydrated composted sewage sludge (BIOSOLIDS) and sludge from dairy wastewater treatment (MUD) were used as organic amendments on four different poplar clones (UNAL, I-214, AF-2 and AF-8) and. These amendments were yearly applied throughout a four years' study aiming to find out the effects on both agronomic (diameter, height and biomass volume of the trees) and thermal (fuel and thermogravimetric analysis) properties of the poplars. The application of MUD improved the agronomic characteristics of the poplars, especially those of UNAL and AF-2. Thermal results were not as conclusive, but pointed to an improvement of the thermal behavior of UNAL under BIOSOLIDS treatment and of AF-2 and AF-8 under MUD fertilization. On the whole, the most favorable case was that of the AF-2 under fertilization with MUD.

1. Introduction

The success of human evolution has been related to the orderly population growth and the sustainable use of resources and energy [1]. However, the current demand in the use of fossil fuels is causing more than apparent decrease in the reserves of these energy resources. It has been predicted that fossil fuels will represent a percentage of 84% of the total energy demand in 2030 [2]. Besides, recent estimations about the duration of such reserves are not encouraging [3–5], since it is thought that the current reserves of oil, coal and gas will last for 40, 60 and 150 years, respectively [6]. Furthermore, it is important to highlight that the world distribution of such reserves is heterogeneous [2].

Forecasts and trends studies [7] indicate that civilization is now facing a major challenge of energy; not being easy to achieve the goals set for the coming years. A major difficulty arises from the growing pressure of emerging countries [8–10] and from their aspirations to reach the developed ones; which implies a growing energetic consume [11].

The knowledge of this fact has led the European Union to set the target to the fulfilment of 20% of its total energy needs with renewable sources by year 2020 [12]. In Spain there are studies [12,13] that indicate that this target for 2020 will be very difficult to achieve.

To reverse the situation there is a global tendency to use renewable energy [14–16]. Renewable energy sources (RES), also known by alternative energy sources are those derived from inexhaustible natural resources that can be drawn permanently [17].

Out of the numerous RES, biomass – and particularly woody biomass - has many advantages and may play an important role in displacing fossil fuels. Biomass resources may come from many heterogeneous sources [18]. This heterogeneity, together with technology, allows the production of energy by different ways. Among them, thermo-chemical processes play an important role in the production of this alternative energy [19].

In Spain, the principal biomass sources are related to forest residues [7] and energy crops [21]. Within the latter, it should be highlighted the case of lignocellulosic energy crops. The environmental benefits of these plantations are well documented and can be outlined acting as carbon sinks, thereby contributing to the reduction of greenhouse gas [22].

When conducting an energy crop, apart from the design and planting density [20], it is essential to select the correct species and, within these, the most suitable clones [21,22]. In this senses, poplar

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(*Populus* sp) is one of the most studied species [23–27]. In fact, several UE countries are considering the use of this species within energy crops [28,29]. Comparative benefits of this species are widely referenced [24,30]. As for the species considered in short rotation forestry (SRF) crops, poplars have (i) high energy and fuel quality, (ii) high yields of biomass dry weight, (iii) rapid juvenile growth, (iv) good regrowth capacity, (v) narrow glasses or large leaves at the top of the cup and, (vi) high adaptability to different areas and resistance to biotic and abiotic stresses [31].

Fertilization is another important aspect to consider in order to successfully establishing an energy crop. In this paper we worked with organic amendments due to their biological and economical potential [32,33] as well as their contribution to the closure of certain cycles (nutrients and pollutants) and to providing a use for a waste that previously had none. Furthermore, this type of fertilizer could increase rates of soil microbial biomass [34] and improve soil structure [35]. Still, in the specific case of poplars, it has been proved that the application of a waste organic amendment significantly increased the trees growth without denoting changes in the nitrate or in the phosphate concentrations in soil solution [36]; something that help to conserve the adjacent aquatic ecosystems.

In this context, the present work, which was conducted during a four years' time period (2010–2013), aimed to study the effects of the application of different organic fertilizations onto different poplar clones. The main purpose was to determine under which conditions (clones and organic fertilizations) the best thermal and agronomic performance of the energy crop were obtained.

2. Materials and methods

2.1. Plots, poplar clones and fertilization

This study was carried out in a plot of 720 m^2 (45 m $\times$ 16 m) at the North-West of Spain (42 27.183 N, 05 53.650 W). Selecting the correct genotype of the species is very important in successfully establishing a plantation [37]. For this reason, four different clones of genus *Populus* were used. Two of these clones were Spanish: *Populus x interamaricana* UNAL and *Populus x euramericana* I-214, which in this work were designated as UNAL and I-214, respectively. Also, two Italian clones specifically imported for biomass production were used: *Populus x euramericana* AF-2 and *Populus x euramericana* AF-8, which were designated as AF-2 and AF-8.

Two different organic amendments together with a control, in the absence of any fertilization, were considered in this work for comparison purposes. The first organic treatment, which was here designated as BIOSOLIDS, was a dehydrated sludge from the León (Spain) sewage treatment plant (STP). The second treatment, which was designated as MUD, was a liquid organic sludge from the wastewater treatment plant of a dairy industry. Both amendments were obtained from the respected sources and applied immediately. According to the number of poplar clones and organic amendments considered in this work, the experimental plot was subdivided into 12 subplots, each of which corresponding to a different poplar clone and a different organic treatment or control (Fig. 1). The characteristics of the organic amendments used in this work can be seen in Table 1.

The above organic amendments were applied once a year throughout the four years duration (from September 2009 to September 2013) of this study. The first fertilization was applied in September 2009 and then annually until the end of the project; whereas poplars were established in April 2010 after the sanitation of the plot. Taking into account the treatments characteristics (Table 1), as well as the agronomic requirements of the crop, each year, a total amount of 143.8 kg of BIOSOLIDS and 1200 L of MUD were applied to the corresponding subplots. Agronomic requirements of the crop were estimated according [38] and were of 29417 mg N/kg wet soil, taking into account the annual organic matter mineralization there is an availability of annual nitrogen of 15021 mg N/kg wet soil. The BIOSOLIDS treatment was employed as a basal dressing and the MUD treatment as a top dressing.

2.2. Soil sampling and characterization

Throughout the duration of this study, soil was sampled every year in September. Soil samples were collected following a standard soil sampling protocol [39], each subplot constituting a sampling unit. An amount of approximately 1 kg of soil in each of the subplots was collected. Along each subplot land surface, soil sampling was done in a zigzag pattern. Every 15 steps a sample was taken by wiping the surface of the land. Soil from 15 to 25 cm depth was sampled by opening a “V” hole in the ground. Each of the sampled portions of soil were deposited in micro perforated plastic bags and labelled. Stones and other impurities were removed from soil samples by a reciprocating sieve with a mesh size of 2 mm, discarding the material that has not gone through the sieve. Soil samples were analyzed for conductivity (UNE 77308: 2001), pH (UNE-ISO 10390:2012), NO_3^- (UNE 77318:2001) and ammonia (UNE 103302:1994).

2.3. Lignocellulosic growth

Throughout the duration of the study, lignocellulosic growth was related with differences from year to year in the trees height and diameter besides biomass volume. The estimation of the biomass volume may be done by different methods. Among them are those based on the utilization of satellite images [40–42] and those employing mathematical expressions [43–45]. Belonging to this last group, it is the model proposed by Refs. [46], which was used in this work for the calculation of the biomass volume, as described in Eq. (1):

$$V_U = 0.3D^2H \tag{1}$$

where V_U the biomass volume (cm^3), D is tree diameter at basal height over bark (cm) and H is the tree height (cm).

During the study, height (H) and diameter (D) of the trees were measured once a year, in September. A caliper ‘Powerfix’ was used to determine the basal diameter at a height of 5 cm from the seedling. Then, the height was measured by a high precision laser (Haglöf Vertex v3 201 DME), as the distance between the base of the seedling and the apical sprout. Then, H and D were used for calculating approximate volumes of wood biomass, according equation (1).

For the different clones and treatments, differences between these parameters related to lignocellulosic growth, namely D, H and V_U, were compared using an ANOVA. Then, the Tukey's HSD test was used to compare treatment means, for which significant ($p < 0.05$) differences were determined by ANOVA.

2.4. Biomass sampling

At each subplot, biomass sampling was yearly carried out in September as described elsewhere [47] and following the guidelines by Ref. [48]. Analogously to soil sampling, for the collection of biomass, subplots were considered as sampling units. Within each subplot, biomass sampling was carried out so to ensure that two consecutive trees were never sampled. The sampled branches were taken at approximately half the height of the tree, carrying out sampling at different orientations. The sampled mass was 150 g of