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Selection and testing of *Populus alba* and *Salix* spp. as bioenergy feedstock: Preliminary results

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HIGHLIGHTS

▶ Growth and production data on white poplar and willow clones for SRF.
▶ Selection of new hybrids of white poplar and willow for bioenergy feedstock crops.
▶ SRC with relative low densities suitable for marginal lands.

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ABSTRACT

Although large amounts of residue from agriculture and forestry are presently available for the production of bioenergy, to ensure a sustainable, long-term supply of biomass, it is necessary to establish and grow perennial energy crops on marginal agricultural land that is specifically intended to produce biomass for energy. Preliminary research has identified several perennial crops as potential biofuel crops including perennial grasses, poplars and willows. The high content of cellulose in these species indicates that the materials could be a potential feedstock for bioethanol production too. To select highly productive white poplar and willow clones suitable for these purposes, progenies of Villafranca (*Populus alba*) and willow clones from different species, mainly *Salix matsudana*, *Salix jessoensis*, *Salix fragilis* and *Salix alba*, were tested. The preliminary results obtained from plantations set up with 1111 plants per hectare are presented. Higher than the average productivity has been obtained from half-sib progenies of the clone 'Villafranca'. Among the families obtained with the willow breeding work, including intra-specific hybrids of *S. alba*, some crosses showed higher growth rates and biomass dry matter yields compared to their parents' mean values.

1. Introduction

In accordance with the target set by the EU directive regarding the share of renewable energy sources (RESs) of the total energy consumption in 2020 (20%), a Program and an Action Plan to increase the share of bio-sources have been adopted in Italy to reach the national target of 17%. According to the most recent data (2009), the percentage of energy consumption from renewable sources is 8.9%, and only 39% of that is from woody biomass of forestry and agricultural crops, biomass residues and wastes of wood and agroindustry [1]. Heat and power cogeneration (CHP) and biofuels from sustainably produced biomass are two important components in the portfolio of renewable energy solutions. Both can become one of the most important if the production and conversion of biomass to either liquid fuel or CHP are accomplished in ways that have highly favorable returns on energy investment. Recently, Chemtex (Mossi & Ghisolfi Group) has developed a system for the production of approximately 40,000 tons per year of 2nd generation bioethanol, and it will serve as a basis for the future commercial scale-up of the process (single-line systems to produce 150,000–200,000 Mg of bioethanol per year) [2].

Currently, large amounts of residue from agricultural and forestry sources (22 and 2.14 Mt of dry matter, respectively) [3] are available in Italy, and in an initial phase, they could be utilized for the production of biofuels or CHP [4,5]. However, to ensure a long-term and sustainable supply of biomass for renewable energy production, it is necessary to establish and grow new perennial energy crops, particularly on marginal agricultural lands [6,7]. Preliminary research has identified several perennial species with the potential for energy production including a number of perennial grasses, poplars and willows. These species have been studied as dedicated energy crops since the early 1980s in Italy [8–11]. In the last 10 years, short rotation coppice (SRC) crops have been inserted in

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the cultural plans of several farms, particularly in Northern Italy, that take advantage of their low input requirement and the added possibility of exploiting set-aside areas [12]. The total surface area reached 6695 ha [13] in 2010, and poplar is the most commonly chosen species for SRC because it is already cultivated in the same area at a low planting density of 270–330 plants per hectare (p ha^{-1}) for the production of wood-based panels and paper [14].

In Italy, SRC planting density range from 1000 to 14,000 p ha^{-1} with rotation periods from 1 to 7 years. There are two different methods of cultivation: a very high density (VHD-SRC) from 5500 to 14,000 p ha^{-1} and a rotation period of 1–4 years and a high density (HD-SRC) from 1000 to 2000 p ha^{-1} and a rotation period of 5–7 years [15]. In general, a single row planting pattern that is more suitable to cultivation is used in Italy for both methods, whereas in other part of Europe, twin rows are preferred because they make harvesting more suitable to mechanization (the two rows are harvested simultaneously) [16,17]. A very high initial density will facilitate rapid crop establishment and produce higher yields in the first rotation [17,18], but the cost of the planting stock is high and frequently repeated harvesting can provoke the loss of stump vigor and reduce successive yields [19]. In a trial carried out at Casale Monferrato (Italy) where the single and twin row patterns were compared at the same planting density (10,000 p ha^{-1}), no statistically significant differences were found for the survival and production of poplar during four harvesting cycles [19]. Farmers in Italy had grown poplar with the VHD-SRC method, but recently they have preferred the HD-SRC method (1000–2000 p ha^{-1}) because the most recent hybrids have enhanced productivity and improved the biomass quality (calorific value) as a result of a better wood/bark ratio [20–22].

The Italian Ministry of Forestry funded this work within the BIOSEA and BIOSEGEN projects to select white poplar (*Populus alba* L.) and willow (*Salix* spp. L) clones in a low input HD-SRC crop. To select highly productive clones suitable for the production of biofuels, a multiclonal plantation program of these species has been established. The purpose of this paper is to evaluate new clones of white poplar and willow that are appropriate for marginal land and the environmental conditions of Italy, the Mediterranean Area and Central Asian countries during the first 2 or 3 years of growth. We have considered not only the driving characteristics for genotype selection in the CRA-PLF breeding program (rooting, biotic and abiotic tolerance, growth rate and productivity of dry matter) but also the specific gravity that is correlated with the energy and cellulose content [23]. These characteristics are important for the potential utilization of these crops as feedstock for biofuel production.

2. Materials and methods

To verify the adaptability, productive potential and stress resistance of different genotypes of poplar (*P. alba* L.) and willow (*Salix* spp. L.) for energy purposes, we established two plantations (Table 1), one for each botanical genus, on the CRA experimental farm at Casale Monferrato in the Piedmont region of Northern Italy (Table 2).

2.1. White poplar selection for short rotation coppice

The experimental trial was established in spring 2009 with 1111 trees per hectare (HD-SRC); 20 experimental clones (Table 3) were compared with the test clone ('Villafranca'). One-year-old pole cuttings of the different clones were utilized. The fields were plowed to a depth of 30–40 cm and were harrowed before planting. Neither soil-active residual herbicides nor fertilizers were applied. During the growing season of the first year, three harrowings were carried out between the rows. During the second and third year, the cultural practices were reduced; weed control by disc harrowing was performed only once in late spring. The plots were irrigated by sprinkler once or twice per year as an emergency intervention.

2.2. Willow breeding and selection as bioenergy feedstock

This trial was established in spring 2010 to screen a subset of the most promising willow clones that were previously selected at CRA-PLF. Twenty-two clones of different origin (including four Chinese, one Japanese and one Argentinean clones) were compared (Table 4) with the two test clones 'Drago' and 'Levante', which were recently patented in the EU. One-year-old willow pole cuttings were planted in properly tilled fields in a single-row arrangement at a density of 1111 p ha^{-1} (HD-SRC). The cultural practices were the same as those carried out in the white poplar trial.

2.3. Measurements and biomass estimation

After leaf fall at the end of each vegetative season, the survival percentage was recorded, and the diameters at breast height (D130) were measured to the nearest 0.5 cm with a digital caliper in each plot of the two trials.

In both trials (white poplar and willow), the above ground biomass was estimated in relation to the allometric curve between the dry weight (DW) in kg of single trees and their diameter (D130) in cm as described by the equation [24]:

$$DW = aD130^b$$

where a and b are constants.

The curves had been previously calculated in two plantations near Casale Monferrato (AL) using data obtained by the destructive sampling of 50 living and undamaged trees per genus that were stratified according to diameter. The two plantations, one of white poplar and one of willow, were planted with the same densities. The total fresh weight (FW) in kg of all the trees was measured in the field immediately after felling using a balance with an accuracy to 10 g. Dry matter content, which is the ratio between the dry weight and fresh weight, was assessed on the stem and branches of a sub sample of 10 trees. From each of them, 7–10 cm long stem sections were collected every meter from the bottom to where the stem diameter was 3–4 cm; the branches were sampled separately. The branch and stem sections, temporarily stored in plastic bags, were weighed in the laboratory (15 km from the fields) using a balance with an accuracy to 0.1 g immediately after sampling and then were oven dried at 103 ± 2 °C to constant weight.

The results of the non-linear regressions are reported in Figs. 1 and 2 for white poplar and willow, respectively.

To measure the specific gravity, defined as the ratio of the weight of the oven dry sample to the weight of a volume of water equal to the volume of the green sample, a stem wood disc (1 cm high) at 1.30–1.50 m was taken above ground level from four shoots of each clone (1-year-old shoots of *P. alba* and 2-year-old

Table 1
Description of the experimental trials of Casale Monferrato (AL) Italy.

Experimental plantation	Trial 1	Trial 2
Species	*Populus alba* L.	*Salix* spp.
Total surface (ha)	0.55	0.62
Clones tested (n.)	20	24
Spacing (m)	3 × 3	3 × 3
Experimental design	Randomized complete blocks	
Replications (n.)	3	3
Trees/plot (n.)	9	9