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Abstract.

A reduction in energetic and economic costs is key to the sustainable development of Short Rotation Coppices (SRC) for energy purposes. During their cultivation, the highest costs are incurred during the planting and harvesting phases. A new planting method, which involves the horizontal disposition of stems or cuttings 120 cm long, at a depth of 5-10 cm, could provide energy and cost savings during planting. The results of three experimental plots in Casale M.to (AL), one in Cannara (PG) and one in Chioggia (VE) are shown: horizontal stems and long cuttings were able to produce from 1 to 5 sprouts per meter (sp m^{-1}), depending on the genotype and environmental conditions. Willow was able to produce on average from 2.1 to 4.8 sp m^{-1} and between poplars, the species *P. ×canadensis* produced more sprouts that *P. deltoides* (3.9 sp m^{-1} compared with 1.9 sp m^{-1}). Yields reached a maximum in a Casale M.to trial with 12.7 oven dry tons per hectare (Odt ha^{-1}) for poplar 'Orion' and 12.3 Odt ha^{-1} for willow 'Levante' at the end of first year. The variability of sprouts production and growth of trees makes this method suitable for SRC or stool-beds.

Keywords: Short Rotation Coppice (SRC), poplar, willow, plantation

1. Introduction

Regardless of whether they are perennial or annual crops, dedicated crops for energy production represent an important environmental, economic and social alternative to fossil fuels [1]. However, to be useful in different situations, dedicated crops should be sustainable on three levels: agronomical production, environmental and economical [2]. Maybe in the future these crops will become economically viable, but currently the price of the primary product (wood chips) does not always cover cultivation costs and any economical return on investment depends on public financing [3-5]. However, the choice of an appropriate genotype and cultivation model suitable to a specific environment and farm organization does enable high yields to be obtained, improving the economic returns [6]. In addition, new technologies and advanced mechanization in this sector could also bring great advantages in terms of time and economic expenditure: for example, in the cultivation cycle of dedicated crops with fast growing woody species, the plantation phase requires an investment of both time and money for the production of cuttings or seedlings, soil preparation and plantation. However, if new methods and machines were introduced, hand-labour to produce cuttings/seedlings and planting costs could be reduced and plantation could be increased.

Among other species, poplar and willow are largely utilized for biomass purposes due to their characteristics [7]. They are fast growth species and show very high rooting ability: stem cuttings or young trees can be planted without roots, both in traditional poplar stand (as one or two year old stems, 4-6 m tall) and biomass stand (as cuttings, 20-30 cm long, or 90 cm long) with a success probability near to 100 % [8-12]. So the vegetative reproduction of a selected genotype is very fast and simple.

In Italy many different types of vegetative materials (like cuttings with variable length, one or two year old stems), planting machines and plantation methods [13-15] were tested in the past. Currently, the short rotation coppices (SRC) are established with cuttings 20-30 cm long and with a diameter above 1-2 cm; for each cutting it is possible to obtain one or more sprouts, but whether done manually or with dedicated machines (like Rotor) [16], each cutting should be planted individually in a row. Considering the high density of SRC (5000-10000 trees·ha^{-1}), labor and time for cuttings preparation and planting has a very high cost [17].

Taking advantage of the rooting ability of poplar and willow, an experiment was set up to evaluate an alternative planting method that uses horizontal stems instead of cuttings, to avoid the costs of cutting preparations. Indeed, in many natural situations and especially in a river basin environment or in traditional poplar stands, the alive branches that fall on the ground horizontally after pruning produce roots and new trees in the spring. Depending on branch or stem portion length, it is possible to count one or more alive sprouts. This characteristic can be exploited to maximize the cost/benefits ratio in the planting phase (mainly in cultivations) as the SRC don't yet ensure suitable rents; in fact, a new method of planting based on such characteristics could reduce both the cost for material production and the time for stand establishment.

2. Material and methods

The main aim of the research herein described was test a new method of planting poplar and willow SRC, utilizing stems or stem portions, avoiding cuttings preparation. The goal is to determine the sprouting ability, growth and productivity of SRC plantations established with this new planting method.

Three experimental plots were established from spring 1997 to spring 2006 on the 'Mezzi' farm of CREA-PLF in Casale Monferrato (AL), northern Italy.

The first experiment (CM1) compare horizontal planting of one year old stems (350 cm long) with the cuttings method of SRC plantation (cuttings of 10, 20 or 30 cm long, vertically planted in the soil). CM1 used the most cultivated poplar clone in Italy, *P. ×canadensis* 'I-214', and the results confirmed the possibility of planting poplar horizontally.

The second experiment, CM2, tested the horizontal planting with improved material: from the basal and median part of each stem were obtained 2 portions 120 cm long, while the apical part was discarded. These are named in the paper 'cuttings 120 cm long'.

The experiment also compared behavior of two species of poplar was compared: *P.* ×*canadensis* and *P. deltoides* (cuttings of the latter generally have a poor rooting ability [9]). In the third experiment, CM3, the method of horizontal planting was applied to a wider number of poplar clones and it was extended to willow clones. This experiment also tested a prototype planting machine made in collaboration with the researchers of the University of Turin, Italy (its characteristics will be explained in a separate paper).

Finally, this new plantation method was applied on two other sites, Cannara (PG) in the region of Umbria and Chioggia (VE) in the region of Veneto, to test its response with different clones and other soil and climate environments: in a heavy soil (PG, central Italy) and a peat soil (VE, north-eastern Italy). Table 1 summarizes the main information of all trials, including the clones tested.

In all trials, the stems were harvested from a stool-bed in January and stored at 0-4 °C until it was time to produce the planting material that needed to be re-hydrated for at least 2 days before planting (water immersion).

The planting method for horizontal stems and long cuttings consisted in opening a furrow, 5-10 cm deep, using a small ploughshare the operator must lie down the stems (CM1) or long cuttings (other trials) in such a way that the upper part of one overlaps the basal portion of the next; the furrow is then closed.

2.1 Mezzi farm, Casale Monferrato (AL)

The ‘Mezzi’ farm of CREA-PLF is located in Casale Monferrato in nothern Italy, on the river Po floodplain (Lat45°08’N, Long08°27’E, Alt116 m asl). The climate is sub-continental with a mean annual temperature of 13 °C and rainfall of about 750 mm per year (with 400 mm during the vegetative season, from April to October). The soil is sandy-loam [18]. The water table is not available for trees as it is at an average depth of 4 m.

2.1.1 First trial: CM1

CM1 was carried out in spring 1997. One-year old stems of clone ‘I-214’ were planted horizontally: stems were 350 cm long and the apical part of each stem (50 cm) was laid over the bottom part of the next. This plantation method was compared with traditional cuttings plantation (vertical planting). The cuttings were prepared in different ways: the cuttings long 10 cm ($Cutt_{10}$), 30 cm ($Cutt_{30}$) and part of the cuttings 20 cm long ($Cutt_{20}$) were mechanically prepared with a band saw; another part of cuttings 20 cm long was manually and accurately prepared ($Cutt_{20m}$), choosing the best buds. Both cuttings and stems were manually planted. Inter-row spacing was 1.80 m and inter-plant distance between vertically planted cuttings was 0.70 m. A plot included 30 vertically planted cuttings or 7 horizontally planted stems. A randomized complete block with 5 replications was the experimental design applied. Soil was ploughed (35 cm) and harrowed before planting. Weed control was performed with a three disc harrow and a manual hoeing along the rows during the growing season. Three sprinkling irrigations (35 mm each time) were applied during growing season to support shoot growth.

2.1.2 Second trial: CM2

CM2 was established in Spring 2004 with cuttings 120 cm long deriving from the basal-medium portion of the stem. Three different clones, one *P.* ×*canadensis* ‘Neva’, and two *P. deltoides* ‘Dvina’ and ‘Lena’ were tested.

Three randomized blocks were applied to evaluate sprouting and growth ability. Soil was ploughed (30 cm) and harrowed before planting. Weeds were controlled by applying chemicals (*Metholachlor* 2.5 $l \cdot ha^{-1}$ + *Pendimetalin* 2.5 $l \cdot ha^{-1}$) immediately after plantation. Between rows, the soil was disc harrowed twice during the vegetative season of the first year; in addition, two sprinkling irrigations with 80 mm of water were needed due to sandy soil for support the young trees during the dry season. One treatment with *Chlorpyrifos-methil* + *Deltamethrin* 2 $kg \cdot ha^{-1}$ was needed against *Chrysomela populi* L. The clones selected are resistant or tolerant to the other main poplar diseases [19].

2.1.3 Third trial: CM3

CM3 was planted in spring 2006; it covers a surface of 2500 m^2 and it is a SRC plantation with 7 poplar clones and 3 willow clones. The spacing between rows is 2 m. The experimental design was randomized complete blocks with 3 replications. Field preparation and field management were done in the same way as for CM2.

2.2 Cannara (PG)

Cannara is located near Perugia, in Central Italy (Lat42°59'N, 12°34'E, Alt185 asl). The experimental trial was within a commercial stand that covers a surface area of more than 6 ha. Mono-clonal plots, with a surface area of 37.5 m^2, were completely randomized with 3 replications. In spring 2007, due to the high clay content, the soil was prepared using subsoiling to reduce soil compaction before being plowed and harrowed. Herbicides were not applied during plantation or plant establishment, no disease control was carried out, and no irrigation or fertilization was carried out; only one weeding (mechanical control) was needed in each vegetative season. Cuttings 120 cm long of 19 clones of *Populus* and *Salix* genus were horizontally planted with an inter-row distance of 2.50 m.

2.3 Chioggia (VE)

The site in Chioggia includes different trials with poplar, willow and others tree species growing on agricultural soils derived from reclaimed land in the delta area of the Po river. The trial of interest, using cuttings 120 cm long horizontally planted, covers a total surface of 1.2 ha, and was established on three fields with a similar area; in each field four clones were tested: 'I-214' (*P. ×canadensis*), 'Imola' (*P. ×canadensis*), 'Vesten' (*P. ×canadensis*), and 'Baldo' (*P. deltoides*) all planted in spring 2014 in single rows with an inter-row distance of 4 m. After corn cultivation, minimum tillage was applied; weed control was performed with repeated mulching and two manual hoeings along the rows. Neither irrigation (water table is at a depth of 50 cm) nor disease control were necessary.

2.4 Field measurements and analysis

In all the plots, the following measurements were performed at the end of the first year:

- number of alive sprouts per meter (sp m^{-1});
- diameter at breast height (Dbh) in mm;
- total height (H) in cm.

In Cannara (PG), due to scarce growth, height and number of sprouts were measured in the first year, while diameter and height were repeated at the end of the third year.

Utilizing the sp m^{-1} values, the final plantation density (Dens) was calculated in trees ha^{-1}, and aboveground dry biomass yield (B) in oven dry tons per hectare (Odt ha^{-1}) or oven dry tons per hectare and per year (Odt ha^{-1} y^{-1}) utilizing a regression equation from diameter (Dbh) and dry weight (DW), [20-22]. Data were analyzed with ANOVA, and a post hoc test was performed when possible, utilizing R software (R Core Team, 2015) [23,24]

3. Results

3.1 Casale Monferrato, CM1

The differences in performance between types of material were statistically significant for all factors analyzed: diameter at breast height, total height, number of sprouts per meter, and biomass yield. The sprouts of stems horizontally planted reached a higher diameter at the end of the first vegetative season, 22 mm, compared with a general mean of 18.6 mm; the same was true for maximum height (336 cm for horizontally planted stems, compared with a mean of 292 cm). The best result of number of sprouts per meter (sp m^{-1}) was measured on trees derived from cuttings 30 cm long ($Cutt_{30}$), that, producing on average 1.4 sprouts per meter, have a rooting near to 100%. The other best result of sprout production was achieved with cuttings manually prepared and 20 cm long ($Cutt_{20m}$); with 1.3 sprouts per meter this underlines the importance of a good were apical bud. All the sprouts of each stem started along the basal-middle part, and more than one meter of stem in the apical part had no sprouts.

Trees derived from $Cutt_{30}$ gave the best biomass yield (4.21 Odt ha^{-1} y^{-1}), directly followed by trees derived from stems horizontally planted (3.58 Odt ha^{-1} y^{-1}), whereas the shorter cuttings prepared with a band saw ($Cutt_{20}$ and $Cutt_{10}$) had the lowest growth and lowest yield (Table 2).

3.2 Casale Monferrato, CM2

Among the genotypes tested, the clone 'Neva' reached a production of 5 sprouts per meter (significantly different from others clones) and, also biomass yield was higher but not statistically significant (Table 3). Since all material was equally prepared, and cultural inputs were the same, the differences among clones are due to genetic factors. In this experiment, with the same time commitment, machinery and material, with the choice of a suitable genotype it has been possible to achieve an approximately 5-fold increase in plantation density and 2-fold increase in biomass yield (Figure 1).

3.3 Casale Monferrato, CM3

Statistically significant differences were found between clones, for all factors considered (plantation density analysis is the same for sp m^{-1} because density comes from a simple calculation). Cuttings 120 cm long produced, as a general mean of the experiment, 3.2 sprouts per meter, but the best clone ('SE65-066') reached 5 sprouts per meter. The mean height at the end of the first year was 315 cm; 'Levante' reached 393 cm, followed by *P. deltoides* '84-078' which reached 373 cm. The maximum diameter was measured on the *P. deltoides* clone '85-037'. Mean biomass yield was 8 Odt ha^{-1}, though clone *P.* ×*canadensis* 'Orion' for example yielded 12.7 Odt ha^{-1}.

The final density tended to be very high, near to 20000 – 25000 trees ha^{-1}. To obtain the same result with a traditional plantation method would demand a high cost for the cuttings preparation, and a huge time commitment for field planting [25].

A contrasts analysis was performed between the genera poplar and willow, and between species *P. ×canadensis* and *P. deltoides*. Differences between poplar and willow were significant for all factors: the willows reached a greater height, produced a higher number of sprouts and had a higher yield, but the poplars had a larger diameter. Among the poplar species, *P. ×canadensis* clones were higher than *P. deltoides* for all factors (Table 4).

3.4 Cannara, PG

The comparison of different poplar genotypes in Cannara (PG) highlighted a variable behavior of sprouting, growth and biomass production, with a wide difference between the best and worst genotypes (Table 5); the highest sprouts production from cuttings 120 cm long was reached by 'Diva', and overall *P. ×canadensis* clones had a higher sprout (about 2.5- 3 sp m^{-1}) whereas some *P. deltoides* clones had a low sprouting ability in this environment and with this plantation method (from 1 to 2 sp m^{-1}). The mean height at the end of the first year was 101.1 cm; the differences among the clones were not statistical significant. The mean diameter at the end of the third year was 32.9 mm; the *P. deltoides* 'Oglio' reached 51 mm. The mean height at the end of the third year was 501.3 cm; the differences among the clones were statistical significant, and the higher clone was 'Imola' with a mean of 693 cm. The clone 'Oglio' yielded 13.23 Odt ha^{-1} y^{-1} , followed by 'Baldo' with 11.49 Odt ha^{-1} y^{-1}. Among willows, clone 'S76-008'(*Salix babylonica* hybrid) had the highest yield, 4.50 Odt ha^{-1} y^{-1}. A contrasts analysis was performed between the genera poplar and willow, and between species *P. ×canadensis* and *P. deltoides*. Differences between poplar and willow were significant for the three variables measured at the end of third year: poplars reached larger diameters, greater height and higher yield. Among the poplar species, *P. ×canadensis* clones were higher but *P. deltoides* had a larger diameters and produced a higher yield

3.5 Chioggia (VE)

The clones of poplar tested in the trial of Chioggia had a similar behavior and *Anova* test did not give significant values (Table 6). The average sprouts production was 0.7 per meter, corresponding to a density of about 1680 trees ha^{-1} (inter-row spacing was 4 m); diameter at breast height reached a mean value of 15.7 mm, but only the clone 'Baldo' had a higher than average value (19.2 mm). Average height was 248 cm. Mean biomass yield was 0.36 Odt ha^{-1}, though clone *P. deltoides* 'Baldo' yielded 0.58 Odt ha^{-1}.

4. Discussion and conclusions

In poplar cultivation, the importance of studies on planting material depends on their possibility to reduce costs and time for material production and planting, while contemporarily improving biomass yield [26, 16]. In some studies on willow SRC grown in the UK, it has been calculated that the costs for material preparation determine around 47% of the planting investment [27], while, material preparation plus establishment count for 69%, and it should be kept in mind that soil preparation is a necessary activity for most crops [28]. More recently in Germany, Schweier and Becker [29] calculated that poplar establishment counts for 13% of the total costs of ten years of cultivation.

In the first experiment (CM1), tests on cutting length, method of cutting preparation (mechanically and manual/accurately) and planting method (vertical or horizontal) reflects the necessity to improve material production (cutting lenght, more sprouts from one stem), and planting time (wide surface planted faster through horizontal disposition of long stems). The results obtained for clone 'I-214' demonstrate that cutting length affects the number of sprouts per meter, growth and biomass production; indeed the growth of cuttings 10 cm long was significantly lower than for other cuttings. Cuttings 30 cm long produced a significantly higher number of sprouts per meter, which is in agreement with previous results obtained by Frison and Piotto [30]; for the cuttings 20 cm long, the accurate preparation positively influenced the growth results; in other experiments the influence of preparation method was barely perceptible and was not statistically significant [31, 32]. The yield obtained from horizontal stems did not statistically differ from the yield obtained by cuttings 30 cm long (that had the highest yield among cuttings). The subsequent experiment CM2 with ‘Neva’, ‘Dvina’ and ‘Lena’, conducted with a more appropriate type of horizontal stem (120 cm long), gave important first results about the potential of using improved material, and it also gave some indication about the behavior of different genotypes. The good rooting and sprouting ability of *P. ×canadensis* genotypes shown, with traditional planting method, in different environmental conditions [33, 34] was also apparent with horizontal plantation: the clone ‘Neva’ reached a density of more than 28000 trees ha^{-1}, a value that via the traditional method of plantation would incur high economic and energetic costs [16]. With the third experiment (CM3) it was possible to probe the response to horizontal plantation among a wider range of genotypes: *P. ×canadensis* clones had better sprouting results than *P. deltoides*, and on average willow performed better than the poplars and reached results in accordance with Lowthe-Thomas *et al.* [28]; in the environment without limitations on water, the number of sprouts strongly and positively influenced the final biomass production, even though some *P. deltoides*, such as ’85-037’, still produced a high biomass due to their large diameter. With the trial of Cannara it was possible to test the same and other genotypes on heavy soil condition. Also in this trial, many *P. ×canadensis* clones produced a high number of sprouts, but with small dimensions: the effects of density on growth, survival and biomass yield were well explained by Bullard *et al*. [35] for willow; the underlying issues are related to the lower growth diameter and higher mortality at very high plantation densities, referable to an effect of self-thinning, tied up to the LAI and the pedological availabilities [36]. Nevertheless, high density is linearly correlated to high biomass yield during first yields. In this trial (PG), at the end of the first year, the average height was 101 cm and it wasn’t possible to measure dbh; the growth was lower with respect to other trials. With reference only to the willow species, this was most likely due to lack of water (no irrigation and low rainfall); some authors [37] have found that for willow planted with the layflat method, drought can have serious impacts during establishment: cuttings 120 cm long, superficially planted (5-8 cm) are much more susceptible to drying out, compared with cuttings vertically planted that can use the water available in the soil up to a depth of 30 cm. Finally, in the trial of Chioggia, established on peat soil, it is clear that the low productivity, derived from low number of sprouts per meter and sprout dimensions depends on environmental characteristics: all the clones had poor results and no significant differences were obtained by Anova; the density obtained (near to 1700 trees ha^{-1}) is similar to 5-y rotation model, another most utilized model in Italy. Interesting results may be obtained in the next years; in another trial of Casale Monferrato [38], comparing the high density model with harvest every 5 years and the very high density model with harvest every two years, the former shows low tree growth and production values during the first and second year, but, subsequently, a rapid growth of trees brought about a greater biomass yield compared to the second model.

For poplar and willow, that show a very high sprouting ability in vegetative reproduction, the method presented in this paper (cuttings 120 cm long horizontally planted) may represent a valid alternative to short cuttings vertically planted, especially for SRC and stool-beds with very high density. However, we must emphasize that the final plantation density that can be obtained via this method can only be estimated during the planning phase, as the exact density achieved will depend on many factors. In fact, the Authors' opinion is that different species and clones respond differently and generally the genotypes that show high rooting values with traditional cuttings [33-34], also show high sprouting ability with horizontal planting. Probably, this new method incurs a reduced time and costs for material preparation and planting [14].

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