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(Article begins on next page)

1 **Alternative planting method for Short Rotation Coppice with poplar and willow**

2

3 **Abstract.**

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

16

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

18

19

20 **1. Introduction**

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

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

41 In Italy many different types of vegetative materials (like cuttings with variable length, one or two
42 year old stems), planting machines and plantation methods [13-15] were tested in the past.
43 Currently, the short rotation coppices (SRC) are established with cuttings 20-30 cm long and with a
44 diameter above 1-2 cm; for each cutting it is possible to obtain one or more sprouts, but whether
45 done manually or with dedicated machines (like Rotor) [16], each cutting should be planted

46 individually in a row. Considering the high density of SRC (5000-10000 trees·ha⁻¹), labor and time
47 for cuttings preparation and planting has a very high cost [17].

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

57

58 **2. Material and methods**

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

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

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

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

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

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

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

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

89

90 **2.1 Mezzi farm, Casale Monferrato (AL)**

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

96

97 **2.1.1 First trial: CMI**

98 CM1 was carried out in spring 1997. One-year old stems of clone 'I-214' were planted
99 horizontally: stems were 350 cm long and the apical part of each stem (50 cm) was laid over the
100 bottom part of the next. This plantation method was compared with traditional cuttings plantation
101 (vertical planting). The cuttings were prepared in different ways: the cuttings long 10 cm (Cutt₁₀),
102 30 cm (Cutt₃₀) and part of the cuttings 20 cm long (Cutt₂₀) were mechanically prepared with a band
103 saw; another part of cuttings 20 cm long was manually and accurately prepared (Cutt_{20m}), choosing
104 the best buds. Both cuttings and stems were manually planted. Inter-row spacing was 1.80 m and
105 inter-plant distance between vertically planted cuttings was 0.70 m. A plot included 30 vertically
106 planted cuttings or 7 horizontally planted stems. A randomized complete block with 5 replications
107 was the experimental design applied. Soil was ploughed (35 cm) and harrowed before planting.
108 Weed control was performed with a three disc harrow and a manual hoeing along the rows during
109 the growing season. Three sprinkling irrigations (35 mm each time) were applied during growing
110 season to support shoot growth.

111

112 **2.1.2 Second trial: CM2**

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

116 Three randomized blocks were applied to evaluate sprouting and growth ability. Soil was ploughed
117 (30 cm) and harrowed before planting. Weeds were controlled by applying chemicals
118 (*Metholachlor* 2.5 l·ha⁻¹ + *Pendimetalin* 2.5 l·ha⁻¹) immediately after plantation. Between rows, the
119 soil was disc harrowed twice during the vegetative season of the first year; in addition, two
120 sprinkling irrigations with 80 mm of water were needed due to sandy soil for support the young
121 trees during the dry season. One treatment with *Chlorpyrifos-methyl* + *Deltamethrin* 2 kg·ha⁻¹ was
122 needed against *Chrysomela populi* L. The clones selected are resistant or tolerant to the other main
123 poplar diseases [19].

124

125 **2.1.3 Third trial: CM3**

126 CM3 was planted in spring 2006; it covers a surface of 2500 m² and it is a SRC plantation with 7
127 poplar clones and 3 willow clones. The spacing between rows is 2 m. The experimental design was
128 randomized complete blocks with 3 replications. Field preparation and field management were done
129 in the same way as for CM2.

130

131 **2.2 Cannara (PG)**

132 Cannara is located near Perugia, in Central Italy (Lat42°59'N, 12°34'E, Alt185 asl). The
133 experimental trial was within a commercial stand that covers a surface area of more than 6 ha.
134 Mono-clonal plots, with a surface area of 37.5 m², were completely randomized with 3 replications.
135 In spring 2007, due to the high clay content, the soil was prepared using subsoiling to reduce soil
136 compaction before being plowed and harrowed. Herbicides were not applied during plantation or
137 plant establishment, no disease control was carried out, and no irrigation or fertilization was carried
138 out; only one weeding (mechanical control) was needed in each vegetative season. Cuttings 120 cm
139 long of 19 clones of *Populus* and *Salix* genus were horizontally planted with an inter-row distance
140 of 2.50 m.

141

142 **2.3 Chioggia (VE)**

143 The site in Chioggia includes different trials with poplar, willow and others tree species growing on
144 agricultural soils derived from reclaimed land in the delta area of the Po river. The trial of interest,
145 using cuttings 120 cm long horizontally planted, covers a total surface of 1.2 ha, and was
146 established on three fields with a similar area; in each field four clones were tested: 'I-214' (*P.*
147 *×canadensis*), 'Imola' (*P. ×canadensis*), 'Vesten' (*P. ×canadensis*), and 'Baldo' (*P. deltoides*) all
148 planted in spring 2014 in single rows with an inter-row distance of 4 m. After corn cultivation,
149 minimum tillage was applied; weed control was performed with repeated mulching and two manual

150 hoeings along the rows. Neither irrigation (water table is at a depth of 50 cm) nor disease control
151 were necessary.

152

153 **2.4 Field measurements and analysis**

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

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

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

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

165

166 **3. Results**

167 **3.1 Casale Monferrato, CM1**

168 The differences in performance between types of material were statistically significant for all
169 factors analyzed: diameter at breast height, total height, number of sprouts per meter, and biomass
170 yield. The sprouts of stems horizontally planted reached a higher diameter at the end of the first
171 vegetative season, 22 mm, compared with a general mean of 18.6 mm; the same was true for
172 maximum height (336 cm for horizontally planted stems, compared with a mean of 292 cm). The
173 best result of number of sprouts per meter (sp m^{-1}) was measured on trees derived from cuttings 30
174 cm long (Cutt_{30}), that, producing on average 1.4 sprouts per meter, have a rooting near to 100%.
175 The other best result of sprout production was achieved with cuttings manually prepared and 20 cm

176 long (Cutt_{20m}); with 1.3 sprouts per meter this underlines the importance of a good were apical bud.
177 All the sprouts of each stem started along the basal-middle part, and more than one meter of stem in
178 the apical part had no sprouts.

179 Trees derived from Cutt₃₀ gave the best biomass yield (4.21 Odt ha⁻¹ y⁻¹), directly followed by trees
180 derived from stems horizontally planted (3.58 Odt ha⁻¹ y⁻¹), whereas the shorter cuttings prepared
181 with a band saw (Cutt₂₀ and Cutt₁₀) had the lowest growth and lowest yield (Table 2).

182

183 **3.2 Casale Monferrato, CM2**

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

191

192 **3.3 Casale Monferrato, CM3**

193 Statistically significant differences were found between clones, for all factors considered (plantation
194 density analysis is the same for sp m⁻¹ because density comes from a simple calculation). Cuttings
195 120 cm long produced, as a general mean of the experiment, 3.2 sprouts per meter, but the best
196 clone ('SE65-066') reached 5 sprouts per meter. The mean height at the end of the first year was
197 315 cm; 'Levante' reached 393 cm, followed by *P. deltoides* '84-078' which reached 373 cm. The
198 maximum diameter was measured on the *P. deltoides* clone '85-037'. Mean biomass yield was 8
199 Odt ha⁻¹, though clone *P. ×canadensis* 'Orion' for example yielded 12.7 Odt ha⁻¹.

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

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

208

209 **3.4 Cannara, PG**

210 The comparison of different poplar genotypes in Cannara (PG) highlighted a variable behavior of
211 sprouting, growth and biomass production, with a wide difference between the best and worst
212 genotypes (Table 5); the highest sprouts production from cuttings 120 cm long was reached by
213 ‘Diva’, and overall *P. ×canadensis* clones had a higher sprout (about 2.5- 3 sp m⁻¹) whereas some
214 *P. deltoides* clones had a low sprouting ability in this environment and with this plantation method
215 (from 1 to 2 sp m⁻¹). The mean height at the end of the first year was 101.1 cm; the differences
216 among the clones were not statistical significant. The mean diameter at the end of the third year was
217 32.9 mm; the *P. deltoides* ‘Oglio’ reached 51 mm. The mean height at the end of the third year was
218 501.3 cm; the differences among the clones were statistical significant, and the higher clone was
219 ‘Imola’ with a mean of 693 cm. The clone ‘Oglio’ yielded 13.23 Odt ha⁻¹ y⁻¹, followed by ‘Baldo’
220 with 11.49 Odt ha⁻¹ y⁻¹. Among willows, clone ‘S76-008’ (*Salix babylonica* hybrid) had the highest
221 yield, 4.50 Odt ha⁻¹ y⁻¹. A contrasts analysis was performed between the genera poplar and willow,
222 and between species *P. ×canadensis* and *P. deltoides*. Differences between poplar and willow were
223 significant for the three variables measured at the end of third year: poplars reached larger
224 diameters, greater height and higher yield. Among the poplar species, *P. ×canadensis* clones were
225 higher but *P. deltoides* had a larger diameters and produced a higher yield

226

227 **3.5 Chioggia (VE)**

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

234

235 **4. Discussion and conclusions**

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

244 In the first experiment (CM1), tests on cutting length, method of cutting preparation (mechanically
245 and manual/accurately) and planting method (vertical or horizontal) reflects the necessity to
246 improve material production (cutting length, more sprouts from one stem), and planting time (wide
247 surface planted faster through horizontal disposition of long stems). The results obtained for clone
248 ‘I-214’ demonstrate that cutting length affects the number of sprouts per meter, growth and biomass
249 production; indeed the growth of cuttings 10 cm long was significantly lower than for other
250 cuttings. Cuttings 30 cm long produced a significantly higher number of sprouts per meter, which is
251 in agreement with previous results obtained by Frison and Piotto [30]; for the cuttings 20 cm long,

252 the accurate preparation positively influenced the growth results; in other experiments the influence
253 of preparation method was barely perceptible and was not statistically significant [31, 32]. The yield
254 obtained from horizontal stems did not statistically differ from the yield obtained by cuttings 30 cm
255 long (that had the highest yield among cuttings). The subsequent experiment CM2 with ‘Neva’,
256 ‘Dvina’ and ‘Lena’, conducted with a more appropriate type of horizontal stem (120 cm long), gave
257 important first results about the potential of using improved material, and it also gave some
258 indication about the behavior of different genotypes. The good rooting and sprouting ability of *P.*
259 *×canadensis* genotypes shown, with traditional planting method, in different environmental
260 conditions [33, 34] was also apparent with horizontal plantation: the clone ‘Neva’ reached a density
261 of more than 28000 trees ha⁻¹, a value that via the traditional method of plantation would incur high
262 economic and energetic costs [16]. With the third experiment (CM3) it was possible to probe the
263 response to horizontal plantation among a wider range of genotypes: *P. ×canadensis* clones had
264 better sprouting results than *P. deltoides*, and on average willow performed better than the poplars
265 and reached results in accordance with Lowthe-Thomas *et al.* [28]; in the environment without
266 limitations on water, the number of sprouts strongly and positively influenced the final biomass
267 production, even though some *P. deltoides*, such as ‘85-037’, still produced a high biomass due to
268 their large diameter. With the trial of Cannara it was possible to test the same and other genotypes
269 on heavy soil condition. Also in this trial, many *P. ×canadensis* clones produced a high number of
270 sprouts, but with small dimensions: the effects of density on growth, survival and biomass yield
271 were well explained by Bullard *et al.* [35] for willow; the underlying issues are related to the lower
272 growth diameter and higher mortality at very high plantation densities, referable to an effect of self-
273 thinning, tied up to the LAI and the pedological availabilities [36]. Nevertheless, high density is
274 linearly correlated to high biomass yield during first yields. In this trial (PG), at the end of the first
275 year, the average height was 101 cm and it wasn’t possible to measure dbh; the growth was lower
276 with respect to other trials. With reference only to the willow species, this was most likely due to
277 lack of water (no irrigation and low rainfall); some authors [37] have found that for willow planted

278 with the layflat method, drought can have serious impacts during establishment: cuttings 120 cm
279 long, superficially planted (5-8 cm) are much more susceptible to drying out, compared with
280 cuttings vertically planted that can use the water available in the soil up to a depth of 30 cm.
281 Finally, in the trial of Chioggia, established on peat soil, it is clear that the low productivity, derived
282 from low number of sprouts per meter and sprout dimensions depends on environmental
283 characteristics: all the clones had poor results and no significant differences were obtained by
284 Anova; the density obtained (near to 1700 trees ha⁻¹) is similar to 5-y rotation model, another most
285 utilized model in Italy. Interesting results may be obtained in the next years; in another trial of
286 Casale Monferrato [38], comparing the high density model with harvest every 5 years and the very
287 high density model with harvest every two years, the former shows low tree growth and production
288 values during the first and second year, but, subsequently, a rapid growth of trees brought about a
289 greater biomass yield compared to the second model.

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

299

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304

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