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Energy and economic evaluation of a poplar plantation for woodchips production in Italy

Abstract

In Europe, farmers prefer the very Short Rotation Coppice (vSRC) cultivation model, with a very high plant density (5500-14000 p ha⁻¹) and a harvesting cycle of 1-4 years; while in Italy, recently, the farmers prefer the Short Rotation Coppice (SRC) method, with a high plant density (1000-2000 p ha⁻¹) and a harvesting cycle of 5-7 years. This is because the most recent poplar hybrids have enhanced productivity and improved the biomass quality (calorific value), as a result of a better wood/bark ratio.

In order to evaluate, from the energy and economic point of view, a poplar SRC, in the river Po Valley, an *ad hoc* study was made and a specific model was developed.

On the basis of this cultivation technique, an energy and economic evaluation of a poplar SRC in Northern Italy was realised. In detail, were considered data of poplar growth, in a plantation for the production of 6 year whips, in Western Po Valley, considering a SRC duration of 6 years and a biomass (15 Mg ha⁻¹ dry matter -D.M. per year) harvest at the end of cycle (6 years). In this computing system it was pointed out that the SRC is very interesting from an energy point of view, since the output/input ratio results to be higher than 18. The same is not true for the poplar SRC from an economic point of view. In order to obtain economic SRC sustainability, the biomass price should be at least 115 € Mg⁻¹ D.M. A large biomass diffusion will be possible only with an increase of the biomass market value, or with economic sustain for its production.

Keywords

Short rotation coppice; biomass production; economic evaluation; energy consumption

27 **Introduction**

28 The cultivation of crops for biomass production on good, arable soils allows to increase the
29 energy production, with many advantages from the environmental point of view. This solution
30 increases the farmers' revenues and leads to advantages for the environment [1,2,3,4,5].

31 In the last 10 years, the cultivation of crops for biomass production has been inserted in the
32 cultural plans of several farms, particularly in Northern Italy; farmers take advantage of their
33 low input requirement and the added possibility of exploiting set-aside areas [6]. In Italy,
34 there are two different methods of cultivation: very Short Rotation Coppice (vSRC), with very
35 high density, from 5,500 to 14,000 plants ha⁻¹ and harvested with a rotation period of 1-4
36 years and Short Rotation Coppice (SRC) with a high density from 1,000 to 2,000 plants ha⁻¹
37 and harvested with a rotation of 5-7 years [7,8]. In Europe, the farmers prefer the vSRC
38 cultivation model [9,10,11,12,13], while in Italy, recently, the farmers prefer the previously
39 described SRC method, because the most recent poplar hybrids have enhanced productivity
40 and improved the biomass quality (high calorific value), as a result of a better wood/bark ratio
41 [14,15,16,17]. Furthermore, it is also preferred, because in the rural development plans of the
42 main Regions of northern Italy, the establishment of this cultural model is financed.

43 Most of the studies carried out until now in Italy have focused only on the vSRC method, as
44 they are more spread throughout the territory; little has been yet experienced on the SRC
45 method [18,19].

46 In order to evaluate from the energy and economic point of view a poplar SRC in the river Po
47 Valley an *ad hoc* study was made and a specific model has been developed.

48

49 **Materials and methods**

50 A series of data were collected, both in the nursery and in the poplar SRC plantation, nearby
51 the experimental farm "MEZZI" of CRA-PLF, close to Casale Monferrato (AL), during 2006-
52 2012 period. All the cultural operations for poplar plantation were analysed: the working time

53 and both machines and manpower requirements were recorded on the field, in compliance
54 with CIOSTA (Comité International d'Organisation Scientifique du Travail en Agriculture)
55 methodology, on at least 5.000 m² surface areas and for periods not shorter than 2 hours [20].
56 The developed model allowed the determination of manpower and energy requirements, as
57 well as the costs analysis considering different crop density and biomass production. The
58 model considers a continuous poplar SRC plantation: the whole acreage is divided into
59 different “modules”, each corresponding to 1 year of the crop cycle, allowing to refer all costs
60 to annuity. Regarding the economic and energetic evaluation, a 6 years rotation, with
61 harvesting carried out at the end of the cycle and with a starting poplar plants density of 1100
62 for hectare was considered, with a 3.00 × 3.00 m spacing and a mean production of 15 Mg ha⁻¹
63 ¹D.M. year⁻¹ [21,22]. For all post-emergency treatment, it was supposed to use traditional
64 tractors with 4 RM, with a maximum width of 2.2 m. In detail, for the nursery and the poplar
65 SRC plantation it was assumed to prepare the soil with ploughing at 40 cm depth after seed
66 bed fertilization – 500 kg ha⁻¹ of 8.24.24 (N,P,K).
67 Secondary tillage was carried out by two harrowing interventions, while for the plantations of
68 rods (1.20-2.00 m in length), an Allasia V1 planter was considered [23]. The cultural
69 operations assumed for the SRC cultivation and nursery were fertilization and weed control,
70 both necessary to allow a high production of biomass [24,25]. Finally, it was assumed to use a
71 heavy cultivator for stumps removal (table 1-2).
72 For biomass harvesting, a chipper prototype Gandini Bio-harvester (purchase cost € 60,000)
73 was used, with a tractor of 190 kW Case Magnum 260 EP (purchase cost € 170,000). The
74 working capacity of the Gandini Bio-harvester is about 60 t h⁻¹ (about 120 plants h⁻¹)[26]. For
75 the transport of the biomass in the farm (about 400 meters distant), two tractors with trailers
76 were used. The average cost of the Gandini Bio-harvester was determined considering
77 contractors costs.

78

79 The manpower requirement was determined considering the number of operators and the
80 working time to carry out every cultural operation.
81

82 The energy consumption were determined considering both direct costs – fuel and lubricant
83 consumption - and primary energy – machine, equipment and mineral fertilizer energy
84 contents (table 3) [27]. Machine fuel consumption was determined by refilling the machine
85 tank at the end of each working phase. The tank was refilled using a 2000 cm³ glass pipe with
86 20 cm³ graduations, corresponding to the accuracy of our measurements.

87 The lubricant consumption was determined in function of the fuel consumption using a
88 specific algorithm setup by Piccarolo [28].

89 The human work was expressed in manpower hour requirement, for every cultural operation,
90 but it was not considered from the energy point of view.
91

92 The economic evaluation was determined for every cultural operation considering both the
93 machine cost and that of the production factors (fertilizers, plant protection products)
94 (table 4).

95 The hourly cost rate of each machine was evaluated using the method proposed by Miyata
96 [29], with prices updated to 2013. An annual utilization of at least 500 hours (tractor used also
97 for other operations) was assumed for tractors, and the power requirement was calculated by
98 taking into consideration the data recorded during experimentation and the drawbar pull and
99 power requirement, in the different operating conditions. Labor cost was set to 18.5 € hour¹.

100 Fuel cost was assumed to be 0.9 € kg (subsidized fuel for agricultural use). Also the tractor
101 hourly cost was determined with the methodology proposed by Miyata [29].

102 For the evaluation of economic sustainability it was determined the Net Present Value (NPV)
103 that indicates the difference between the total income and the total costs determined

104 considering a biomass value of 100 € Mg⁻¹D.M. This determination was done for different
105 costs of land and water use [30].

106

107 **Results**

108 Near 27 hours per year⁻¹ of manpower were required for the cultivation of one SRC hectare.
109 The biomass harvesting required less than 45% of the total time, while the pesticides
110 application required more than 9% (Fig. 1).

111

112 The energy consumption for the cultivation and management of 100 ha of poplar irrigated
113 SRF is of 15.2 GJ ha⁻¹ per year and represents about the 5% of the biomass energy production
114 (about 270 GJ ha⁻¹ for year). The input/output ratio is close to 18. The largest part of energetic
115 input (44%) is linked to cultural operations, in particular at the top dressing (36% of the total
116 energy requirement). Harvesting and biomass transport to the farm storage represents about
117 25% of the total energy requirements; the flood irrigation does not require any energy input
118 (Fig. 2).

119 In conclusion, for arable surfaces between 50 and 200 ha, the total energy cost resulted
120 between 4.9 and 5.2% of the energy produced.

121 In the total balance, the direct energy cost results to be 1.9% and the indirect energy cost the
122 3.0%, for a 50 ha SRC cultivation and 3.2% for a 200 ha SRC cultivation.

123

124 The production cost of the SRC with 6 year cycle resulted closely connected to both the
125 cultivated surfaces and to the production level. Considering a biomass production of
126 90 Mg ha⁻¹ D.M. per cycle, equivalent to about 180 Mg ha⁻¹ W.B., the production cost is close
127 to 122 € Mg⁻¹ D.M. for SRC surfaces of 100 ha (Fig. 3), a value higher than the market price
128 of wood chips (95 € Mg⁻¹ D.M.) .

129 The cultural operations that have the higher weight on the total production costs are the “crop
130 management operations” (near 26,9%) (Fig. 4). The most expensive are the interrow
131 cultivations (weed control) for post-emergence treatment and the irrigation intervention; but
132 these operations are indispensable to get a high biomass production. Besides, land use costs
133 showed also a high incidence on the total costs. For example, considering a 100 ha SRF
134 surface, with $15 \text{ ha}^{-1}\text{year}^{-1}$ D.M. biomass production, for every cycle and zero cost for
135 irrigation, the biomass cost production is 113 € Mg^{-1} D.M., with land use cost of $200 \text{ € ha}^{-1}\text{year}^{-1}$.
136 In the case of a land use cost of $400 \text{ € ha}^{-1}\text{year}^{-1}$ the biomass production cost is of
137 126 € Mg^{-1} D.M. The land rent cost weights upon total production cost for the 11 and 21%
138 respectively. Considering zero the cost rate of land, the biomass production cost fluctuates
139 from 103 € Mg^{-1} D.M. to 119 € Mg^{-1} D.M. with 50 and 300 € ha^{-1} irrigation costs respectively
140 (Fig 5-6).

141 Nevertheless, it has to be considered the influence of the transport and storage costs in terms
142 of biomass losses on the total biomass production cost. The transport cost weights upon total
143 cost for the 2 and 15% for distances of 5 and 50 km respectively (Fig. 7).

144

145 **Discussion**

146 The poplar SRC plantation, in the considered condition, - 6 years rotations, with harvesting
147 carried out at the end of the cycle and a production of $15 \text{ Mg ha}^{-1}\text{D.M. year}^{-1}$, - is very
148 interesting under the energy point of view, since the output/input ratio results to be higher
149 than 18.

150 This value is 5 points higher than that calculated for a vSRC by Manzone et al [17]. The better
151 results are to be attributed at the minor energy consumption for SRC planting, because the
152 rods preparation is less expensive compared to cuttings production and the SRC starting
153 investment ($1,700 \text{ plants ha}^{-1}$) is minor to vSRC plantation ($6,700 \text{ plants ha}^{-1}$).

154 Furthermore, the use of rods in SRC planting reduces also the energy consumption for the
155 weed control, because the shoots are placed at a height (50 – 120 cm) greater than that of the
156 cuttings and they can better compete with the weeds.

157
158 The largest part of energy input (44%) is linked to cultural operations, in particular at the top
159 dressing (36.8% of the total energy requirement) necessary to have a high biomass production
160 ($15 \text{ Mg ha}^{-1} \text{ D.M. year}^{-1}$) [31] as well as to choose the most appropriate clone for the site [11].

161
162 In the total balance, the energy input per unit biomass produced is 4.1% of the energy output.
163 This value is similar to that found in another analysis made in Sweden on willow SRC [32].

164
165 The SRC economic evaluation, differently from energy point of view, is negative because the
166 market price of the woodchip is low respect to value of production. In fact, in order to get
167 economic SRC sustainability, the biomass price shall be at least $115 \text{ € Mg}^{-1} \text{ D.M.}$ ($\text{€ } 15$ more
168 than to currently market price).

169 But with this model, in 6 years trees with a diameter at breast height of 150-200 mm are
170 grown. So the basal part of the trunk, up to 4-6 m, can be used to produce industrial wood
171 (OSB panel, packaging) with a value higher than the one of wood chips for energy. In this
172 case the economic balance become positive [33].

173 Since the tree have not a small diameter ($> 150 \text{ mm}$), this biomass plantations
174 offer woodchips of high quality, with high fibres content (85–90%) and favourable particle-
175 size distribution. On the contrary, vSRC presented a high bark content ($>20\%$) and
176 occasionally a mediocre particle-size distribution, being often too rich in fines ($>10\%$). These
177 problems were especially serious with fuel derived from 1-year old vSRC sprouts [18].

178 A material with high bark content have a low market price because showed a low lower
179 heating value and a high ash content [34,35,36]

180

181 Besides, it is to highlight that the rods planting is a difficult operation management due to the
182 reduced available time (march and april) and because the planters used have a low working
183 rate and required a high manpower [23].

184

185 **Conclusions**

186 A large SRF plantation diffusion will be possible only with an increase of the biomass market
187 value or with economic support for the production.

188 At present, Italian farmer prefer the SRC cultivation model respect to that vSRC cultivation
189 model because from tree with 6 years of age is possible to obtain wood assortment of high
190 economic value to sell to sawmills (packaging) or for OSB panel production.

191 It is to underline that SRC cultivation can contribute to solve the problem of the exceeding
192 traditional cultivations and that it is able to improve the relations between agriculture and
193 environment. It's getting more important to find low environmental impact cultural solutions
194 able to maximize the biomass yield by using the poplar auxometric curve.

195

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