1 **Energy and CO2 emissions associated with mechanical planters used in**

2 **biomass plantations**

3

4

5 **Abstract**

6 Until now, SRC has been studied from many points of view (economic sustainability,

7 environmental impact, harvesting systems, etc.), but few studies of the actual planting

8 operations have been carried out. The objective of this study was to evaluate the energy

9 input and CO2 emission were evaluated during very Short Rotation Coppice (vSRC)

10 planting. The analysis was performed considering different planter types and tree

11 species (poplar, willow and black locust).

12 This work showed that the energy input and CO_2 emission of vSRC planting is linked to

13 different planter types and, consequently, to the type of planting material used (rods,

14 cuttings and rooting plants). Among the combinations tested, rods planters showed the

15 lowest value for energy consumption (356 MJ ha^{-1}) and CO_2 emission (31 kg ha^{-1})

16 compared to universal planters type (1,028 MJ ha^{-1} and 92 kg ha^{-1}). No difference

17 between tree species was observed in this experiment. Results highlighted that the

18 energy input required by the planting operation is only 1.7% of the total energy input of

19 the vSRC.

20

21 **Keywords**

22 Short Rotation Coppice, planters, productivity, fuel consumption, energy input, CO_2

23 emission

24

1. Introduction

In Europe, there are two different methods of SRC cultivation: very Short Rotation Coppice (vSRC) with a very high density, from 5,500 to 14,000 plants per hectare, and a harvesting cycle of 1-4 years, and Short Rotation Coppice (SRC) with a high density, from 1,000 to 2,000 plants per hectare, and a harvesting cycle of 5-7 years [1]. In general, because the trees do not have a small diameter (>150 mm), the SRC with the highest rotation time (5-7 years) offers woodchips of high quality, with a high fibre content (85–90%) and a favourable particle-size distribution. On the contrary, vSRC presents a high bark content (>20%) [2-3] and occasionally a mediocre particle-size distribution that is often too rich in ash (>10%) [2, 4]. Nevertheless, farmers prefer the vSRC cultivation model because it has a lower rotation period and allows for a more rapid change of the tree culture in the case of poor economic benefits [5]. Furthermore, its cultivation and harvest machines and methods are more familiar to farmers.

The main forestry species used in fast-growing wood crops for biomass production are willows, poplars, eucalyptus and black locust [6-7]. Generally, the choice of the forestry species is made as a function of the soil and landscape conditions where the SRC is planted [8].

Over the years, many aspects of vSRC have been studied - economic sustainability [8], environmental impact [9-10], and harvesting systems [11-12] - but SRC planting has not been well studied [13]. In fact, the machines and implements used in planting operations are adapted from other agricultural sectors (mainly the horticultural sector) or are only

49   prototypes [14-15]. Generally, the choice of planters is made on the basis of the tree

50   species used in vSRC because different tree species present a different planting material

51   (rods, cuttings, and rooting plants) and consequently require different types of planters.

52   In fact, in poplar and willow vSRC, it is possible to use cuttings and rods, while in black

53   locust and eucalyptus vSRC, only rooting plants can be used [13, 16].

54

55   Often, when an evaluation of the energy or of the environmental impact of biomass

56   plantations is performed, the average values are considered independently from the

57   planter types used [17]. However, this assumption is not completely correct because the

58   planter types both in the amount of power that they require and in their productivity

59   [16].

60

61   To improve the understanding of the energy consumption and CO2 emission required in

62   the planting operation, the goal of this study is to evaluate the performance of six

63   different types of planters used in vSRC planting in order to show which one is

64   mechanically more efficient.

65

66   **2. Materials and methods**

67

68   In this experiment, different types of planters used in a vSRC plantation were tested.

69   Trials were performed using a "rod planter" (a machine that works only with rods, three

70   "cutting planters" (machines that work only with cuttings), and two "universal planters"

71   (machines that can work with both cuttings and rooting plants) (Table 1) [16]. In this

72   study, rod was considered a stem of at least 3 m length and 20 mm bottom diameter.

73

74   Because these planters have a large mass (approximately 600-700 kg) and size, they

75   require a tractor of adequate mass to guarantee longitudinal stability during manoeuvres.

76   In the test, each planter was coupled with a tractor with the minimum mass required to

77   guarantee longitudinal stability during the manoeuvres (Table 1). All of the tractors

78   chosen showed a nominal power of at least 44 kW.

79

80   The planters were tested the establishment of a very Short Rotation Coppice plantation

81   of hybrid poplar (*Populus x canadensis*), willow (*Salix*) and black locust (*Robinia*

82   *pseudoacacia*) because these species can be considered to be representative of the

83   planters used [16].

84

85   All of the planters were tested on sandy soil, with a moisture content between 8 and

86   10%. The tests were carried out in an area of 3 hectares, with plots that were 200 metres

87   in length and 150 meters in width. This area was a fenced ~~area~~ field in northwest Italy,

88   near the town of Alessadria (45° 8' 33" N; 8° 28' 11" E).

89

90   A starting plant density of 6,700 plants per hectare was adopted for all of the tree

91   species. The trials were carried out assuming a distance between rows of 3.00 metres

92   and a distance between plants of 0.50 metres [16].

93

94   All of the tests were performed under the same weather conditions (air temperature 9-11

95   C°, and relative humidity 69-73%) and lasted for 3 days. The planters were allotted by

96   random methods. Because the planters showed a different working width (3 and 6

97 metres as a function of the number of rows worked), each test consisted of five full runs

98 (1000 metres) carried out continuously (with four turns). For this reason, during data

99 analysis, a different surface worked by the planters was considered, which consisted of

100 3000 m^2 for planters equipped with only a planting device (one row) and 6000 m^2 for

101 planters that worked with two planting devices (two rows). The author considered a

102 distance of 1000 m to be sufficient to determine the fuel consumption and productivity

103 [15]. Each combination of planter and tree species was replicated three times, for a total

104 of 42 replications (black locust was planted only with the "universal planters") (Table

105 2).

106

107 Before testing, the soil was prepared by ploughing at a 40 cm depth. For all of the

108 "cutting planters", cuttings of a diameter of 9 to 25 mm and length of 200 to 220 mm

109 were used. The "universal planters", in addition to working with to those used for the

110 "cuttings planters", also worked with the black locust rooting plants that were 0.60 m in

111 height. The "rod planters" worked with rods that had a diameter of 20 to 40 mm and a

112 length of 3.00 metres.

113

114 *2.1. Field capacity*

115

116 To attribute fuel and energy consumption and CO_2 emission to the work surface unit,

117 the field capacities of all of the planters were calculated. Field capacity was determined

118 considering the expended time, which was recorded following the CIOSTA (Comité

119 International d'Organisation Scientificue du Travail en Agricolture) methodology [25].

120 Each time element was quantified using a centesimal digital stopwatch (Hanhart®

121 PROFIL 5). Specifically, the field capacity was calculated by dividing the worked

122 surface area by the unit time and was expressed in ha h^{-1}.

123

124 *2.2. Fuel consumption*

125

126 The fuel consumption for the entire planting operations was determined by the

127 "topping-off system." This method involves measuring the fuel consumption by

128 refilling the tractor tank after each test. The tank was refilled using a 2000 cm^3 glass

129 pipe with 20 cm^3 graduations, corresponding to the accuracy of the measurements. In

130 this work, the fuel consumption was determined considering the manoeuvres that were

131 carried out in the headland up to the point of a change in the forward direction and the

132 runs that were necessary to load the planters.

133 To determine the specific fuel consumption for the planting operations, the actual power

134 required to move the planters was calculated in relation to the traction force and the

135 forward speed used in the working conditions. Specifically, the traction force was

136 measured using a tractor of 140 kW of nominal power (tractor A) and a dynamometer

137 Allemano TCA with an accuracy of 0.03%. The net force required to move only the

138 planters was calculated as the difference between the force required to pull the tractor

139 coupled with each planter (tractor B + planter) and that necessary to pull only tractor B

140 (Fig. 1).

141

142 The lubricant consumption was estimated as a function of diesel consumption according

143 to the ASABE methods [19].

144

145   *2.3. Energy consumption*

146

147   In this experiment, the total energy required for vSRC planting was determined by

148   considering the direct energy consumption – the energy input to perform the planting

149   operation (fuel and lubricant consumption) – and the indirect energy consumption – the

150   energy used for the manufacturing the tractors and implements. In particular, an energy

151   content of 92.0 MJ kg^{-1} for the tractors and an average value of 69.0 MJ for each

152   kilogram of machine mass was considered for all of the planters [20]. The direct energy

153   input was calculated considering an energy content of 37.0 MJ L^{-1} for the diesel [21]

154   and 83.7 MJ kg^{-1} for the lubricant [20]. Additionally, 1.2 MJ kg^{-1} was added to these

155   values, as additional fossil energy source was used in their transportation and

156   distribution [22].

157   In this study, a lifetime of 10,000 and 5,000 hours was considered for the tractors and

158   the planters, respectively [23]. The energy spent for maintenance and repair was

159   considered to be 55% of the energy required for manufacturing the machines [24]. The

160   energy requirement for the production of the cuttings, rooting plants, and rods was not

161   considered in this evaluation.

162   The energy output was attributed to the unit surface worked and biomass harvested,

163   considering a dry matter energy content of poplar wood of 18.8 MJ kg^{-1}. This

164   calculation was performed considering an average biomass production of 15 Mg ha^{-1} per

165   year and a 6 year rotation with harvesting carried out every 2 years [25].

166

167   *3.3. Environmental assessment*

168

169 The environmental impact of the planting operations was calculated based on the CO_2

170 emission due to the fuel combustion during the work and machinery manufacturing.

171 Specifically, a value of 3.76 kg per litre of diesel [26-27] and a value of 2.94 kg for each

172 kg of lubricant [28] released into the atmosphere were assumed. In addition, a value of

173 159 g per each MJ of energy content in the machines was considered in the calculation

174 of the frequency of maintenance and repair on the environmental impact [12].

175

176 The data were processed using Microsoft Excel and SPSS 21 (2015) statistical software,

177 using an ANOVA procedure with a GLM approach and adopting a significance level of

178 $\alpha = 0.05$. Eventual differences between treatments were checked with the Scheffe's test

179 because it has a higher statistical power given this data distribution [29]. Scheffé's

180 method is a single-step multiple comparison procedure which applies to the set of

181 estimates of all possible contrasts among the factor level means [30].

182

183 **3. Results**

184

185 *3.1. Field capacity*

186

187 The highest field capacity (1.20 ha h^{-1}) was obtained using the Salix Maskiner Step (rod

188 planter) independent of the tree species considered (poplar or willow) (Table 3). In

189 contrast, the lowest field capacity was observed for the universal planters (Allasia R1

190 and Berto), with values that ranged between 0.27 ha h^{-1} and 0.29 ha h^{-1}. In this case, no

191 difference was noted between the tree species tested. Intermediate values in productivity

192 (0.56-0.57 ha h^{-1}) were obtained from the cutting planters.

193

194   Results showed significantly different performances only between the planter

195   categories; there were no significant differences between specific makes and models

196   that were included in each category (Table 3).

197

198   *3.2. Fuel consumption*

199

200   The diesel consumption varied between 6.19 and 8.89 litres per hour (Table 4). The

201   universal planters showed the lowest value, while the Salix Maskiner Step (Rod planter)

202   showed the highest value. In the trials, the hourly fuel consumption increased according

203   to the power of the tractor, with a linear trend that was independent of the planter's type

204   and the tree species planted (Fig. 2) (Table 4)..

205

206   Referring to the fuel consumption ~~of~~ <u>for</u> the unit of worked surface, the best

207   performances were obtained by the Salix Maskiner Step (7.82 L ha^{-1}), while the worst

208   performances were observed in the Allasia R1 planter (22.24 L ha^{-1}) (Table 5). That

209   difference should not be underestimated because by using a correct planter, it is possible

210   to save a substantial amount of diesel (3 times).

211

212   Results showed significant differences in the values between the planter categories,

213   which could be due to the different working width and forward speed of the planters. In

214   fact, the universal planters that worked only with one row showed the highest fuel

215   consumption per unit surface, while the lowest value was obtained by the Salix

216 Maskiner planter, which worked with two rows and with a high forward speed (up to 4

217 km h^{-1}) (Table 5).

218

219 No difference was noted between tree species (poplar, willow and black locust) in the

220 fuel consumption (Table 5).

221

222 Results indicate the average specific fuel consumption in the planting operation of 63.5

223 g kWh^{-1}. In addition, for this parameter, no differences between the planter types and

224 tree species were observed in the statistical analysis (Table 6).

225

226 *3.3. Energy consumption*

227

228 The energy consumption of the tested planters ranged between 356 and 1,028 MJ ha^{-1} as

229 a function of the differences in their mass, fuel consumption and field capacity. In

230 particular, the rod planter showed the lowest value, while the universal planters showed

231 the highest value. Regarding these values for the material planted, only 54 kJ per plant

232 (cutting) was observed with the Salix Maskiner, while approximately 154 kJ per plant

233 was calculated for the universal planters. In general, the cutting planters presented

234 values that were approximately 60% less than those of the universal planters (Table 6).

235

236 Results did not indicate any difference between the tree species (poplar, willow and

237 black locust) that were planted (Table 6).

238

239 *3.4. Environmental assessment*

240

241 The CO_2 emission calculated in this study ranged between 31.19 kg ha^{-1} (5 g per plant)

242 and 95.79 kg ha^{-1} (14 g per plant). Different values were obtained for each planter

243 category during the CO2 emission calculation. An average value of 92 kg ha^{-1} (14 g per

244 plant) was observed for the universal planters. These values were approximately 40%

245 higher than those calculated for the cutting planters and 65% higher than those

246 calculated for the rod planter. Additionally, for this parameter, no differences between

247 tree species were noted during the statistical analysis carried out at a significance level

248 of $\alpha = 0.05$ (Table 7).

249

250 **4. Discussion**

251

252 For field capacity, better results (1.20 ha h^{-1}) were obtained using the rod planter

253 because with this machine, it is possible to operate at a higher forward speed (4.0 km h^{-}

254 ^{1}). By contrast, universal planters showed lower field capacities (0.28 ha h^{-1}) compared

255 to cutting planters (0.56 ha h^{-1}) only as a function of the number of rows worked (one

256 row instead of two rows). In fact, assuming an equal working width for both machine

257 categories, there are no differences regarding the working rate. These results are in line

258 with those obtained in other studies [13, 15-16].

259

260 Hourly fuel consumption is proportional to the tractor's engine power [31]. High values

261 were obtained for planters coupled to tractors with a high nominal power. Regarding

262 fuel consumption per unit surface, the situation changes because ~~the~~ fuel consumption is

263   linked to ~~the~~ working rate. In fact, the best results were obtained by the Salix Maskiner

264   because with this planter, it is possible to operate on two rows simultaneously with a

265   high forward speed (up to 4.0 km h^{-1}) [16].

266

267   Furthermore, the data analysis indicated that for vSRC planting, it is possible to

268   consider an average specific fuel consumption of a tractor of 63.5 g kWh^{-1}. This value is

269   approximately 50% lower than the values obtained in biomass-harvesting operations

270   (115-120 g kWh^{-1}) [24, 32-33].

271

272   The energy consumption analysis indicated that for vSRC planting, up to 1,04 MJ ha^{-1} is

273   necessary when using universal planters, while this value decreased by approximately a

274   factor of five when the rod planters are used. This low value can be attributed to a

275   different working width and forward speed [15]. Therefore, improvements can be

276   obtained by building planters with a double planting device. As to raising forward

277   speed, the solution is more complex. The low forward speed is linked to human work

278   because the planters are manually fed [16]. Therefore, to increase forward speed, it is

279   necessary to develop a specific device that is able to feed the planter automatically. In

280   fact, the setup of automatic planting devices could allow to obtain good results, not only

281   in terms of the work productivity [33-34], but also in terms of the energy efficiency.

282

283   The energy consumption observed in the planting operations was only 1.7% of the total

284   energy input to the vSRC plantation [10]. Furthermore, considering a biomass

285   production of 15 Mg per year and a cycle of 2 years [25, 35], the energy required by the

286   planting operations has a low impact on the total biomass production (minor, at 0.5%).

287 This value is lower (approximately 60%) than the energy input to the harvesting

288 operations that was obtained by Fiala and Becenetti [12] (1.1% of the energy content in

289 biomass produced).

290

291 In this study, the energy consumption of the universal planters – planters that work with

292 all forestry species – is constant for all of the tested forestry species. This situation

293 could be positive because it permits the selection of tree species as a function of only

294 site conditions and their cultivation limits and potentialities [36]. In contrast, the type of

295 planting material (rods, cuttings or rooting plants) could directly influence the choice of

296 planter models and, consequently, the energy consumption.

297

298 Furthermore, the data analysis shows a different value for the CO_2 emission during

299 biomass planting as a function of planter type. Lower results were observed for the rod

300 planters (31 kg ha^{-1}) in comparison to 92 kg ha^{-1} emitted when universal planters were

301 used. This difference can be attributed to the differing productivity of the planters. In

302 fact, in this study, the rod planter presented the highest values, while the universal

303 planters presented the lowest values. Nevertheless, a high forward speed could have

304 negative impacts on crop performance or survival. In general, these results are in line

305 with those obtained during an environmental impact assessment of biomass production

306 by dedicated poplar plantations [37-38].

307

308 **5. Conclusions**

309

13

310 The energy input of vSRC planting is linked to different planter types and,

311 consequently, to different types of propagation material (rods, cuttings and rooting

312 plants). The rods planter has the lowest energy consumption and CO2 emission. In

313 contrast, no difference was found when comparing the different tree species (poplar.

314 willow and black locust). This study have also demonstrated that the energy

315 consumption of planting operations is very small compared to the energy content in

316 biomass produced (approximately 0.5%). Furthermore, this work showed that the

317 specific fuel consumption that is required by vSRC planting is lower than 5% compared

318 to that required for biomass harvesting.

319 Finally, in the future, it would be interesting to conduct a specific evaluation on

320 productivity, energy consumption and CO_2 emission during the production of the

321 different planting materials to obtain a complete profile of the total energy input and

322 CO_2 emission required in the planting operations.

323

324

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