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Efficiency of a compactor in wood chip volume reduction

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(Article begins on next page)

1 Efficiency of a compactor in wood chip volume reduction

2

3 Abstract

The baling of freshly harvested wood chips was tested in an Orkel MP2000, a 4 5 baling machine extensively used in agriculture and industry to densify residues. Wood chips from two different feedstocks: poplar (Populus x euroamericana) 6 7 and black locust (Robinia pseudoacacia). Baling effected a volume reduction of 8 43 % with respect to the loose bulk density of the piled chips. Each bale has an 9 average mass of 638 kg, and the time consumption to produce one bale was typically 98 s - 122 s. Productivity then varied from 19.8 t h⁻¹ and 21.7 t h⁻¹ of the 10 fresh (green) wood chips. Diesel fuel consumption ranged from 1.4 L t⁻¹ to 1.5 L 11 12 t⁻¹ of fresh chip weight and represented about 12 % of the production cost. The packaging cost is approximately $23 \in t^1$ of fresh chips equivalent to a bale cost 13 14 of 15 €. Comminuted wood pressed into bales could provide a valid solution in 15 the use of conventional agricultural and forestry machines. In fact, the handling and transportation of bales can be performed by means of equipment normally 16 17 used in other agro-forestry activities (front loaders of tractors). In addition, 18 pressed woodchips in packaged bales with waterproof sheets also guarantees a 19 useful storage technique with significant storage surface reduction relative to 20 loose wood chips.

- 21
- 22

23 Keywords: agroforestry, <u>poplar, black locust</u>, woodchips, volume reduction,
24 bales

26 Introduction

27 In the last years, many governments support through subsidies, tax-exemptions 28 and other incentives the use of wood biomass how a concrete alternative to 29 fossil oil use [1]. Wood biomass is available in many forms, but the woodchip is 30 that most common because offers benefits in terms of omogeneity size and 31 increased load density [2]. For this reason, bulky biomass should be chipped as 32 early as possible in order to simplify the passages all along the supply chain [3]. 33 This explains the ever greater use of chippers which allow size reduction of 34 wood biomass before transportation [4]

35

36 One of the weak points of energy wood chains is the biomass transportation 37 from the forest landing to the boiler [5-6]. This operation is critical because the 38 vehicles must have a low operating cost [7-8]. In fact, biomass transportation 39 can influence the final biomass cost up to 20% for a distance of 50 km [9]. 40 Another important aspect to consider in wood chip transportation is the vehicles' 41 versatility. Generally, the versatility of these vehicles is gauged through their 42 capability to directly load the wood chips in the field, as well as the possibility to 43 use standard farm equipment for loading them [10]. At the same time, it is also 44 measured as a function of the possibility to load different biomass types.

45

Usually, biomass transportation, particularly woodchips transportation, is
performed by specific trucks defined as "trucks with large volumes" because
they are equipped with a container sized to reach the maximum volume allowed
by road standards. Unfortunately, these trucks have a higher rental cost and

50 can be loaded by specific handlers able to reach heights of at least 5 meters51 [10-11].

52

In order to also use conventional vehicles for the transport of wood chips, it is necessary to pack the biofuel in a "single unit" with high density. An average weight of approximately 500 kg for each "single unit" could be suitable because that weight is the usual payload of all farm handlers. In this way, the wood chips could be loaded and transported by any vehicle equipped with a load floor.

58

On the basis of the foregoing discussion, the goal of this study is to evaluate the
performance of a packing machine, normally used in maize ensilage, during
wood chip packaging.

62

63 Materials

The machine chosen for the test was an Orkel MP2000 Compactor (Fig. 1). The
Orkel MP2000 was used both in the industrial sector for baling of urban waste
and in the agricultural sector for the wrapping of silage and milling products.

67 The machine operates automatically due to an integrated hydraulic system. All

functions are inspected by the electrical CAN-BUS control system.

69 The optimal amount of material is supplied to the compaction chamber under

the supervision of an advanced and reliable sensor system. The wrapping takes

71 place parallel to the baling. After the wrapping with a waterproof sheet, the

bales are gently placed on the ground. This working system allows the machine

to be operated by a single operator. In fact, the operator must only be

concerned with filling the loading hopper and removing the wrapped bales.

During the test, the machine was powered by a tractor with 110 kW nominalpower.

77

The machine was tested with wood chips obtained from two different feedstock: 78 79 poplar (Populus x euroamericana) and black locust (Robinia pseudoacacia L.). 80 Hybrid poplar and black locust are the main species used in biomass 81 plantations and, for this reason, they were considered representative of the 82 feedstock handled by wood chips compaction. The material used in the trials 83 was obtained from biomass plantations of twelve years old sited in Moncalieri 84 Turin/Italy (44°58'44"N, 7°43'07"E; 246 m above sea level). The average butt diameter of the individual pieces was 220 mm, while the maximum diameter 85 86 was 270 mm. All of the wood was freshly felled and had moisture contents (i.e. 87 water mass fractions) of 55% and 45% for poplar and black locust, respectively. The material was comminuted in the field by a drum chipper (Pezzolato PTH 88 89 900) and transported in the farm where it was immediately processed. The 90 woodchips produced were made available in two piles built near the machine tested. A wood chip volume of 66 m³ (whole capacity of three trailers used for 91 92 wood chip transportation) for each tree species tested (poplar and black locust) 93 was used in this experiment. During the test, the compactor was stationed near the pile (approximately 15 meters). A telescopic handler, equipped with a 94 bucket with a 3 m³ capacity to move the wood chips into the feeding device, 95 96 was used. The bales were moved with another telescopic handler equipped with 97 a specific device (crab) (Table 1).

100	Methods
101	The particle size distribution of the chips used for the experiment was
102	determined for one kilogram samples with an oscillating screen according to the
103	European Standard EN 15149-1: 2011. The chips were divided into the
104	following eight length classes: <3.15 mm, 3.16-8 mm, 9-16 mm, 17-31.15 mm,
105	31.16–45 mm, 46–63 mm, 64–100 mm, and >100 mm. Each fraction was then
106	weighed with a precision scale.
107	
108	The sampling unit consisted of a single trailer (22 m ³). The machine was
109	studied while carrying out its scheduled commercial activity and observations
110	were blocked for each trailer. Subsequently, the results were divided by the
111	number of bales produced and the values were expressed per single bale.
112	
113	Productivity was calculated according to methodology described by Magagnotti
114	and Spinelli [12] where a complete trailer was considered as a cycle. Working
115	times were recorded following the IUFRO classification [13]. Average times
116	were shown per single bale.
117	
118	Productivity was calculated measuring the weight of each bale produced.
119	Moisture content was estimated on one sample per trailer weighing immediately
120	and after drying for 24 hours at 103° C in a ventilated oven.
121	The fuel consumption for the entire compacting operation was determined by
122	the "topping-off system" [14]. This method involves the fuel consumption being

measured by refilling the tractor tank after each trailer volume was processed
(11 bales). The author considered this time sufficient to estimate the real
consumption necessary to produce a single bale.

126

127 Machine cost was calculated using the procedure described by Miyata [15]

128 (1980), with an estimated annual utilization of 200 hours (approximately 9,000

129 bales). The corresponding investment costs were 340,000 €. In all cases, the

130 depreciation period was assumed to be ten years. Value retention at the end of

131 this period was estimated to be 20 % of the original investment. Repair and

132 maintenance costs were directly obtained from the machine owner. The labor

133 cost was set to $18.5 \in h^1$. Fuel cost was assumed to be $1.1 \in L^1$ (subsidized

134 fuel for agricultural use). The total cost included 20 % profit and overheads [16].

135 Further details are shown in Table 2.

136

137 All data were checked for normality and statistically analyzed with either

138 parametric or non-parametric tests, according to distribution (SPSS 2014).

139

140

141 **Results**

142

143 The time consumption to produce one bale was typically 98 s - 122 s. Diesel

144 fuel consumption ranged from 0.60 L to 0.62 L for each bale equal to 0.48 L m⁻³

145 and 0.52 L m⁻³, respectively (Table 3). The bulk density value obtained in this

146 work was 323 kg m⁻³. This value was similar for the two species tested and it

147 was determined by weighing 6 trailer loads with a certified weighbridge.

148 Productivity then varied from 19.8 t h⁻¹ and 21.7 t h⁻¹ of the fresh (green) wood

149 chips and diesel fuel consumption ranged from 1.4 L t⁻¹ to 1.6 L t⁻¹ of fresh chip

150 weight. Independent of the two species considered, the machine showed a

151 working rate of 33 bales per hour and a net productivity (productivity calculated

152 with unproductive time) of 43 bales (Table 3).

153

154 For each bale, having an average weight of 638 kg (Table 3), it was possible to

guarantee a volume reduction of 43%. Nevertheless, a material loss of 1.5%

156 (Table 3) resulted during the wood chip compaction.

157

158 Considering a significance level of 0.05 with U of Mann-Whitney test (used 159 because the homogeneity of the variance was not verified), variations in time 160 consumption, bale weight, volume reduction, fuel, and working rate were not 161 related to the two feedstocks.

162

163 During the trials, the compactor has guaranteed a good level of efficiency

showing a highly productive working time (approximately 70%). Unproductive

time (supportive work time and delay), mainly due to machine preparation and

166 malfunctions, were reduced (13%) (Fig. 2).

167

168 Unit cost was calculated by dividing the hourly cost by net productivity (43 bales 169 h^{-1}). The resulting packing costs were 23 \in f¹ of fresh chips (approximately 15 \in

170 per each bale). Fuel cost represented about 12 % of the production cost (Fig.

171 **3**).

172

173

174 **Discussion**

175

176 The compactor tested highlighted a high productivity, similar to a chipper with

177 the same power (19.8 t h^{-1} and 21.7 t h^{-1}). This result was confirmed after

acquiring the database of Spinelli and Magagnotti [17]. That aspect is very

179 important because the wood chip packaging can be performed simultaneously

180 during the chipping operation without unproductive times.

181

182 Work efficiency of the compactor is in line with the machines used in wood chip

183 production. In fact, the overall incidence of net packing time was similar to what

184 was recently reported in a general survey of chipping operations in Italy [18],

although the distribution of unproductive time was different. This situation may

186 depend on the peculiarities of the different feedstock used (homogenous wood

187 chips instead of stem and brushwood with different sizes and shapes).

188

189 In this study, as in chipping operations [19-20], the use of harder (black locust)

190 and softer wood (poplar) species have not influenced the compactor's

191 performance. Any differences in fuel consumption and in productivity were

192 noted during the trials.

In absolute terms, the fuel consumption of the compactor (from 1.4 L t⁻¹ to 1.6 L t^{-1}) was in line with the figures reported by Nati et al. [19] (from 0.8 L t⁻¹ to 1.6 L t⁻¹ 196 $\frac{1}{2}$) and by Spinelli et al. [20] (1.7-1.8 L t⁻¹ for poplar) for industrial drum chippers.

197

198 Unfortunately, the packing cost that resulted was high ($23 \in f^1$ of the fresh wood

199 chips – that value is referred to uncompressed wood chips), approximately 30%

of the actual Italian market wood chip price ($70 \in t^{-1}$ of the fresh woodchip).

201 Nevertheless, compacted material is easier to move and stack. In fact, moving

and staking bales could be performed by equipment normally used in the

203 ensilage and haymaking sectors.

204 In addition, because of the impermeable plastic films used for bale packages,

the bales could be stored anywhere, including outdoors.

206

207 Generally, wood chips are transported with specific "high-volume" lorries. These 208 vehicles show an important limit in the drop side height (4 meters). Specific 209 equipments (telescopic handlers) are needed to load them. Conventional 210 agricultural and forestry loaders (front loaders of the tractor or mechanical 211 shovels) do not have sufficient loading heights (generally, the max loading 212 height is 3.5 meters). The use of conventional equipment is possible only with 213 ramps where the loader can go up or trenches where the lorries can go down. 214 Wood chips pressed in bales could be a valid solution to this problem. In fact, 215 packaged bales can be loaded and transported by lorries equipped with only a load floor without drop sides because, thanks to their high mass (700 kg m⁻³), it 216 217 is possible to obtain the max lorries' payload with only a single layer of bales.

219	Furthermore, using pressed bales in wood chip storage (wood chip volume
220	reduction of 43%), the biofuel storage surface could be reduced 10 times in
221	comparison to wood chip storage in piles [21-22]. That aspect is very important
222	because the power stations are driven to optimize the interim step of wood chip
223	storage given the discontinuous nature between its harvest and its actual
224	energy production, [23]. In this case, farms could store the biofuel and transfer it
225	to the power station only when needed.
226	
227	Finally, plastic sheets used for bale packaging create an anaerobic
228	environment, which is less favorable to microbial development, that prevents
229	the proliferation of different microorganisms, which normally attack uncovered
230	piles. This storage technique allows lower losses regarding matter and energy
231	[21].
232	Because plastic material used in packaging bale is recyclable, this material can
233	be sold at a market price of $60 \in t^1$ after the bales are used.
234	
235	Conclusions
236	Conventional compactors can be used also in the forestry sector for wood chip
237	pressing and packaging and are capable of achieving the same productivity of
238	chipping machines to which they should be coupled. That solution seems ideal
239	for agro-forestry and wherever the production of wood chips is a complementary

240 business within the scope of a larger agricultural economy. In this case,

temporary "conversion" offers substantial benefits to part-time users because itallows for better depreciation of the invested capitals.

Finally, comminuted wood pressed into bales could provide a valid solution in the use of conventional agricultural and forestry machines. In fact, the handling and transportation of bales can be performed by means of equipment normally used in other agro-forestry activities (front loaders of the tractor). In addition, pressed wood chips in packaged bales with waterproof sheets also guarantee a valid storage technique and storage surface reduction.

249

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