

1 Efficiency of a compactor in wood chip volume reduction

2

3 Abstract

4 The baling of freshly harvested wood chips was tested in an Orkel MP2000, a
5 baling machine extensively used in agriculture and industry to densify residues.
6 Wood chips from two different feedstocks: poplar (*Populus x euroamericana*)
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
10 typically 98 s - 122 s. Productivity then varied from 19.8 t h⁻¹ and 21.7 t h⁻¹ of the
11 fresh (green) wood chips. Diesel fuel consumption ranged from 1.4 L t⁻¹ to 1.5 L
12 t⁻¹ of fresh chip weight and represented about 12 % of the production cost. The
13 packaging cost is approximately 23 € t⁻¹ of fresh chips equivalent to a bale cost
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
16 and transportation of bales can be performed by means of equipment normally
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.

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22

23 **Keywords:** agroforestry, poplar, black locust, woodchips, volume reduction,

24 bales

25

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

46 Usually, biomass transportation, particularly woodchips transportation, is
47 performed by specific trucks defined as "trucks with large volumes" because
48 they are equipped with a container sized to reach the maximum volume allowed
49 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 meters
51 [10-11].

52

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

58

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

62

63 **Materials**

64 The machine chosen for the test was an Orkel MP2000 Compactor (Fig. 1). The
65 Orkel MP2000 was used both in the industrial sector for baling of urban waste
66 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
68 functions are inspected by the electrical CAN-BUS control system.

69 The optimal amount of material is supplied to the compaction chamber under
70 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
72 bales are gently placed on the ground. This working system allows the machine
73 to be operated by a single operator. In fact, the operator must only be

74 concerned with filling the loading hopper and removing the wrapped bales.
75 During the test, the machine was powered by a tractor with 110 kW nominal
76 power.
77
78 The machine was tested with wood chips obtained from two different feedstock:
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
85 diameter of the individual pieces was 220 mm, while the maximum diameter
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.
88 The material was comminuted in the field by a drum chipper (Pezzolato PTH
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
91 tested. A wood chip volume of 66 m³ (whole capacity of three trailers used for
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
94 the pile (approximately 15 meters). A telescopic handler, equipped with a
95 bucket with a 3 m³ capacity to move the wood chips into the feeding device,
96 was used. The bales were moved with another telescopic handler equipped with
97 a specific device (crab) (Table 1).

98

99

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 m³). 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

123 measured by refilling the tractor tank after each trailer volume was processed
124 (11 bales). The author considered this time sufficient to estimate the real
125 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 € h⁻¹. Fuel cost was assumed to be 1.1 € 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
155 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
164 showing a highly productive working time (approximately 70%). Unproductive
165 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 € t⁻¹ of fresh chips (approximately 15 €

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
178 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],
185 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.

193

194 In absolute terms, the fuel consumption of the compactor (from 1.4 L t⁻¹ to 1.6 L
195 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) 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 € t⁻¹ of the fresh wood
199 chips – that value is referred to uncompressed wood chips), approximately 30%
200 of the actual Italian market wood chip price (70 € t⁻¹ of the fresh woodchip).

201 Nevertheless, compacted material is easier to move and stack. In fact, moving
202 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,
205 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
216 load floor without drop sides because, thanks to their high mass (700 kg m⁻³), it
217 is possible to obtain the max lorries' payload with only a single layer of bales.

218

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 € 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,

241 temporary “conversion” offers substantial benefits to part-time users because it
242 allows for better depreciation of the invested capitals.

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

249

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