Efficiency of a compactor in wood chip volume reduction

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Abstract

The baling of freshly harvested wood chips was tested in an Orkel MP2000, a baling machine extensively used in agriculture and industry to densify residues. Wood chips from two different feedstocks: poplar (Populus x euroamericana) and black locust (Robinia pseudoacacia). Baling effected a volume reduction of 43 % with respect to the loose bulk density of the piled chips. Each bale has an average mass of 638 kg, and the time consumption to produce one bale was typically 98 s - 122 s. Productivity then varied from19.8 $t\ h^{-1}$ and 21.7 $t\ h^{-1}$ of the fresh (green) wood chips. Diesel fuel consumption ranged from 1.4 $L\ t^{-1}$ to 1.5 $L\ t^{-1}$ of fresh chip weight and represented about 12 % of the production cost. The packaging cost is approximately 23 € t^{-1} of fresh chips equivalent to a bale cost of 15 €. 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 tractors). In addition, pressed woodchips in packaged bales with waterproof sheets also guarantees a useful storage technique with significant storage surface reduction relative to loose wood chips.

Keywords: agroforestry, poplar, black locust, woodchips, volume reduction, bales

Introduction

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

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

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

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.

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.

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.
The machine operates automatically due to an integrated hydraulic system. All functions are inspected by the electrical CAN-BUS control system.
The optimal amount of material is supplied to the compaction chamber under the supervision of an advanced and reliable sensor system. The wrapping takes 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 nominal power.

The machine was tested with wood chips obtained from two different feedstock: poplar (*Populus x euroamericana*) and black locust (*Robinia pseudoacacia* L.). Hybrid poplar and black locust are the main species used in biomass plantations and, for this reason, they were considered representative of the feedstock handled by wood chips compaction. The material used in the trials was obtained from biomass plantations of twelve years old sited in Moncalieri 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 was 270 mm. All of the wood was freshly felled and had moisture contents (i.e. 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 900) and transported in the farm where it was immediately processed. The woodchips produced were made available in two piles built near the machine tested. A wood chip volume of 66 m^3 (whole capacity of three trailers used for wood chip transportation) for each tree species tested (poplar and black locust) was used in this experiment. During the test, the compactor was stationed near the pile (approximately 15 meters). A telescopic handler, equipped with a bucket with a 3 m^3 capacity to move the wood chips into the feeding device, was used. The bales were moved with another telescopic handler equipped with a specific device (crab) (Table 1).

Methods

The particle size distribution of the chips used for the experiment was determined for one kilogram samples with an oscillating screen according to the European Standard EN 15149-1: 2011. The chips were divided into the following eight length classes: <3.15 mm, 3.16-8 mm, 9-16 mm, 17-31.15 mm, 31.16–45 mm, 46–63 mm, 64–100 mm, and >100 mm. Each fraction was then weighed with a precision scale.

The sampling unit consisted of a single trailer (22 m^3). The machine was studied while carrying out its scheduled commercial activity and observations were blocked for each trailer. Subsequently, the results were divided by the number of bales produced and the values were expressed per single bale.

Productivity was calculated according to methodology described by Magagnotti and Spinelli [12] where a complete trailer was considered as a cycle. Working times were recorded following the IUFRO classification [13]. Average times were shown per single bale.

Productivity was calculated measuring the weight of each bale produced. Moisture content was estimated on one sample per trailer weighing immediately and after drying for 24 hours at 103° C in a ventilated oven.
The fuel consumption for the entire compacting operation was determined by 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.

Machine cost was calculated using the procedure described by Miyata [15] (1980), with an estimated annual utilization of 200 hours (approximately 9,000 bales). The corresponding investment costs were 340,000 €. In all cases, the depreciation period was assumed to be ten years. Value retention at the end of this period was estimated to be 20 % of the original investment. Repair and maintenance costs were directly obtained from the machine owner. The labor cost was set to 18.5 € h^{-1}. Fuel cost was assumed to be 1.1 € L^{-1} (subsidized fuel for agricultural use). The total cost included 20 % profit and overheads [16]. Further details are shown in Table 2.

All data were checked for normality and statistically analyzed with either parametric or non-parametric tests, according to distribution (SPSS 2014).

Results

The time consumption to produce one bale was typically 98 s - 122 s. Diesel fuel consumption ranged from 0.60 L to 0.62 L for each bale equal to 0.48 L m^{-3} and 0.52 L m^{-3}, respectively (Table 3). The bulk density value obtained in this work was 323 kg m^{-3}. This value was similar for the two species tested and it was determined by weighing 6 trailer loads with a certified weighbridge. Productivity then varied from 19.8 t h^{-1} and 21.7 t h^{-1} of the fresh (green) wood chips and diesel fuel consumption ranged from 1.4 L t^{-1} to 1.6 L t^{-1} of fresh chip weight. Independent of the two species considered, the machine showed a working rate of 33 bales per hour and a net productivity (productivity calculated with unproductive time) of 43 bales (Table 3).

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

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

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

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

per each bale). Fuel cost represented about 12 % of the production cost (Fig. 3).

Discussion

The compactor tested highlighted a high productivity, similar to a chipper with 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 important because the wood chip packaging can be performed simultaneously during the chipping operation without unproductive times.

Work efficiency of the compactor is in line with the machines used in wood chip production. In fact, the overall incidence of net packing time was similar to what was recently reported in a general survey of chipping operations in Italy [18], although the distribution of unproductive time was different. This situation may depend on the peculiarities of the different feedstock used (homogenous wood chips instead of stem and brushwood with different sizes and shapes).

In this study, as in chipping operations [19-20], the use of harder (black locust) and softer wood (poplar) species have not influenced the compactor's performance. Any differences in fuel consumption and in productivity were 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}) and by Spinelli et al. [20] (1.7-1.8 L t^{-1} for poplar) for industrial drum chippers.

Unfortunately, the packing cost that resulted was high (23 € t^{-1} of the fresh wood chips – that value is referred to uncompressed wood chips), approximately 30% of the actual Italian market wood chip price (70 € t^{-1} of the fresh woodchip). Nevertheless, compacted material is easier to move and stack. In fact, moving and staking bales could be performed by equipment normally used in the ensilage and haymaking sectors.
In addition, because of the impermeable plastic films used for bale packages, the bales could be stored anywhere, including outdoors.

Generally, wood chips are transported with specific “high-volume” lorries. These vehicles show an important limit in the drop side height (4 meters). Specific equipments (telescopic handlers) are needed to load them. Conventional agricultural and forestry loaders (front loaders of the tractor or mechanical shovels) do not have sufficient loading heights (generally, the max loading height is 3.5 meters). The use of conventional equipment is possible only with ramps where the loader can go up or trenches where the lorries can go down. Wood chips pressed in bales could be a valid solution to this problem. In fact, 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 is possible to obtain the max lorries’ payload with only a single layer of bales.

Furthermore, using pressed bales in wood chip storage (wood chip volume reduction of 43%), the biofuel storage surface could be reduced 10 times in comparison to wood chip storage in piles [21-22]. That aspect is very important because the power stations are driven to optimize the interim step of wood chip storage given the discontinuous nature between its harvest and its actual energy production, [23]. In this case, farms could store the biofuel and transfer it to the power station only when needed.

Finally, plastic sheets used for bale packaging create an anaerobic environment, which is less favorable to microbial development, that prevents the proliferation of different microorganisms, which normally attack uncovered piles. This storage technique allows lower losses regarding matter and energy [21].

Because plastic material used in packaging bale is recyclable, this material can be sold at a market price of 60 € t^{-1} after the bales are used.

Conclusions

Conventional compactors can be used also in the forestry sector for wood chip pressing and packaging and are capable of achieving the same productivity of chipping machines to which they should be coupled. That solution seems ideal for agro-forestry and wherever the production of wood chips is a complementary business within the scope of a larger agricultural economy. In this case, temporary “conversion” offers substantial benefits to part-time users because it allows 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.

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