Productivity and woodchip quality of different chippers during poplar plantation harvesting

Published version:

DOI:10.1016/j.biombioe.2015.10.010

Productivity and woodchip quality of different chippers during poplar plantation harvesting

Abstract

In this work, the productivity and work quality of different types of chipping machines used for biomass comminution produced by dedicated plantations were evaluated. Drum and disc chippers with different powers were compared with feller-chippers and grinders. Machines were tested using only one tree species (poplar) and two different feedstocks: branchwood (seven-year-old treetops and biomass produced by a vSRC) and whole-trees (materials produced by an SRC). This study showed a similar performance for all types of machines tested in terms of working rate using different feeding systems, i.e., automatic and forestry crane. However, different results were obtained for woodchip quality. The whole tree comminution was able to guarantee the best woodchips, and chippers produced better wood chips in comparison to grinders. The results obtained indicate that productivity is linked to engine power and that feedstock size can influence wood chip quality. Furthermore, feller-chippers are able to guarantee the same productivity and wood chip quality as "conventional" chippers.

Keywords

, Chipping machines, branchwood, whole-trees, *Poplar spp.*; productivity, woodchip quality.

1. Introduction

The comminution of wood is performed to homogenize different wood assortments (logs, branches, etc.) and to increase the load density [1].

Typically, woodchips are used for energy production and making chipboard panels. At present, in Italy and in Europe, large amounts of woodchips are used as biomass for energy production because there are many economic incentives for this biofuel use [2-5].

In Europe, large amounts of woodchips are produced by dedicated cultivations: short rotation coppices (SRC). Recently, the ligno-cellulosic species cultivation has increased because several farms have included SRCs in their cultural plans [6]. The main forestry species cultivated in Europe are poplar (*Populus* spp.) [7], willow (*Salix* spp.) [8], black locust (*Robinia pseudoacacia*) [9], and eucalyptus (*Eucalyptus* spp.) [10]. Forestry species can be cultivated with a high planting density (5,500–14,000 ~~trees~~ ha^{-1}) and harvested every 1–4 years (very short rotation coppice - vSRC) or with a lower planting density (1,000–2,000 ~~trees~~ ha^{-1}), with harvesting ranging from 5 to 7 years (short rotation coppice - SRC) [11].

Woodchips used for energy production must be of high quality (uniform size), and every chip should be of a size smaller than 60 mm to guarantee the correct automatic feeding of the power station [12]. Furthermore, woodchips should have low cortex and moisture contents because the cortex content affects ash production and the moisture content decreases the lower ~~Calorific~~ heating value (L~~C~~HV) [13]. If cortex and moisture content depend on timber assortment type, the chip sizes are mainly related to the chipper characteristics.

The chipping operation can be made during the biomass harvest or some days after tree cutting. This operation can be performed by two different groups of machines: chippers, i.e., machines using sharp tools (knives) to cut or slice wood, and grinders, i.e., machines using blunt tools (hammers) to smash or crush wood [14]. In particular, grinders are used for contaminated wood, as their blunt tools are less sensitive to the wearing effect of contaminants but offer a rather coarse product [15]. In contrast, chippers are exclusively applied to clean wood and offer a finer and better product [12].

Chippers used for woodchip production for energy use can be divided by the function of their comminution devices, i.e., discs and drums [16]. All chippers offer high product quality, but disc chippers are more energy efficient than drum chippers. However, drum chippers are generally more productive [16]. Chippers can also be divided by frame type, i.e., mobile or stationary [17]. The first type are used principally for wood chipping in fields or forests, whereas the second type are assembled directly at "woodyards or terminals". Of course, the latter have a greater size and power. In SRCs, in addition to these “conventional” chippers, specific self-propelled machines exist for simultaneously harvesting and chipping the biomass produced (feller-chippers). These chippers are modified foragers equipped with a specific head that is able to cut and chip small trees [18].

Over multiple years, these different chipping machine types were tested singularly at different sites and using different feedstock types. On the basis of these tests, the goal of this work is to evaluate the productivity and work quality of different types of chipping machines used for biomass comminution produced by SRC and vSRC under the same working conditions and using the same feedstock. Drum and disc mobile chippers with different power sizes were compared with feller-chippers and grinders. Machines were tested using only one tree species (poplar spp.), but two different feedstocks were used (branchwood and whole-trees).

2. Materials

For this experimentation, eight different machines were chosen. In particular, three of these were powered by tractor PTOs, whereas the other five were powered by an independent engine. The tested machines required power ranging between 103 and 420 kW. In the tests, drum chippers and disc chippers were used. In addition, one grinder and three feller-chippers (self-propelled) were analysed (Table 1).

To obtain the best performances, all machines were equipped with a "No stress" electronic device capable of managing the speed of the feed rolls in relation to the available power. For each machine category, an appropriate feeding system was used; self-propelled chippers were fed automatically, whereas "conventional" chippers and the grinder were fed by a forestry crane.

All stationary machines, in order to reduce the operator's effect, as is well known in other forestry sectors [19], were fed using only one forestry crane driven by the same operator. The crane used in the test was a DALLA BONA AS610 fixed to a 4 WD tractor (Same ANTARES 110).

The poplar tree species (*Populus x euroamericana*) used in all tests is one of the main species found in Italy, and it can be considered representative of all wood types used for biomass production [20]. Because the feedstock size can influence productivity [21], in the trials, two feedstock types were used: branchwood (treetops of seven-year-old trees and biomass produced by a 2-year-old very short rotation coppice) and whole tree (materials produced by a 7-year-old short rotation forest).

In this work, we also considered treetops because in some cases, for the economic balance of an SRC to be positive, the basal part of the trunk, up to 4-6 m, is used to produce industrial wood (OSB panel, packaging) [22].

Branchwood had an average diameter (measured to approximately 10 mm from the cutting section) of between 50 and 120 mm, whereas whole trees had a base diameter of between 280 and 400 mm.

Due to the limited size of their cutting heads and to the specific cutting system type, not all chipping machines tested were able to work with two different feedstocks. Feller-chippers 1 and 2 worked on the vSRC plantations (branchwood) only, whereas feller-chipper 4 worked only in the SRC (whole tree).

All of the wood was freshly processed, with a water mass fraction of approximately 55%.

Feedstocks were made available in large piles (approximately 100 m^3) built at the field edge. All machines, except feller-chippers, were stationed near the piles, and a forestry crane was used to move the wood into the feeding device. Feller-chippers worked directly in plantations (vSRC and SRC) because the feed of their cutting heads was conducted automatically in the forward speed setting. The trials were performed on a poplar vSRC, where the distance between the rows was 3.00 meters and the distance between trees was 0.50 meters (areal density of 6,700 ~~trees~~ ha^{-1}), and a poplar SRC with the same distance between the rows but with a distance between trees of 3.00 meters (1,600 trees per hectare).

Each feller-chipper was tested on a rectangular area of 0.25 hectare, with dimensions of approximately 105 m in length and 24 m in width (eight rows). In particular, the rows had lengths of 95 m and headlands of 5 m.

Chips were blown into three-axle trailers with a capacity of 35 m^3. Trailers were towed by farm tractors so that the whole operation was based exclusively on farming equipment.

3. Methods

The research was conducted in northwestern Italy, near the town of Alessadria (45° 8' 33" N; 8° 28' 11" E), between January and March, 2012.

The sampling unit consisted of a full trailer. The experimental design aimed at testing the effect of the technical characteristics of each machine category used for woodchip production (disc chipper, drum chipper, feller-chippers, and grinder) on the productivity. Each treatment was replicated three times (Table 2).

All machines worked with new knives and hammers.

Productivity was estimated through a detailed time-motion study conducted at the cycle level [23], where a full trailer load was assumed to be a cycle. Cycle times were defined and split into time elements according to the IUFRO classification [24]. The working rate of the chipping operation was expressed in terms of dry mass (~~Mg~~ t ~~DM~~ h^{-1}) and density (m^3h^{-1}). Furthermore, these parameters were also calculated as functions of chipper engine power (~~Mg~~ t h^{-1} and m^3h^{-1} x kW). The net chipping productivity of each chipper was determined considering only the productive working time.

Outputs were estimated by measuring the volume and weight of all woodchips produced during each test. The weight of each trailer was measured by a certified weighbridge with an accuracy of 10 kg (Ferrero® FL311). Before determining the trailer weight, the load was levelled equal to the tipper topsides. This operation was necessary to obtain biomass density values.

Moisture content determination was conducted using the gravimetric method according to European Standard CENT/TS 14774-2 [25] on one sample (1 kg) per trailer, which were collected in sealed bags and weighed fresh.

The quality of wood chips was assessed on one sample (1 kg) per trailer according to European Standard EN 15149-1 [26]. Seven sieves were used to separate the following eight chip length classes: <3.15 mm (fines), 3.16-8 mm, 9-16 mm, 17-31.5 mm, 31.16–45 mm, 46–63 mm, (acceptable size), 64–100 mm, and >100 mm (oversize particles). Each fraction was then weighed according to a precision scale with an accuracy of 0.01 g (Sartorius® GP3202).

All data collected were processed using Microsoft Excel and analysed with SSPS (2013) advanced statistics software to check the statistical significance of the eventual difference between the trials. The difference between machines was determined using the Ryan-Einot-Gabriel-Welsch (REGW) test because it has higher statistical power with this data distribution.

4. Results

Time consumption ranged from 29 to 196 s m^{-3} for branchwood and from 32 to 104 s m^{-3} for whole trees (Table 2).

Independent of feedstock and machine type used, the net chipping time was 78% higher, whereas the supportive work time and delay showed an incidence of total work time of only 2-8%. Complementary work times of the grinder were very low (approximately 8%) in comparison to the other machine types analysed (12-19%) (Table 2).

The statistical analysis showed all differences in the net chipping time for all machines and feedstock types tested (Table 3).

In branchwood chipping, a higher value of productivity (102.67 m^3h^{-1} equal to 16.29 t h^{-1}) was obtained using machine 8, whereas the lowest value was obtained using machine 1 (19.33 m^3h^{-1} equal to 3.06 t h^{-1}).
Net productivity expressed per unit of nominal power of the machine ranged between 30 and 38 kg h^{-1} x kW (Table 4).

In whole tree chipping, a higher working rate (112.67 m^3h^{-1} equal to 18.14 t h^{-1} of dry matter) was obtained using machine 7, whereas a lower value (34.67 m^3h^{-1} equal to 6.07 t h^{-1} of dry matter) was found with machine 4. Higher net productivity expressed in dry matter per unit of nominal power of the machine was obtained with machines 5 and 6 (60 kg h^{-1} x kW), whereas a lower value (32 kg h^{-1} x kW) was found with machine 4 (Table 4).

In a comparison of all productivity values, that obtained for whole tree chipping (0.053 t h^{-1} x kW) was approximately 30% higher than that obtained for branchwood chipping.

Furthermore, considering that the chippers were only fed with forestry cranes, the data processing output showed an average productivity of 0.22 m^3h^{-1} or 0.035 t of dry matter per kW of nominal power in branchwood chipping, and 0.34 m^3h^{-1} or 0.058 t of dry matter per kW of nominal power in whole tree chipping.

In general, chipper productivity increased in relation to the nominal power engine (Fig. 1).

In whole tree chipping, it is possible to obtain a higher data correlation ($R^2 = 0.99$; $y = 0.3747x – 6.880$; $P < 0.0001$) if the value of machine 4 (190 kw) is not considered (Fig. 1). This machine, in contrast to the other machines tested, cannot work continuously because, before performing the chipping operation, it needs to reach the tree, cut it, and successively place it in the feeding mouth. The sequence of these operations reduces its productivity (Table 4).

Table 4 shows the particle size distribution of the chips produced using different machines. The acceptable size accounted for the majority of the sample weight, but the oversize particle content was substantial (14.8% of the total weight). The particle size distribution did not differ significantly between the considered feedstocks (Table 5).

Disc and drum chippers produce high-quality woodchips and show little presence of fine particles in comparison to grinders (hammers) (Table 6).

5. Discussion

In vSRC and SRC harvesting, independent of feeding systems adopted by chippers (automatically or with forestry crane), the supporting work time and delay are low (8% of total working time). This value is similar to those obtained in other works performed using traditional chippers [27], but it is substantially lower (four times) in comparison to the self-propelled forager modified for wood chipping tested on a poplar plantation with a diameter of 270 mm [28]. This difference could be attributed to the smaller tree sizes and the optimal conditions (large square and large head field) that machines have worked during the trials. Overall, it is very important to highlight that the working time can also be linked to the operator's training and skill level [29].

Productivity is influenced particularly by rotation length of the SRC harvesting because a different plantation edge can lead to different feedstock types. In fact, it is lower when the wood assortment processed is characterized by a small size (branchwood - vSRC). This effect may be attributed to low feedstock density and the greater difficulty of its operation. This feedstock can also cause some problems in feeding operations, where the branches can become stuck in the feeding mouth of the chippers. These operative problems were also shown in other studies [12, 30].

Furthermore, this study has highlighted that cutting operations performed simultaneously with the chipping operations (feller-chippers) do not considerably reduce chipping operation productivity or influence woodchip quality. The results also indicate the strong performance of feller-chippers, which in previous tests, have shown economic advantages [31] and less soil compaction [32] compared to other machines used in tree cutting and wood comminution. Nevertheless, machine 4 (i.e., a feller-chipper that worked only in the SRC – a plantation with a medium-length rotation) showed a low working rate because its working process was not continuous due to the difficulty of cutting trees with large diameters (up to 400 mm). In fact, as reported by Hauk et al. [33], when the SRC rotation length is long (7 years), manual harvesting becomes economically competitive.

In this study, it is noted that independent of the machine type used (self-propelled chippers, feller-chippers or grinders) in biomass comminution, the productivity was strictly related to the nominal engine power. These results are comparable with those found in previous works [12, 17]. The difference of singular values could be linked to different forestry cranes used and differences in operator skills.

The particle size distributions obtained in this experiment are very similar to those obtained in other experiments conducted in similar conditions [34-38].
The woodchips are of high quality for all of the chippers tested (acceptable size > 80%) except for the grinder (acceptable size < 67%). This trend is similar to that found in other works where the biomass was processed with grinders [15]. Independent of the machine type considered, in this work, feedstock biomass sizes influenced woodchip quality. The best biofuels were obtained with the whole tree chipping (acceptable size > 88%). The production of many fine particles using branchwood or materials with small diameters was also confirmed by Spinelli et al. [39]. In contrast to Nati et al. [40], in this study, disc and drum chippers show no significant difference in woodchip quality (Table 5). This result could be related to the single forestry species (poplar) processed in this study.

Considering the importance of forestry species [34-35, 41] and the effect of wear knives on the machine productivity and woodchip quality [42], it could be useful to improve these results with others studies conducted with the same machines but using different forestry species and wear knives.

6. Conclusions

This study showed similar performances for all type of machines tested in terms of specific working rate (working rate expressed by unit of nominal power). No difference in productivity was obtained using different feeding systems (automatic and with forestry crane) and commination systems (disc, drum or hammers). However, different results were obtained in woodchip quality. In fact, in order to obtain high-quality wood chips, large size feedstock (whole tree) and chippers (drum or disc) were required.

This information is very important because it is useful for consideration during biomass plantation planning and management.

Finally, the data obtained in this experiment highlight that in the SRC, it is better to use feller-chippers. In fact, these machines, in addition to ensuring the same performance of "conventional" chippers in terms of productivity and wood chip quality (results obtained in this work), are able to reduce soil compaction and hourly costs (results obtained in other studies ~~[30-31]~~).

References

[1] Bjorheden R. Optimal point of comminution in the biomass supply chain. Proceedings of the Nordic-Baltic Conference on Forest Operations, Copenhagen 23-25 september 2008. danish Forest and landscape, Copenhagen Denmark.

[2] Stupak A, Asikainen A, Jonsel M, Karltun E, Lunnan Al. Sustainable utilization of forest biomass for energy. Possibilities and problems: policy, legislation, certification and recommendations and guidelines in the Nordic, Baltic and Other European countries. Biomass Bioenergy 2007;31:666-84.

[3] Mattotea F. Esempio di bando per i contributi agli impianti a legna. Alberi e territorio 2004;12.

[4] Hellrigl B. Osservazioni e riflessioni sulle celerocolture arboree per energia. Monti e Boschi 2003;1.

[5] Verani S, Sperandio G, Picchio R, Marchi E, Costa C. Sustainability assessment of a self-consumption wood-energy chain on small scale for heat generation in central Italy. Energies 2015;8(6):5182-97.

~~[6] Spinelli R, Nati C, Magagnotti N. Harvesting short-rotation poplar plantations for biomass production. Croat J For Eng2008;29(2):129-139.~~

[6] Spinelli R, Nati C, Magagnotti N. Using modified foragers to harvest short-rotation poplar plantations. Biomass Bioenergy 2009;33(5):817-21.

[7] Manzone M, Bergante S, Facciotto G. Energy and economic evaluation of a poplar plantation for woodchips production in Italy, Biomass Bioenergy 2014;60:164-70.

[8] Ericsson K, Rosenqvist H, Ganko E, Pisarek M, Nilsson L. An agro-economic analysis of willow cultivation in Poland. Biomass Bioenergy 2006;30:16-27.

[9] Manzone M, Bergante S, Facciotto G. Energetic and economic sustainability of woodchip production by black locust (robinia pseudoacacia L.) plantations in Italy, Fuel 2015;140:555-60.

[10] De Morogues F, The NN, Berthelot A, Melun F. Thoughts on the profitability of short and very short rotation coppice cycles with eucalyptus and poplar. Rev For Francaise 2011;63(6):705-21.

[11] Testa R, Di Trapani AM, Foderà M, Sgroi F, Tudisca S. Economic evaluation of introduction of poplar as biomass crop in Italy. Renewable and Sustainable Energy Reviews 2014;38:775-80.

[12] Spinelli R, Nati C, Sozzi L, Magagnotti N, Picchi G. Physical characterization of commercial woodchips on the Italian energy market. Fuel 2011;90:2198-202.

[13] Picchio R, Spina R, Sirna A, Lo Monaco A, Civitarese V, Del Giudice A, et al. Characterization of woodchips for energy from forestry and agroforestry production. Energies 2012;5:3803-16.

[14] Pottie M, Guimier D. Preparation of forest biomass for optimal conversion. FERIC Special Report SR-32, 1985. Pointe Claire, Canada. p. 122.

[15] Strelher A. Technologies of wood combustion. Ecological Engineering 2000;16:25-40.

[16] Spinelli R, Cavallo E, Eliasson L, Facello. Comparing the efficiency of drum and disc chippers. Silva Fennica 2013;47(2).

[17] Spinelli R, Magagnotti N. Comparison of two harvesting systems for the production of forest biomass from the thinning of Picea Abies plantations. Scandinavian Journal of Forest Research 2010;25:69-77.

[18] Civitarese V, Faugno S, Pindozzi S, Assirelli A, Pari L. Effect of short rotation coppice plantation on the performance and chip quality of a slf-propelled harvester. Biosystem engineering 2015;129:370-7.

[19] Lindroos O. The effects of increased mechanization on time consumption in small-scale firewood processing. Silva Fennica 2008;42:791-805.

[20] Rosso L, Facciotto G, Bergante S, Vietto L, Nervo G. Selection and testing of *Populus alba* and *Salix spp*. as bioenergy feedstock: preliminary results. Applied Energy 2012;102:87-92.

[21] Liss JE. Power requirement and energy consumption in fuel-chip production using a tractor-mounted chipper. Department of Operational Efficiency, Swedish University of Agricultural Sciences. 1987. Licentiate thesis.

[22] Coaloa D, Nervo G, Scotti A. Multi-purpose poplar plantations in Italy. In: Improving Lives with Poplars and Willows. Abstracts of submitted papers. 24th Session of the International Poplar Commission, Dehradun, India, 30 October-2 November 2012. Working Paper IPC/11 FAO, Rome, Italy. p.74.

~~[23] Magagnotti N, Spinelli R. COST action FP0902 e good practice guideline for biomass production studies. 2012. Florence, Italy: CNR IVALSA, ISBN 978-88-901660-4-4; pp 41.~~

[23] Magagnotti N., Kanzian C., Shulmeyer F., Spinelli R. A new guide for work studies in forestry. International Journal of Forest Engineering 2013;24(3):249-53.

[24] Bjorheden R, Apel K, Shiba M, Thompson MA. IUFRO forest work study nomenclature. Garpenberg: Swedish University of Agricultural Science, Dept. of Operational Efficiency, 1995. p. 16.

[25] UNI EN 14774-2. Solid biofuels, determination of moisture content – oven dry method, Part 2: total moisture - simplified method 2010.

[26] EN 15149-1. Solid biofuels, determination of particle size, Part 1: oscillating screen method 2011.

[27] Spinelli R, Visser R. Analyzing and estimating delays in wood chipping operations. Biomass Bioenergy 2009;33:429-33.

[28] Manzone M, Spinelli R. Wood chipping performance of a modified forager. Biomass and Bioenergy 2013;55:101-6.

[29] Purfurst FT, Erler J. The precision of productivity models for the harvester – do we forget the human factor? In: Precision Forestry in Plantations, semi-Natural and Natural Forests. Proceeding of the International Precision Forestry Symposium. Stellenbosch University, South Africa, 5-10 March 2006:465-75.

[30] Assirelli A, Civitarese V, Fanigiulo R, Pari L, Pochi D, Santangelo E, Spinelli R. Effect of piece and tree part on chipper performance. Biomass Bioenergy 2013;54:77-82.

[31] Vanbeveren SPP, Schweier J, Berhongaray G, Ceulemans R. Operational short rotation woody crop plantations: Manual or mechanised harvesting? Biomass Bioenergy 2015;72:8-18.

[32] Pecenka R, Ehlert D, Lenz H. Efficient harvest lines for Short Rotation Coppices (SRC) in Agriculture and Agroforestry. Agronomy Research 2014;12(1):151-60.

[33] Hauk S, Wittkopf S, Knobe T. Analysis of commercial short rotation coppices in Bavaria, southern Germany. Biomass Bioenergy 2014;67:401-12.

[34] Nati C, Spinelli R, Fabbri P. Wood chips size distribution in relation to blade wear and screen use. Biomass Bioenerg 2010;34:583-7.

[35] Spinelli R, Magagnotti N, Paletto G, Preti C. Determining the impact of some wood characteristics on the performance of a mobile chipper. Silva Fennica 2001;45:85-95.

[36] Spinelli R, Hartsough B, Magagnotti N. Testing mobile chippers for chip size distribution. Int J For Eng 2005;16:29-35.

[37] Spinelli R, Cavallo E, Facello A, Magagnotti N, Nati C, Paletto G. Performance and energy efficiency of alternative commination principles: chipping vs. grinding. Scand J For Res 2012;27(4):393-400.

[38] Spinelli R, Nati C, Pari L, Mescalchin E, Magagnotti N. Production and quality of biomass fuels from mechanized collection. Appl En 2012;89:374-9.

[39] Spinelli R, Nati C, Sozzi L, Magagnotti N, Picchi G. Physical characterization of commercial woodchips on the Italian energy market. Fuel 2011;90(6):2198-2022.

[40] Nati C, Eliasson L, Spinelli R. Effect of chipper type, biomass type and blade wear on productivity, fuel consumption and product quality. Croatian Journal of Forest Engineering 2012;35(1):1-7.

[41] Papworth R, Erickson J. Power requirements for producing wood chips. For Prod J 1966;16:31-6.

[42] Facello A, Cavallo E, Magagnotti N, Paletto G, Spinelli R. The effect of knife wear on chip quality and processing cost of chestnut and locust fuel wood. Biomass Bioenergy 2013;59:468-76.