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Energy consumption and CO_2 analysis of different types of chippers used in wood biomass plantations

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HIGHLIGHTS

- Disc chippers, drum chippers, feller-chippers and grinders were tested.
- All machines were tested with two poplar feedstocks: branchwood and whole-trees.
- This study focused on energy consumption and CO_2 emission.
- Self-propelled feller-chippers are more efficient than conventional chippers.

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ABSTRACT

Woodchip is preferred to all biomass forms because it shows standardised sizes and offers additional benefits in terms of load density. In Europe, a large amount of woodchip is produced by dedicated cultivations: very Short Rotation Coppice (vSRC) and Short Rotation Coppice (SRC). The chipping operation can be done during the biomass harvest or some months after tree cutting. This operation can be performed by different machines: disc chippers, drum chippers, feller-chippers and grinders.

The goal of this work was to determine the energy and the CO_2 emission of different types of chippers used in biomass comminution produced by poplar vSRC and SRC. All machines were tested with two different feedstocks: branchwood (treetops and biomass produced by vSRC) and whole-trees (biomass produced by SRC).

Fuel consumption ranged between 14.36 and 59.52 l h^{-1} and energy consumption varied from 0.92 to 0.62 MJ Mg DM^{-1}, respectively, for branchwood and whole-trees feedstock type. In addition, an average value of 16.40 kgCO_2eq Mg DM^{-1} in branchwood chipping and an average value of 10.80 kgCO_2eq Mg DM^{-1} were obtained in CO_2 assessment.

This experiment indicated that self-propelled feller-chippers were significantly more convenient than "conventional chippers" in biomass comminution produced by dedicated plantations.

1. Introduction

Energy produced by renewable sources is considered a valid solution for reducing environmental pollution caused by the use of fossil fuels [1,2]. In fact, recently, the European Union has provided incentives for renewable energy production [3]. Among all renewable energy sources, biomass is the one that has the greatest possibility for fossil fuel substitution [4], especially woodchip [5], which is preferred over all other biomass forms because it shows standardised sizes and offers additional benefits in terms of load density [6].

The chipping operation can be done during the biomass harvest [7] or some months after tree cutting [8]. This operation can be performed by two different groups of machines: chippers – machines using sharp tools (knives) to cut or slice wood; and grinders – machines using blunt tools (hammers) to smash or crush wood [9].

In particular, grinders are used when dealing with contaminated wood, as their blunt tools are less sensitive to the wearing effect of contaminants [10], but offer a biofuel of low quality level, unsuitable for use in some plants [11]. In contrast, chippers are exclusively applied to clean wood and offer a finer and better product [12]. For wood comminution, mobile and stationary chippers are used, but the former, despite their inferior performance, are more diffused in forestry yards [13].

In Europe, a large amount of woodchip is produced by dedicated cultivations: Short Rotation Coppice (SRC). In recent years, the ligno-cellulosic species cultivation has increased because several farms have inserted SRC in their cultural plans [14]. The main forestry species cultivated in Europe are poplar (*Populus* spp.) [15],

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willow (*Salix* spp.) [16], black locust (*Robinia pseudoacacia* L.) [17] and eucalyptus (*Eucalyptus* spp.) [18]. Forestry species can be cultivated with a high planting density (5500–14,000 plants ha^{-1}) and harvested every 1–4 years (very Short Rotation Coppice – vSRC) or with a lower planting density (1000–2000 plants ha^{-1}) and harvested ranging from 5 to 7 years (Short Rotation Coppice – SRC) [19].

Until now many works have focused on various aspects of vSRC or SRC: genotype selection [20], cycle duration [21], biomass production [22], planting techniques [23], weed control and fertiliser effect [24], pesticides application [25], irrigation effect [26], etc. Among all SRC cultural operations, biomass harvesting is considered crucial for a farmer to estimate the economic sustainability of the crop in advance [27]. In fact, recently, the biomass harvesting operation has been studied from different points of view: harvesting techniques [28], economic and energetic costs [29], and wood chip quality [30]. Since biomass harvesting-especially woodchip production [29] – requires approximately 25% of the total SRC energy input [31], it is very important to make a correct choice of the machine used to reduce total energy consumption.

In recent years, some works have focused on the evaluation of chipper performance but unfortunately, all of these have considered only a single machine or various machines but not under the same work conditions (these experimentations are different in terms of feedstock characteristics, materials and methods used) [7,13,27]. They do not give sufficient information to compare the performance of different types of chipper machines used in SRC plantations.

In order to overcome this deficiency, a specific study was performed in which the performances of different types of machines used in wood chip production were assessed under the same working conditions. On this basis, the goal of this work was to determine the energy and the CO_2 emission of different types of chippers, usually used in biomass comminution produced by poplar vSRC and SRC, in the same area and using the same feedstocks. In particular, in this study, disc and drum chippers, feller-chippers and grinders were tested with two different feedstocks: branchwood (treetops and biomass produced by vSRC) and whole-tree (biomass produced by SRC).

2. Materials

For this study, eight different machines were chosen. In particular, three of these were powered by the tractor's PTO, while five by an independent engine. All machines required power between 103 and 420 kW. In the tests, drum chippers and disc chippers were compared to one grinder and three feller-chippers (self-propelled) (Table 1).

For each machine category an appropriate feeding system was used; self-propelled chippers were fed automatically, while "conventional" chippers and the grinder were fed by forestry cranes.

All stationary machines, in order to reduce the effect of the operator's training and skill level, already well known in other forestry sectors [32], 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).

All machines were tested with only poplar tree species (*Populus x euroamericana*). Hybrid poplar is the main species used for the afforestation of north Italian farmland, and it can be considered representative of all types of wood used for biomass production [20]. Since the feedstock size can cause an effect on machine performance [33], in the trials, two feedstock types were used: branchwood (seven year-old treetops and biomass produced by a two year-old very Short Rotation Coppice), and whole tree (materials produced by Short Rotation Forestry of seven year-olds).

In this work, treetops were also considered because in some cases, in order to become positive, the economic balance of SRC, the basal part of the trunk, up to 4–6 m, is used to produce industrial wood (OSB panel, packaging) [34].

Branchwood had an average diameter (measured to about 10 mm from cutting section) of between 50 and 120 mm, while the whole tree had a base diameter 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 the two different feedstocks. Feller-chippers 1 and 8 worked on vSRC plantations (branchwood) only, while feller-chipper 4 worked only in SRC (whole tree).

All wood was freshly processed, with a moisture content of about 55%.

Feedstock was 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 the forestry crane was used to move the wood into their feeding device. Feller-chippers worked directly into the plantation (vSRC and SRC) because the feed of their cutting heads has carried out automatically during forward speed. The trials were performed on a poplar vSRC, where the distance between the rows was of 3.00 m and the distance between plants was of 0.50 m (density of 6700 plants per hectare), and a poplar SRC with same distance between the rows but with a distance between plants of 3.00 m (1600 plants per hectare).

Each feller-chipper was tested on a rectangular area of 0.25 ha with sizes of approximately 105 m in length and 24 m in width (8 rows). In particular, the rows showed a length of 95 m and a headland 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 Alessandria, between January and March 2012.

The sampling unit consisted of a full trailer. The experimental design aimed at testing the effect of machine categories used for woodchip production (disc chipper, drum chipper, feller-chippers, and grinder) on productivity, energy consumption and CO_2 emission.

All machines worked with new knives and hammers.

Table 1
Technical characteristics of the chippers and grinder tested.

Machine (n°)	Machine (type)	Powered system	Power (kW)	Chipper (type)	Knives (number)	Mouth feeding size (mm)	Feeding system
1	Feller-chipper	Power Take Off	103	Disc	3	250 × 600	Automatically
2	Chipper	Power Take Off	130	Disc	3	700 × 600	With crane
3	Chipper	Indep. engine	170	Drum	4	650 × 900	With crane
4	Feller-chipper	Power Take Off	190	Disc	2	700 × 600	Automatically
5	Chipper	Indep. engine	200	Drum	4	350 × 600	With crane
6	Chipper	Indep. engine	310	Drum	2	650 × 900	With crane
7	Grinder	Indep. engine	320	Hammer	38	700 × 1500	With crane
8	Feller-chipper	Indep. engine	420	Drum	4	300 × 600	Automatically