Quality, productivity, energy and costs of wood chip produced by Cedrus deodara plantations: a case study in ITALY

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Abstract

The main tree species planted for woodchips production for energy use are: poplar (*Populus* spp.), willow (*Salix* spp.), black locust (*Robinia pseudoacacia L.*) and eucalyptus (*Eucalyptus* spp.). Nevertheless, in the course of the years, other tree species were planted (i.e. *Pinus strobus* L.; Pauwlonia spp...). The scope of this study is the evaluation of energy and economic advantages, and quality of woodchip produced by a *Cedrus deodara* plantation situated in Italy.

The plantation had a surface of 1.2 ha and trees were 14 years old.

An amount of 363 t of fresh comminuted wood (about 300 t ha^{-1}) was produced by the plantation considered. A total time of 39.5 h (about 5 days) was required to transform all trees in woodchip. The moisture content of woodchip produced was 52%, while the average Low Heating Value (HHV) was 8.51 MJ kg^{-1}. In this study, economic (production cost = 93 € t^{-1} DM) and energetic (output/input ratio = 74) evaluations of woodchip produced by *Cedrus deodara* plantations were positives. Nevertheless, the results obtained in this experimentation are close to the climate conditions and soil characteristics of Northwestern Italy.

Keywords

Cedrus deodara; biomass production; woodchip quality; economic evaluation; energy consumption

1. Introduction

In the last decade, the European Union initiated incentives for energy production from renewable sources [1] in order to reduce GHG emission derived from fossil fuels [2-3]. Energy can be produced by different renewable energy sources, but biomass appears to have the greatest potential to replace fossil fuel [4]. In fact, at present, biomass is one of the major renewable resources at the worldwide level (14% of the world's annual consumption) [5]. Between all biomass types used for energy production, woodchip is the most appreciated [6] because it guarantees homogenous sizes and benefits during the transport in comparison to other biomass forms [7].

Generally, woodchips are produced by the comminution of residues derived by forest utilisations [8] or wood biomass harvested in dedicated plantations [9]. From an environmental point of view, woodchips produced using forestry residues are discouraged because this can cause a significant loss of nutrients in the soil [10-11], while biomass produced by dedicated plantations is an incentive in different countries [1]. <u>In addition, the forest wood is not easy exploitable resource due to soil (slope, mud…) and weather conditions</u> [12]. Actually, in Europe, a large amount of woodchip is produced by dedicated cultivations [13]. These dedicated cultivations, compared to other traditional plantations, shows a high interest because, having a short harvesting cycle (from 2 up to 16 years) [14-16] means that it is able <u>to guarantee an short return time</u> [17]. Thanks to this opportunity, the tree species cultivations were inserted in the cultural plans of several farms, especially in Italy [18]. Moreover, farmers also take advantage by their low input requirement and the possibility of exploiting set-aside areas [19].

Depending on the local climate conditions and soil characteristics, different tree species can be cultivated in biomass plantations. The main tree species planted are: poplar (*Populus* spp.) [17], willow (*Salix* spp.) [20], black locust (*Robinia pseudoacacia L.*) [21] and eucalyptus

(*Eucalyptus* spp.) [22]. Typically, farmers chose these species because they have a higher adaptability and have shown good biomass production without using intensive agricultural practices with a shorter harvesting cycle. Nevertheless, in the course of the years, other tree species were cultivated in order to verify their potential for biomass production and soil adaptability (i.e. *Pinus strobus* L.; *Pauwlonia* spp...) [23-24]. In particular, at the end of 90's in Northwestern Italy (Piedmont Region) some nurserymen proposed *Cedrus Deodara* (Roxb) G. not only as an ornamental tree species, but with a potential tree species for biomass production thanks to its rapid growth. In fact, this tree species is usually used for fuelwood production in the Indian Himalaya [25]

Since these species were planted only at an experimental level in small local zones, results obtained during their cultivation were poor and, sometimes were not published in the international literature. On the basis of these considerations, in order to improve the knowledge of the potential of these "experimental" tree species on biomass production, the scope of this study is the evaluation of the economic and energetic advantages, and quality of woodchip produced by a *Cedrus deodara* (Roxb) G. plantation site in Italy.

2. Materials and methods

Data were collected in an experimental plantation of *Cedrus deodara* R sited near Turin town (N 45.012995, E 7.720007) in the Northwest of Italy, during the period from 2001 to 2014. This area is characterized by a sandy soil (loss) and a Temperate climate (average annual air temperature of 15.4 C,° and average annual precipitations of 920 mm). The plantation had a surface of 1.2 ha and the land had a slope of 5%. Plant layout was 6 x 6 metres and trees were 14 years old. Before performing the planting activity, the soil was prepared by ploughing at a depth of 0.5 m after a mineral seed bed fertilisation of PK 8-24 (500 kg ha^{-1}). Secondary tillage was performed with a harrowing intervention, while for rooting plants (about 1 m in height), an auger drill (length = 1 m; diameter = 0.3 m) fixed on the tractor was used.

The weed control was performed between first and third year of plantation using a disc harrow. At the end of the cycle the stumps were removed using a heavy cultivator (Table 1). When biomass was harvested the trees showed an average diameter at breast height (DBH) of 260 mm and an average height of 18.5 m. These values were calculated considering the measurement of 20 trees chosen inside of the plantation with random method. Diameters were measured using a tree calliper with an accuracy of 5 mm, while tree heights were determined by a ruler (0.01 m of readability) after cutting the trees.

Tree cutting was performed using a chainsaw with a power of 4 kW. After, trees were extracted in the headland, where they were successively chipped. Extracting of full trees was achieved by a tractor with a hydraulic grapple mounted on a 3 point attachment and all trees were piled near the chipper. The drum chipper used in the trials was a PTH 1200/820 HACHERTRUCK (Pezzolato S.p.a.) and it was equipped with new blades. Woodchip was loaded into the lorry containers simultaneity with chipping operations. In detail, for wood chip transportation, two trucks with trailer equipped with a “large volume” container (110 m^3) were used (Table 2).

2.1. Working time and productivity

Productivity was calculated at the cycle level according to the procedure set up by Magagnotti and Spinelli [26]. In detail, a single row (23 trees) was considered as a cycle in cutting and extracting operations, instead each full truck load was assumed as a cycle in chipping operation. Two different units were considered because each forestry activity required a different working step. In fact, only after to have piled all material of a row it was possible to cut another row. The chipping operation started only when all trees were piled. Total working time was subdivided into different time elements following the International Union of Forest Research Organisations IUFRO classification [27].

During the test, a centesimal stopwatch (Hanhart® PROFIL 5) was used to record working time elements.

In this study, productivity was calculated by dividing the biomass to unit area for the time required to transform trees in woodchips. It was expressed in terms of weight (t DM h^{-1}) and volume (m^3 h^{-1}).

2.2. Woodchip quality

The woodchip quality was evaluated considering the moisture content, ash content, chip size and Low Heating Value (LHV).

The moisture content was determined with the gravimetric method according to European standard UNI EN 14774-2 [28] on 1 kg samples collected for each lorry loaded. That measurement was replicated three times. In the same samples, the ash content was also determined following UNI EN 14775 [29] (Table 3)

The wood chip size was screened according to European Standard EN 15149-1[30] using 8 L samples (Table 3). Samples were collected with a randomised method, with 3 samples taken for each lorry loaded. In particular, the wood chips were split into eight classes: <3.15 mm, 3.16-8 mm, 9-16 mm, 17-31.5 mm, 31.16–45 mm, 46–63 mm, 64–100 mm, and >100 mm. Successively, a precision scale (0.001 g precision) was used to weigh each fraction.

The Low Heating Value (LHV) was calculated according to European Standard UNI EN 14918 [31] if function of HHV and moisture content of the wood, adopting the following formula:

$$LHV = HHV(1 - M) - KM$$

where:

HHV = High Heating Value (MJ kg^{-1})

M = wet basis moisture content
K = latent heat of water vaporisation (constant - 2.447 MJ kg^{-1}).

Higher Heating Value (HHV) was tested using an oxygen bomb calorimeter. This parameter was tested on biomass samples consisting by woodchip mixed (wood without the presence of bark, bark, and needles). In order to evaluate the influence on the HHV of the single tree parts, the HHV was determined also for wood without bark, bark, and needles. The volume percent incidence of the single tree parts on the woodchip produced was determined subdividing the different single tree parts of ten wood chips samples of 0.25 m^3 (1 samples for each truck loaded).

2.3. Energy consumption

Energy input was estimated considering fuel and lubricant consumption and energy required for the manufacture of machines [32]. In the input calculation, different coefficients were assumed as a function of specific energy content: machine with engine 92.0 MJ kg^{-1}, equipment without engine 69.0 MJ kg^{-1}, fuel 37.0 MJ L^{-1}, and lubricant 83.7 MJ kg^{-1} [33-34]. For fuel and lubricant, an additional energy consumption of 1.2 MJ kg^{-1} was considered for their distribution [35]. Furthermore, an additional value of 55% of the total energy content in each machine was considered for maintenance and repair [36].

In this study, the fuel consumption was determined by a “topping-off system”, refilling the machine tank at the end of each working cycle [37], while the lubricant consumption was estimated in a measure of 2% fuel consumption [38].

2.4. Economic evaluation

The economic evaluation was carried out considering a continuous *Cedrus Deodara* plantation: the whole acreage was divided into different “modules”, each corresponding to one year of the crop cycle, thereby enabling all costs to be considered on an annual basis. In particular, the economic value of the woodchip produced was determined considering the hourly cost of each machine and production factors costs (fertilisers, fuel) used in each cultural operation. This calculation was performed following the methodology proposed by Ackerman et al [39], with prices updated to 2015 (Table 2).

In this study, the annual utilisation of 1,000 hours and a life of 12,000 hours were considered for tractors (with the tractor also being used for other operations) and an average annual utilisation of 1,600 hours and a life of 8,000 hours were considered for chippers and other equipment [39-41].

Manpower cost was assumed to be 18.5 € hour^{-1}. For fuel and lubricant, a cost of 0.9 € kg^{-1} and 5.0 € kg^{-1}, respectively, was considered (subsidised fuel and lubricant for agricultural use). In this calculation, a cost of 180 € ha^{-1} per year was assumed for land renting (local market price).

The economic advantages of the plantation were evaluated calculating the Net Present Value (NPV) which indicates the difference between total income and total cost. In this study, a market price of 100 € t DM was considered for the woodchip.

Since the production cost is linked to biomass processed and transport operations, woodchip cost was calculated for different biomass production per unit surface and transportation distance.

Data analysis was performed using Microsoft Excel Software and the SPSS 21 statistical software. The statistical significance of the eventual differences between the treatments was tested with the REGW-F test, adopting a significance level of $\alpha = 0.05$, because it has high statistical power with this data distribution [42]. The REGW-F is a multiple step-down procedure used when all sample means are equal. This test is more powerful than Duncan's multiple range test and Student-Newman-Keuls (which are also multiple step-down procedures).

3. Results

3.1. Working time and productivity

An amount of 363 t of fresh comminuted wood (about 300 t ha^{-1}) was produced by the plantation considered. All material was transported to the power station in 10 travels and it was possible to confirm that the woodchip produced was a bulk density of 330 kg m^{-3}.

A total time of 39.5 h (about 5 days) was required to transform all trees in woodchip. On the basis of these results, the total productivity (felling, extraction, chipping and transportation) obtained in the trials was of 9.2 t h^{-1} (27.8 m^3 h^{-1}). In detail, the higher working efficiency was observed in chipping wood (84%), while the higher incidence of unproductive times was obtained in cutting operations (10%). That low value is attributed to the breaks which the operator takes to rest. The higher incidence of complementary working time observed during biomass transport is due to pauses for lorry loading (Table 4).

Woodchip production by *Cedrus deodara* plantation required 27.5 h ha^{-1} of manpower, while the extraction required 8.8 h ha^{-1}.

Referring the results to volume unit of woodchip produced (m^3), a similar repartition of the incidence of different operations is pointed out (Fig. 1).

3.2. Woodchip quality

The moisture content of woodchip produced was 52%, while the average High Heating Value (HHV) was 19.91 MJ kg^{-1}. Consequently, the average Low Heating Value (LHV) calculated before the woodchip transportation was 8.51 MJ kg^{-1}. In addition, from HHV data analysis of single tree parts is pointed out that the highest value is attributable to needles (21.29 MJ kg^{-1}), instead average values were observed for the bark (21.12 MJ kg^{-1}). Furthermore, data analysis also showed an average ash content of the biomass tested of 1.9 %. This value is equal to that found for needles (1.9 %), but lower than value obtained for bark (2.2 %). Statistical analysis showed no difference between lorries loaded for each parameter considered (Table 5 and 6). Woodchip produced was also of good quality from a particle size point of view, because about 90% of chips were in the central size class, with a length between 8 and 100 mm (Table 7).

3.3. Energy consumption

Energy consumption for the cultivation and management of a *Cedrus deodara* plantations was 5.4 GJ ha^{-1} per year and represents about 5% of the biomass energy production (about 400 GJ ha^{-1} per year). The energy balance was positive because the output/input ratio was close to 74. Between all working phases, the harvesting operation showed the higher value of input (51.7%), while the planting operation highlighted the lower value (2.9 %). Soil preparation (fertilization, ploughing, and harrowing) had an incidence on the total input of the 21.1 % (Fig. 2). Energy required by cultural operations (weed control) was resulted trifling (< 1%) compared to biomass produced.

Furthermore, the energy analysis highlighted an incidence of 84% of the direct consumption (fuel and lubricant consumptions) on the total input.

3.4. Economic evaluation

The production cost of the woodchip, considering a transportation distance of 50 km, was 93 € t^{-1} DM. That value may decrease by 15% for an amount of biomass available of 450 t ha^{-1}

(Fig. 3). In the whole cultivation cycle of a *Cedrus deodara* plantation, biomass harvesting and transportation were working phases that had a highest incidence on the wood chips production cost: 26.5 % and 20% respectively. Planting operation showed an incidence of 14% (Fig. 4).

Furthermore, the woodchip cost can also range between 81 and 112 € t^{-1} DM for distances of 5 and 100 km respectively. Those results highlight an incidence of the transport operation on production cost of up to 30%. Assuming a woodchip market value of 100 € t^{-1} DM (present market value of woodchip), the economic advantage of biomass production is guaranteed for transportation distances lower than 65 km (Fig. 5).

4. Discussion

The theoretical wood increment observed in the plantation tested was 11.2 t DM ha^{-1} per year (value calculated diving the biomass harvested for trees' age); that value is in line with other biomass plantation (Poplar, Willow, and Black locust) sites in the same climate conditions (10-15 t DM ha^{-1} per year) [43-45]. Nevertheless, readers must consider that affirmation only in relative terms and not in absolute terms because it can possible those results are valid only for specific site conditions (soil, precipitations, …) and for the cultivation period considered. In fact, the *Cedrus deodara* SRC "performances" should be tested in different site conditions and cultivation cycles in order to establish the real potentiality of this tree species. In addition, this experimentation is lacking of information about the real wood increment of trees in the course of the years: important parameter to verify a correct duration of the cultivation period [44].

Working efficiency of the biomass harvesting observed in this study was similar to that observed during woodchip production by Picea abies plantations [46] and biomass plantations [47]. That value, although was obtained adopting a harvesting system with separated phases (felling, extraction, and chipping) is also similar with that obtained during biomass harvesting using a specific self-propelled chipper able to harvest and chip the wood simultaneously in a single phase [48]. In contrast, these two harvesting methods were different for productivity: values obtained in this work are 2 – 6 times lower than the productivity shown by dedicated machines (self-propelled chipper) used in plantations that were only 6 years old [49].

Chips obtained by wood of *Cedrus deodara* comminution showed a good quality. The moisture content observed in this study (51%) is similar to that obtained in other tree species (Poplar, Pine, etc) used for biomass production [50-52]. The net calorific value (19.91 MJ kg^{-1}) of the woodchip is in line with the value obtained in another study where is evaluated the net calorific value of wood pellets produced with the same tree species (20.36 MJ kg^{-1}) [53]. Another important aspect that is highlight by the HHV analysis is the different calorific value of the trees parts. The highest value was observed in needles analysis, while the lowest value was obtained in wood without bark testing. That difference could be correlate at the different resin content: bark and needle that had a higher resin content shoved the higher HHV values. Nevertheless, independently by tree parts considered, the HHV values are greater than the minimum value reported in EN 14961-3 for the energy wood (15.5 MJ kg^{-1}) [54]. In addition, the value is also higher than that relating to the tree species that is normally used in biomass plantation for energy wood production (poplar, willow, black locust and eucalyptus) [55]. Good results were also obtained in ash content, where the value observed in the tests (1.9 %) is lower than the limit of wood for energy use (0.5-3%) [56]. This parameter can be affected by the amount of tree parts presence: in fact, lowest values (0.9 %) was observed for wood without presence of bark, while highest values (2.2 %) for bark. This trend is in line with the values range found in another study carried out in Norway spruce trees where also in this case the highest values were observed for bark (about 2.0 %) and needles (about 1.80 %) [57].

Wood chips produced by *Cedrus deodara* plantation, under the conditions considered, gave interesting results from energy and economic points of view. In fact, both the energy balance and production cost were positive and in line with the values obtained other experimentations performed in poplar [58], willow [59], black locust [21], eucalyptus [22] and *Pinus radiata* [60] plantations.

The higher value of output/input calculated in this study (73) compared to that obtained in plantations characterised by a harvesting cycle of 6 years (18) is due to the greater biomass presence per unit surface and to low cultural operations carried out during all cultivation cycle of the plantation tested (a only mechanical weed control performed during for the first three years of plantation) [16].

The highest incidence on the energy input is linked to harvesting and chipping operations (51.7%). This situation is known in the biomass production sector and has been highlighted by many authors over the course of the years [61]. In fact, in the last year, a specific study was carried out on the energy required by different types of machines used in biomass harvesting and chipping in order to optimise the energy consumption during woodchip production [40].

Considering a market price of the woodchip of 100 € t DM, the economic evaluation is positive because the production cost calculated in this study is 7% less than (93 € t DM) of the currently woodchip price. This result should not be underestimated because the production cost of biomass obtained by dedicated plantations (SRC) with a short harvest cycle is about 15% higher than the current woodchip price [17, 21, 58].

In addition, considering the large size of trees, the economic sustainability could be increased if the basal part of the trunk (4-6 m) was used for industrial purposes (OSB panel, packaging) with a greater market value [62].

Nevertheless, readers should consider that the economic sustainability of woodchips is linked to transportation distance [63] and biomass available per unit surface [64]. In fact, data processing has highlighted that for biomass production lower than 270 t ha^{-1} and for a transportation distance greater than 80 km, the production cost is higher than the market price considered (100 € t DM) (Fig. 3 and 4).

5. Conclusions

The study highlighted good economic and energetic advantages in woodchip production on south Europe climate conditions of *Cedrus deodara* plantation considering a cultivation cycle of 14 years. In addition, the results also highlighted that from *Cedrus deoadara* it is possible to produce wood chips of high quality in term of LHV compared to other tree species that are typically used in biomass plantations in Italy (Poplar, Black locust, and Eucalyptus). Nevertheless, the results obtained in this experiment are valid only to climate conditions and soil characteristics of Northwest Italy. For this reason, in the future, it could be interesting to carry out other experiments in other soil and climate conditions in order to evaluate the real potential of this exotic species in fuelwood production in the European territory.

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