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Kiwi Clear-Cut: First Evaluation of Recovered Biomass for Energy Production

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Academic Editor: Mejdi Jeguirim

Received: 4 October 2017; Accepted: 7 November 2017; Published: 10 November 2017

Abstract: Among the various types of agricultural waste, significant amounts of energy can be obtained from woodchips derived from comminuted pruning residues. This study aimed to assess the feasibility of using kiwi orchard clear-cut biomass for energy production. The field trial was conducted in a commercial kiwi (*Actinidia chinensis*) orchard located in Northwest Italy. We evaluated the biomass yield, woodchip quality, energy consumption, and economic sustainability of this practice. Processed data determined the available biomass to be 20.6 tonnes dry matter ha^{-1}. Woodchip analysis showed a biomass moisture content of 53% and a relatively low heating value of about 7.5 MJ·kg^{-1}. Furthermore, the average ash content was 2.4%. Production cost was 99.6 €·t^{-1} dry matter, which was slightly less than the market price of 100 €·t^{-1} dry matter for woodchips. In summary, kiwi clear-cut recovered biomass may be a valid alternative biomass source.

Keywords: kiwi clear-cut; biomass production; woodchip quality; energy; production cost

1. Introduction

According to Eurostat, the 2015 annual Italian primary energy consumption was approximately 120 tonnes of oil equivalent (Mte), a value that, under the current national fossil fuel-dominated energy use, would grow to 145 Mte by 2020 [1]. Despite this forecasted increase, the 2011 National Renewable Energy Action plan (NREAP) has set a goal for 17% of the Italian gross final energy consumption to come from renewable sources [2]. Not surprisingly, NREAP has inspired many studies on the use of different renewable sources of energy, and these studies have shown that bioenergy can be obtained from liquid, such as biodiesel, gases, such as biogas and syngas, and solid biofuels. Combustion in boilers to produce hot water and steam is the most common technique used to derive energy from solid biomass [3–6]. Among the various feedstocks, solid biomass are the most efficient material from which energy can be recovered, is the most effective in conversion technology, and is the least expensive to produce [7,8]. Solid biomasses include wood, wood wastes, such as sawdust and woodchips, pellets, straw, stalks, and animal manure, and they are composed of several organic components that can be broken down for energy production [9–12]. The only limit to bioenergy generation is biomass availability.

The agricultural sector, at both the European [13,14] and Italian [15,16] levels, represents large potential sources of solid biofuels. Furthermore, agricultural wastes impact the environment less than plantations dedicated to biomass production, such as short rotation coppices [17]. Among the agricultural waste types, significant amounts of energy-producing woodchips can be obtained from comminuted pruning residues [18]. Currently, about 286,000 ha of orchards exist in Italy [19]. Within Italy, the Piemonte region (Northwest Italy) contains more than 63,000 ha of orchards and 43,000 ha of vineyards [20]; these lands produce sizeable pruning residues that are potential sources of wood biomass [21,22]. Presently, residues are often directly burned or mulched in the field and left between the rows [23]. These two management practices are costly in terms of manpower, economic sustainability, and environmental pollution. Furthermore, mulching may contribute to disease proliferation [14], and burning, even though it is considered a low-cost practice [24], can produce significant atmospheric particulate emissions [25].

Some studies have focused on this topic. Grella et al. [26] demonstrated that as much as 3 Mg dry matter (DM) ha^{-1} can be produced from orchard tree pruning residues, while other studies have highlighted that this agro-energetic chain is sustainable from an economic point of view [27,28]. In addition, different authors have found that this biomass is capable of replacing fossil combustibles, both in small-scale boilers [22] and in power stations [18]. Furthermore, this biomass type shows a favorable profile in terms of pollution emissions because it offers many environmental protection benefits [29]. Nevertheless, few studies to date have focused on the energy that might be produced from the wood biomass currently available in orchard tree clear-cut. Of the types of orchard trees, this study focused on kiwi trees due to their importance at the national (Italian) level and their importance in global production. Notably, at the European level, kiwi cultivation in Italy accounts for about 37,000 ha of the world's 99,000 ha land area under production [1].

According to the latest available data [19], 24,000 ha are dedicated to kiwi cultivation in Italy. The Piemonte region ranks first in the country, with about 5000 cultivated ha, averaging 17 years of age [30]. The destructive bacteria *Pseudomonas syringae* pv. Actinidiae has been spreading to Piemonte since 2010 and is now threatening its kiwi production sector. Cuts following pruning operations, areas of detached leaves, flower buds, or fruits due to thinning and harvesting, are potential sites for bacteria penetration into the vegetative tissues [30]. To limit disease spread, the Ministerial Decree of 20 December 2013 has introduced extraordinary measures to address kiwi infection [31]. Depending on the degree of bacterial diffusion, destruction of either the entire orchard or single trees is required.

Based on these considerations, many farmers have decided to remove infected kiwi orchards and replace them with young healthy plants or other orchard tree species. Because of the high amount of kiwi biomass that must be removed from the fields and stored with specific techniques in order to limit bacteria distribution, this agricultural activity is difficult and intensive. A valid solution to these problems can be found in biomass burning; with this system, reducing the environmental contamination with bacteria is possible thanks to biological material incineration.

In addition to this situation, kiwi orchard management requires periodical tree turnover every 15–20 years, so farmers plan this turnover to guarantee even fruit production. For this reason, the availability of this type of biomass can be assumed to be constant on an annual basis. In addition, according to Grella et al. [26], 2.5 tonnes of dry matter per ha per year are available from pruning residues.

This study aimed to assess the feasibility of using biomass produced from kiwi orchard clear-cut for energy production purposes, investigating the use of biomass for feeding thermal and energy power stations. Specifically, we evaluated the biomass yield, woodchip quality, energy consumption, and economic sustainability of this practice.

2. Materials and Methods

The field trial was conducted in a commercial kiwi (*Actinidia chinensis*) orchard located at Costigliole Saluzzo (44°33′ N, 07°21′ E) in Cuneo Province, Piemonte Region, Northwest Italy. Trees were planted in 1998 in a low-density orchard, spaced at 4.0 m along rows and 4.0 m between rows, at 625 plants ha^{-1}. The field where the orchard was located was 140 m by 90 m wide, with a total surface area 12.6 ha.

2.1. Dendrometric Analysis

Within the kiwi plantation, three plots were identified with a randomized block design. Five trees per plot were chosen for dendrometric analysis. Trunk diameters were determined using a tree caliper

(Stihl®, Waiblingen, Germany) with a readability of 5 mm, while tree heights were measured with a metal ruler (Stanley® FatMax 5 m, New Britain, CT, USA) that permitted accuracy to 0.05 m.

2.2. Tree Cutting and Chipping

A 2 kW chainsaw (Stihl® MS 231, Waiblingen, Germany) was used to cut the trees. The trunk of each tree was cut at soil level and at its top to separate the trunk from the head of the plant. The head is the largest portion of the tree and includes all branches. This allowed assessment of the relative biomass production by plant part. After cutting, the biomass was harvested using a trailer (Silvercar® SRC502, Marene (CN), Italy) and farmyard manure loader (Baratti® mod. 500, Visano (BS), Italy) powered by a 52 kW power tractor (Carraro® TRX 7800 S, Rovigo, Italy). Afterwards, the harvested material was piled in the headland and immediately chipped. The average distance between harvest point and pile point was 65 m. The chipper was fed with a farmyard manure loader (Baratti® mod. 500, Visano (BS), Italy) and all chipping occurred with a drum chipper (Pezzolato PTH 900/660, Envie (CN), Italy) powered by a 136 kW tractor (New Holland T7.235, Torino, Italy). The woodchip was transported to power station by an agricultural trailer with a capacity of 27 m^3 (Randazzo® R 265, Fossano (CN), Italy).

2.3. Working Time and Productivity

Two employees cut and harvested the material, while a single worker chipped and transported it. Total biomass was calculated from the weight of all materials collected during wood harvest [32]. Each loaded trailer was weighed using a steel weighbridge set flush to the pavement (Tassinari Bilance®, Persiceto, Italy) and readable to within 40 kg. As these operations are similar to those performed in the forestry sector, work times were measured by centesimal stopwatch (Hanhart® PROFIL 5, Gütenbach, Germany) and recorded per the International Union of Forest Research Organizations IUFRO classification [33]. In this experiment, a loaded trailer was considered as one unit of work.

Productivity was calculated from available biomass per unit of surface divided by the time required to process the trees into chips. Biomass production was estimated from individual survey area material weights grossed up to total crop area, and expressed as dry matter per unit area [26]. Trailer weigh time was not considered in the productivity calculation because this operation is not performed under real conditions. Collected data assumed a transport distance of 15 km, which was the actual distance between the field test site and nearest power station.

2.4. Woodchip Quality

The quality of the woodchip produced was analyzed using the main parameters used to characterize biofuel: moisture content, size, calorific value, and ash content. Woodchip size was determined from three randomized samplings of 8 L each, collected during chipping. The material was split into eight classes as described in European Standard EN 15149-1 [34]. Successively, each fraction was weighed on a precision scale with precision to 0.001 g. The moisture content of the woodchip was measured following European Standard UNI EN 14774-2 [35] using the gravimetric method, and replicated three times. The same samples were used to determine calorific value per European Standard UNI EN 14918 [36]. In detail, the high heating value (HHV) was determined by calorimeter (IKA® 200, Staufen im Breisgau, Germany), while the low calorific value (LHV) was calculated as a function of the HHV and moisture content of the biomass according to the formula:

$$LHV = HHV \times (1 - M) - KM \quad (1)$$

where HHV is the high heating value ($MJ \cdot kg^{-1}$;), M is the moisture content, and K is the latent heat of water vaporization and is constant at 2.447 $MJ \cdot kg^{-1}$.

The ash content was measured following European Standard UNI EN 14,775 [37], by taking 20 g of dried biomass incinerated at 570 °C for a period of 5 h, using a muffle furnace (Sinergica® ZE, Milano, Italy). Samples were weighed before and after incineration using a digital scale with an accuracy of 0.0001 g (PCE® AB 100, Capannori (LU), Italy). The ash content was expressed as a percentage of the initial value and calculated according to the formula:

$$Ac = (Wf/Wi) \times 100 \quad (2)$$

where Ac is the Ash content (%), Wf is the weight of the sample after incineration (g), and Wi is the weight of the sample before incineration (g).

2.5. Energy Consumption

In this experiment, the energy consumption was calculated considering these different working phases: cutting trees, harvesting and piling trees, chipping trees, and woodchip transportation from field to power station, which was assumed to be 15 km. The energy consumption was determined considering direct energy consumption, which is the energy input required to perform the chipping operation (fuel and lubricant consumption), and the indirect energy consumption, which is the energy used for manufacturing the tractors and implements. For the indirect energy calculation, a value of 92.0 MJ for self-propelled machines and 69.0 MJ for equipment per each kilogram of machine mass were assumed [38,39]. The direct energy was determined using 37.0 $MJ \cdot L^{-1}$ for fuel and 83.7 $MJ \cdot kg^{-1}$ for lubricant [38,39]. Moreover, a value of 1.2 $MJ \cdot kg^{-1}$ was used for both the fuel and lubricant to represent their transportation energy consumption throughout the region [40]. We used 55% of the total energy for each machine as an estimate for their maintenance and repair [41]. Fuel consumption was measured after refilling the machine tank at work start and finish [42]; we assumed lubricant consumption to be 2% of the consumed fuel [43].

2.6. Economic Evaluation

Woodchip production cost was determined from hourly machine costs used in all activities. That calculation was performed by the Miyata method [44] updated to 2015 (Table 1).

Table 1. Machine purchase costs considered in the economic evaluation.

Machine		Purchase Cost (€)
Type	**Model**	
Chainsaw	Stihl MS 231	900
Trailer	Silvercar SRC502	13,000
Loader	Baratti 500	8500
Tractor	Carraro TRX 7800 S	28,000
Chipper	Pezzolato PTH 900/660	160,000
Tractor	New Holland T7.235	145,000

Specifically, an annual use of 500 h and a life of 10,000 h were assumed for tractors (tractors also used for other activities), while an average of 350 h worked per year and a life of 2500 h were assumed for the other equipment including the chipper [44,45]. We used a cost of 18.5 $€ \cdot h^{-1}$, including obligatory health and social insurance, for manpower, and costs of 0.9 $€ \cdot kg^{-1}$ and 5.0 $€ \cdot kg^{-1}$, respectively, for fuel and lubricant [46]. Furthermore, the evaluation was performed using a retention value of 20% of the original investment and a depreciation period of 10 years. Maintenance and repair costs were calculated directly from the machine's owner. Overheads and profit were included as 20% of the total cost [47]. To evaluate the economic sustainability of the woodchip production from kiwi clear-cut, the costs were determined by considering different amounts of biomass available per unit surface and transportation distance. Moreover, an average value of 100 $€ \cdot t^{-1}$ DM was assumed based on current Italian woodchip market pricing.

Data were processed using Microsoft® Excel Software (Microsoft Corporation, Redmond, WA, USA) and SPSS v. 21 statistical software (IBM, Torino, Italy). The statistical significance of treatment differences was tested with the REGW-F test, adopting a significance level of $\alpha = 0.05$. The REGW-F test was used because it is a multiple step-down procedure that highlights high statistical power of data distribution [48].

3. Results

3.1. Dendrometric Analysis

Kiwi plantation trees averaged 175 ± 34 mm in basal diameter and 2150 ± 150 mm in height. Moreover, the processed data indicated 20.6 t DM·ha^{-1} of available biomass. Tree heads, including branches, represented about 60% of the entire plant biomass.

3.2. Working Time and Productivity

In this study, 27.8 Work Unit (WU) hours per hectare were necessary to complete the full cycle to turn kiwi clear-cut into woodchips. The round trip travel time required for woodchip transportation was 1.94 h across a distance of 15 km. The operations that demanded the highest manpower were harvesting and piling, at 47% of the total; woodchip transportation required the lowest, at 7% (Figure 1).

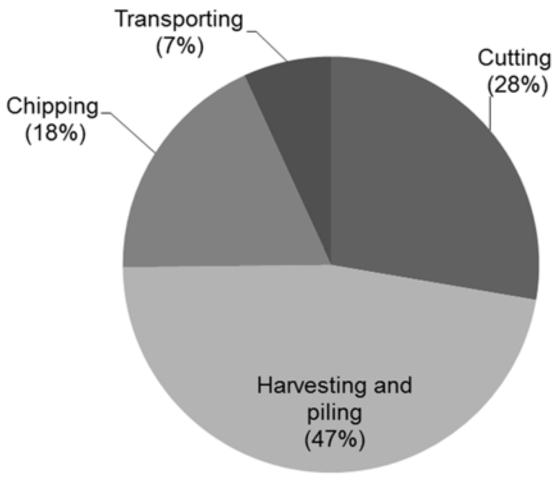

Figure 1. Manpower required in different operations.

Biomass harvesting and piling yielded high work efficiency, in terms of net working time, of 84%, in contrast to the high amount of unproductive time/inefficiency observed with cutting, at 10%. This result stems from the rest breaks required by the operator (Table 2).

Table 2. Measures of time elements for each working operation.

	Net Working Time (%)	Complementary Working Time (%)	Unproductive Time (%)
Cutting	79	11	10
Harvesting and Piling	84	10	6
Chipping	80	17	3
Transporting	78	20	2

Productivity was 0.13 ha·h^{-1} and 0.08 ha·h^{-1} for cutting and chipping, respectively. The high value associated with biomass transport was due to the short distance used (15 km) (Figure 2).

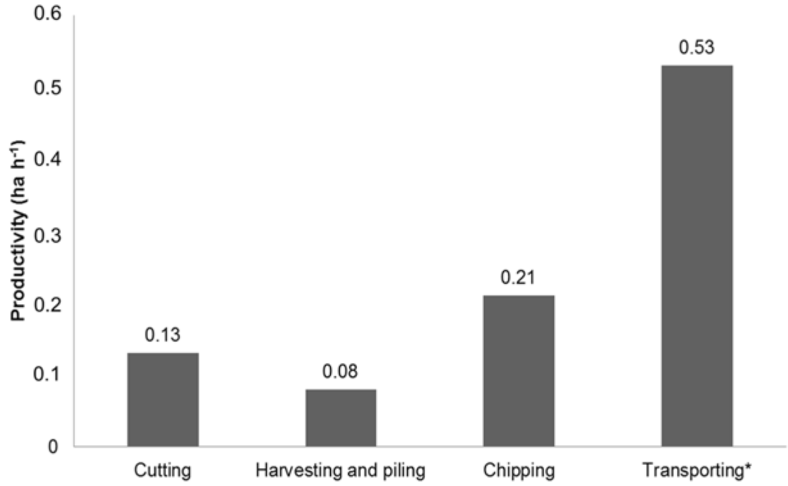

Figure 2. Productivity values obtained in the different working operations. * indicates value obtained with a 15 km transport distance.

3.3. Woodchip Quality

Woodchips obtained from kiwi tree comminution averaged a 53% moisture level. Each transportation trip transported an average amount of 7910 kg of biomass. Considering the trailer volume of 27 m^3, the average bulk density of the comminuted wood transported to the power station was 294 kg·m^{-3}. Eighty percent of the obtained material was found to be of an acceptable size, in the range of 9 to 63 mm, regardless of being sourced from the plant head or trunk, despite the fact that trunk chipping generally contains more oversized particles compared to those from the trunk (Figure 3).

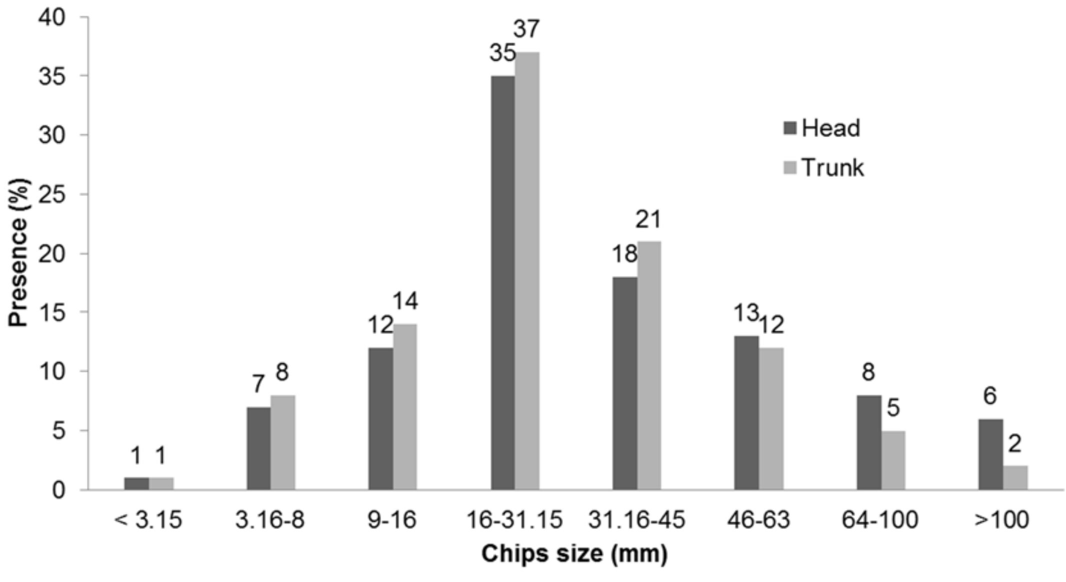

Figure 3. Woodchip size distribution during head and trunk tree comminution.

Notably, iron training wires were also inside the tree heads, as the lateral branches are wrapped over the wires, as they develop vigorously during the growing season. Woodchip analysis resulted in an average HHV of 18.8 $\pm$ 0.55 MJ·kg^{-1} for trunks and 18.6 $\pm$ 0.21 MJ·kg^{-1} for heads. Given the 53% biomass moisture content, the low heating value for trunks was 7.5 MJ·kg^{-1}, and that for heads was 7.4 MJ·kg^{-1}. Furthermore, the average ash content was 2.4% for both parts.

3.4. Energy Consumption

Woodchip production from both the head and trunk of kiwi plants required an average fuel consumption of 8.6 L·t^{-1} DM. The energy consumption for woodchip production was about 1 GJ·t^{-1} DM woodchips. Wood chipping required the highest energy input, at 48%, while tree cutting used the lowest, at 9% (Figure 4).

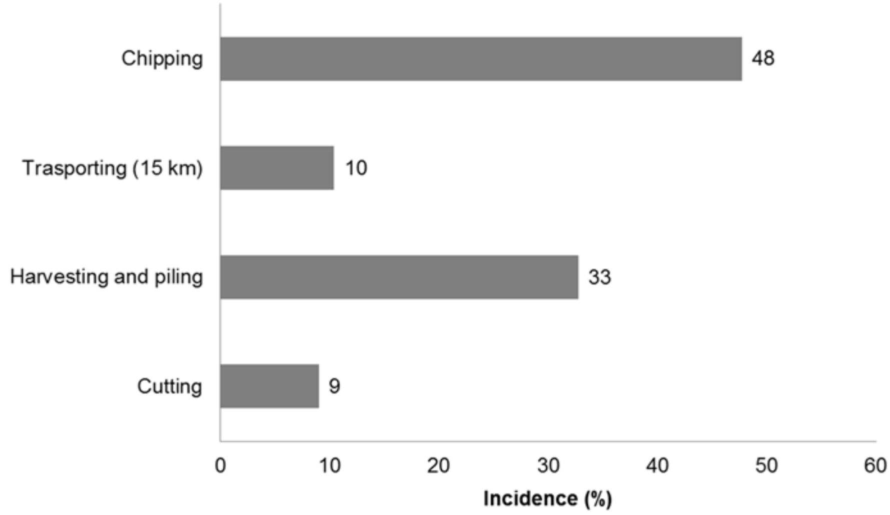

Figure 4. Incidence of the different working operations on the total energy required for woodchip production.

3.5. Economic Evaluation

The production cost calculated for the available biomass amount obtained in this study of 20.6 t DM· ha^{-1} was 99.6 €·t DM^{-1}. Across all woodchip comminution activities, chipping was most expensive, accounting for 32% of the total cost, and biomass transportation cost the least, at 18%. Intermediate values were observed for the harvesting and piling combined operation and cutting activity (Figure 5).

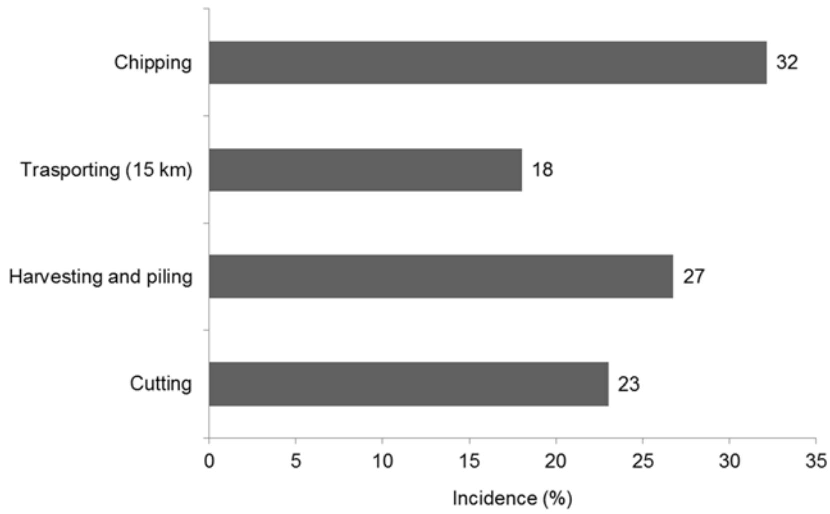

Figure 5. Breakdown of the single operations on the total woodchip production cost.

This result is significantly affected by the transport distance used in the scenario. The value used here (17.8 €·t DM^{-1}) corresponds to a 15 km distance. The value increases faster than it would in a linear cost–distance relationship; it rises to 38 €·t DM^{-1} when the distance is doubled to 30 km (Figure 6).

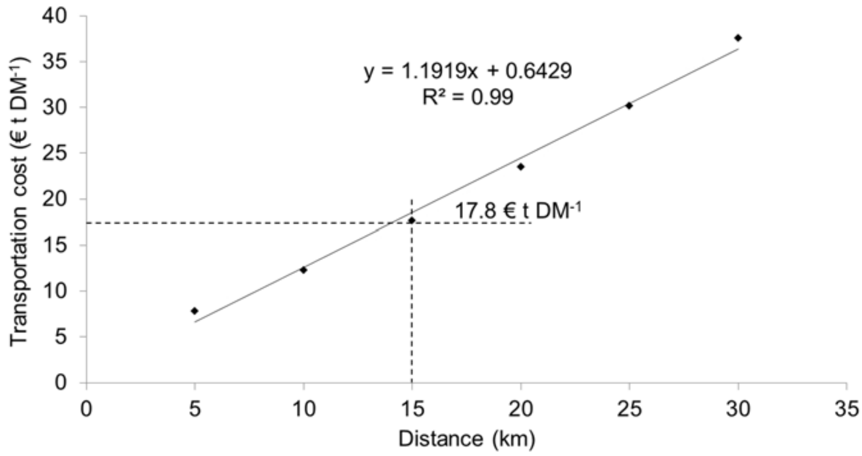

Figure 6. Transportation cost as a function of distance.

Interestingly, the results highlighted that the economic sustainability of woodchip production can be guaranteed when a market value of 110 €·t DM^{-1} and a transport distance of 15 km are maintained, and the available biomass is at least 17.5 t DM·ha^{-1} (Figure 7).

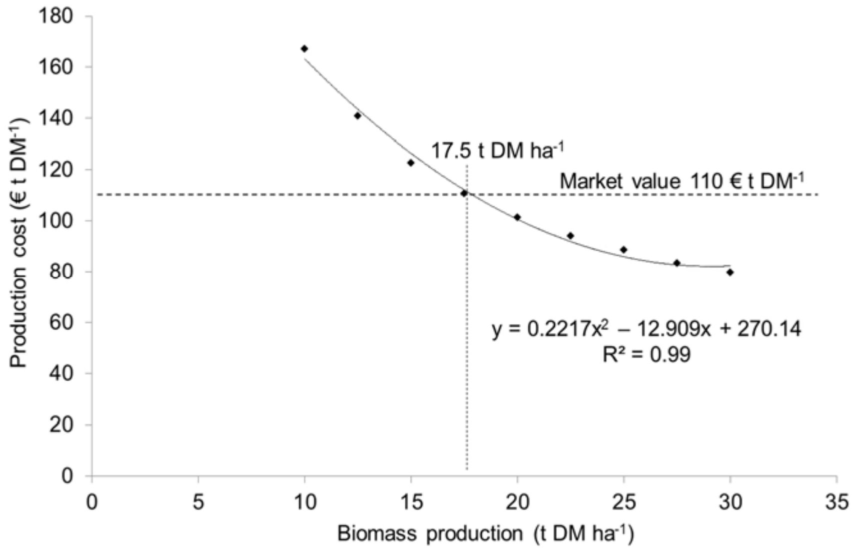

Figure 7. Woodchip production cost as a function of biomass production.

4. Discussion

The biomass available per hectare of kiwi clear-cut calculated in this study, at about 20 t DM per year, is consistent with that produced by a specific biomass production plantation situated in the same geographic area [49]. This finding is crucial because it indicates that a power station could use the same logistics for both cultivations. Furthermore, the work efficiency obtained in kiwi plantation chipping was similar to that observed in other studies of woodchip production from short rotation coppice (SRC) [50], which suggests that generalizations can be made. A key difference in this study was the seven-fold lower productivity value compared to that calculated for SRC, which uses dedicated feller-chipper machines [51]. This arises from the different harvesting methods used. In SRC, the biomass is harvested with a machine that can simultaneously cut and chip the biomass, whereas the operations are performed in two parts in kiwi plantations. This also results in a lower manpower requirement for SRC management compared to that in a kiwi plantation [52–54].

Woodchips produced from kiwi plantations are quite suitable for energy use. In fact, the moisture content of the woodchips is similar to forest-sourced hardwood (poplar) [55] and softwood (pine) [56] comminution. The kiwi HHV of 18.6 MJ·kg^{-1} is not only above the threshold stated in EN 14961-3 for energy-rich woods of 15.5 MJ·kg^{-1} [57], but also above that observed for tree species usually cultivated for woodchip production in Northwest Italy, including poplar, willow, and black locust [58].

The experiment also demonstrated that a consistent and standard-sized chip as required by the market can be ensured, independent of comminution type (trunk or head) [59]. The presence of steel wire pieces embedded in the kiwi plant heads did not play a big role in our study.

The ash content analysis had a good result. Woodchip incineration produced an ash content of 2.4%, which is a lower value than the 3.0% typically found in solid biofuels [60].

The energy consumption analysis highlighted the use of the chipping phase, at 48%, on the overall energy required to complete the cycle from plantation plant to woodchip, which is consistent with values calculated for dedicated biomass plantations [61]. The criticism all woodchip supply operations face regarding energy use must be underscored. Indeed, the relative energy use of different chippers was studied last year in an effort to optimize the energy equation of wood comminution [45,62].

Finally, with an average woodchip market value of 110 €·t DM^{-1}, economic sustainability is guaranteed whenever the biomass availability is more than 17.5 t DM·ha^{-1}. Although this value is insufficient to cover woodchip production costs of biomass plantations (SRC), it is considered a relatively good biomass production per unit [52–54], because the cost of biofuel is strongly linked to transport distance [55]. The economic sustainability of woodchip production in this study was found when a transportation distance of only 15 km was assumed. The sustainability curve would improve as the distance increased.

5. Conclusions

Biomass recovered from kiwi clear-cut may be a valid alternative to other biomass sources. This study reported good productivity, energy, and economic sustainability results for woodchip produced by kiwi clear-cut. The biomass available from kiwi plantations at the end of their cultivation cycle was sufficient to cover the costs of each woodchip production phase, including cutting, harvesting and piling, chipping, and transporting. The observed biofuel quality was also high in calorific value. One caution to its use is the presence of iron wires in the plant heads, which may cause problems during wood comminution.

Acknowledgments: The project was carried out with the financial support of the Regione Piemonte under the PSR 2007-2013—Misura 124—Azione 1 program ("Fruitgas" project. Grant n° 08000460736).

Author Contributions: Marco Manzone and Fabrizio Gioelli performed the experiments and analyzed the data; Marco Manzone wrote the paper and Paolo Balsari and Fabrizio Gioelli revised it.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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