energies

MDPI

Article

Storage of Fine Woodchips from a Medium Rotation Coppice Eucalyptus Plantation in Central Italy

Luigi Pari [1], Simone Bergonzoli [2,*], Paola Cetera [1], Paolo Mattei [1], Vincenzo Alfano [1], Negar Rezaei [1], Alessandro Suardi [1], Giuseppe Toscano [3] and Antonio Scarfone [1]

1 Council for Agricultural Research and Economics—Research Centre for Engineering and Agro-Food Processing (CREA-IT), Via della Pascolare, 16, Monterotondo, 00015 Roma, Italy; luigi.pari@crea.gov.it (L.P.); paola.cetera@crea.gov.it (P.C.); paolo.mattei@crea.gov.it (P.M.); vincenzo.alfano@crea.gov.it (V.A.); negar.rezaei@crea.gov.it (N.R.); alessandro.suardi@crea.gov.it (A.S.); antonio.scarfone@crea.gov.it (A.S.)
2 Council for Agricultural Research and Economics—Research Centre for Engineering and Agro-Food Processing (CREA-IT), Via Milano 43, Treviglio, 24047 Bergamo, Italy
3 Department of Agricultural, Food and Environmental Sciences, Marche Polytechnic University, Via Brecce Bianche, 60131 Ancona, Italy; g.toscano@univpm.it
* Correspondence: simone.bergonzoli@crea.gov.it; Tel.: +39-0363-49603

Received: 7 April 2020; Accepted: 4 May 2020; Published: 8 May 2020

check for updates

Abstract: *Eucalyptus* spp. has received attention from the research and industrial field as a biomass crop because of its fast growth and high productivity. The features of this species match with the increasing demand for wood for energy production. Commonly, the wood used for energy production is converted in chips, a material susceptible to microbial degradation and energy losses if not properly stored before conversion. This study aims at investigating two outdoor storage systems of Eucalyptus wood chips (covered vs. uncovered), assessing the variation in moisture content, dry matter losses and fuel characteristics. The class size of the material was P16, which was obtained using a commercial chipper appositely searched to conduct the study. The results highlighted how the different storage methods were influenced by the climatic condition: the woody biomass covered showed the best performances in terms of dry matter losses achieving 2.7% losses vs. The 8.5% of the uncovered systems. However, fuel characteristics displayed minor changes that affected the final energy balance (ΔEn = −0.2% in covered; ΔEn = −6.17% in uncovered). Particle size varied in both methods with respect to the start conditions, but the variation was not enough to determine a class change, which remained P16 even after storage.

Keywords: eucalyptus; woody biomass; storage of fine wood chips; moisture content; calorific value; ash content; dry matter loss

1. Introduction

Short and medium rotation coppice (SRC and MRC) are fast-growing tree plantations that generally produce high quantities of woody biomass in productive cycles of 2 years (SRC) and 5–6 years (MRC) [1]. According to species and site-fertility, the stump regenerates after cutting, and the production cycle can be repeated until the coppice is no longer productive. The woody biomass obtained from the plantations can be used as a renewable energy source [2] through different thermo-chemical conversion processes [3]. In Mediterranean environment, Eucalyptus plantations are having a success thanks to the use of fast growing inter-specific clones [4], suitable for employment in SRC and MRC. The most cultivated European countries are Spain and Portugal, with an amount of cropped area above 600,000 ha [5]. In Italy, the cultivated surface is approximately 70,000 ha, of which 20,000 are utilized for bioenergy production in Sicily and Sardinia [6]; the rest are cultivations addressed to soil protection or as windbreak, rarely utilized as firewood. Despite a still-limited distribution, there is a growing interest in cultivating eucalyptus in Italy, especially for MRC plantations, which can obtain trunks suitable for firewood production, a product having a higher economic value with respect to wood chips [7].

SRC and MRC are also gaining interest because international policies promote the production of forest woody biomass as a renewable energy source (European Energy 2020 strategy—Directive 2009/28/EC) [8]. It was observed that plantations provide also environmental advantages, working as a mechanism to promote local biodiversity during the growing period [9].

However, doubts about harvest and storage systems still remain, raising barriers to the feasibility of these crops and marketability of the products, limiting their distribution. In the last decade, some important achievements have been reached in the mechanization sector through innovation in technology [10], but a clear demand for more research is needed to address the problem of storage systems [11]. Certainly, the conservation of the material and the relative costs are important issues that need attention.

Wood is generally stored in whole tree sections or in form of chips. Storing whole tree sections is considered a suitable solution to avoid energy losses [12]; this is because the surface of the wood exposed to potential microbial activity is very low with respect to other forms utilized for wood storage, such as the chips [3]. On the other hand, the handling of tree trunks is more expensive with respect to the direct chipping of the material, mainly for transport and other logistic aspects; for this reason, the mobile chipping in harvesting site is considered the most practical and feasible solution in the woody biomass-for-energy chain [13].

Unfortunately, wood chips are susceptible to microbial degradation and during storage high loss of dry matter can occur if the material is stored in the wrong conditions. The loss of dry matter implies a high loss of energy, that in some cases can be very high, as demonstrated by Pari et al. [14]. Other risks of managing wood chips include the spontaneous combustion of chip piles due to particular thermo-chemical reactions and potential human health hazards caused by airborne fungal spores [15]. Many studies have been performed to identify suitable storage methods able to address these problems [16]. Despite the storage time and conditions, many of these issues are related to the quality of the chips, especially the particle size, which influences the air circulation inside the pile. When air circulation is not enough, the dehydration process of the woody biomass slows down and determines the persistence of moisture, which in turn facilitates the microbial degradation and the heat development processes [17]. However, at present there is a growing interest in the market of "microchip", i.e., a wood chip of homogeneous size (about 7 mm target length) with high commercial value that can exploited in conventional pellet stoves and boilers upon minor modifications to the feeding apparatus and a new setting of the combustion system [18]. Specifically, a microchip must possess also other physic-chemical characteristics such as Ash content $A \leq 1\%$, Moisture content $MC \leq 10\%$, Bulk density BD $150 < x < 250$ kg/m^3, lower heating value $Q_{LHV} \geq 16$ MJ/kg, and the presence of fine fractions $FF \leq 1\%$ according to current standards (ISO 17225-1:2014) [19]. The production of microchip obviously implies additional passages with respect to the production of traditional chips such as the screening and the forced drying to obtain a product that is homogeneous in size, with a low fine fraction and moisture content.

The information right now on the storage behavior of P16 size class wood chips, a product that possess the prerogative to became microchip, but that, at the same time, could experience high degradations during storage for the limited air circulation occurring inside the pile, is still very limited. Previous studies are mainly focused on the storage of woody biomass belonging to P45 size class and very few studies exist on Eucalyptus chip storage. Considering that, this study proposes the evaluation of the storage dynamics performance of P16 wood chips obtained from a eucalyptus MRC plantation in Mediterranean environment by using a storage method (chip pile) and two treatments (covered and uncovered pile). The aim is to fill the knowledge gap on P16 Eucalyptus storage by using an already studied and spread storage method.

The current research on wood chip storage refers mainly to materials typically used in biomass power plants of medium and large scale, i.e., wood chips with an approximate mean length of 3 mm, belonging to the size class of P45. This specific size class is required because power plants components are generally standardized and the presence of smaller or larger material may create problems during the system functioning; such problems may include the clogging of the feeding apparatus of the boiler, the presence of unburned material in the ash collector, and inefficient combustion. For this reasons, small size wood chips were not of relevant interest until a few years ago.

Nowadays, the demand for microchips for domestic uses has increased, and deeper attention should be payed to products having the potential to be employed for such uses. The present study proposes an evaluation of the storage performance of P16 size class wood chips, a material with a mean length of 7 mm, potentially converted into microchips upon further processing. Considering that, the study proposes the evaluation of the storage dynamics performance of P16 wood chips obtained from a eucalyptus MRC plantation in a Mediterranean environment by using a storage method (chip pile) and two treatments (covered and uncovered pile). The aim is to fill the knowledge gap on P16 Eucalyptus storage by using an already studied and spread storage method.

2. Materials and Methods

The study was conducted between April and October 2018 at a Research Centre for Engineering and Agro-Food Processing (CREA-IT) in Monterotondo, near Rome, Central Italy (42°10′19″ N latitude, 12°62′66″ E longitude). The wood chips utilized derived from a five-year-old Eucalyptus plantation at the first productive cycle (Figure 1) Production data and further plantation characteristics are provided in Pari et al. [20]. The tree felling was performed in early April and plants were chipped immediately after using a Farmi Forest CH260. This chipper was appositely selected because in previous studies it demonstrated the ability to produce small size chips. In a work proposed by Spinelli et al. [21], nine commercial chippers were compared for chip size distribution; the study displayed that Farmi Forest CH260 was the only machine producing P16 chips (more than 60% of the chips size between 16 and 3 mm), which is the main prerogative of microchips [21]. The cutting configuration of commercial chippers can be also re-adjusted to produce finer woodchips, as verified in other studies [22].

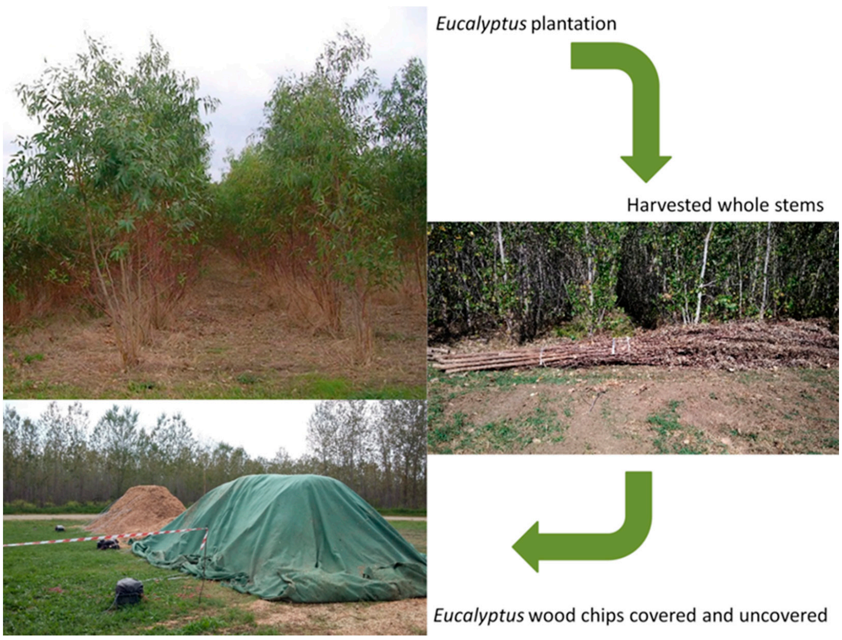

Figure 1. Experimental phases from field to storage site.

2.1. Climatic Parameters

The storage of Eucalyptus wood chips was carried out outdoors with two different storage systems (covered vs. uncovered); the material was exposed to the same weather conditions and the climatic parameters such as temperature, precipitation, wind speed and wind direction were recorded during the entire storage period (6 months). These parameters were recorded using a weather cab (Davis Instruments, 3465 Diablo Avenue, Hayward, CA 94545-2778 U.S.A) "DAVIS VANTAGE PRO 2" placed in the proximity of the storage site and connected to wireless net.

2.2. Storage Conditions

Around 34.6 tonnes of comminuted woody biomass (approximately 100 m^3) has been stored in two piles, 8 m long, 4 m wide and 3 m tall. The material was stored for 6 months in a flat site close to the plantation. To isolate the chips from the soil and avoid contamination, a polyvinyl chloride (PVC) sheet was laid on the ground, working as storage floor. The shape and the orientation of the two piles were maintained as similar as possible, to ensure that climatic factors had the same influence on both treatments. One of the piles was covered using a Toptex textile tissue, i.e., a material able to allow transpiration and avoid the penetration of precipitations. Each pile consisted of three sections (replicates), each one including six sampling points (TC1, TC2, TC3, TC4, TC5, TC6); in total, 18 sampling points per pile were utilized (Figure 2); a similar scheme was utilized in previous studies [15]. Internal temperature during storage was monitored by placing one pT-100 thermocouple in each sampling point. The probes were connected to a computerized data monitoring cab, connected to the web and remotely controlled.

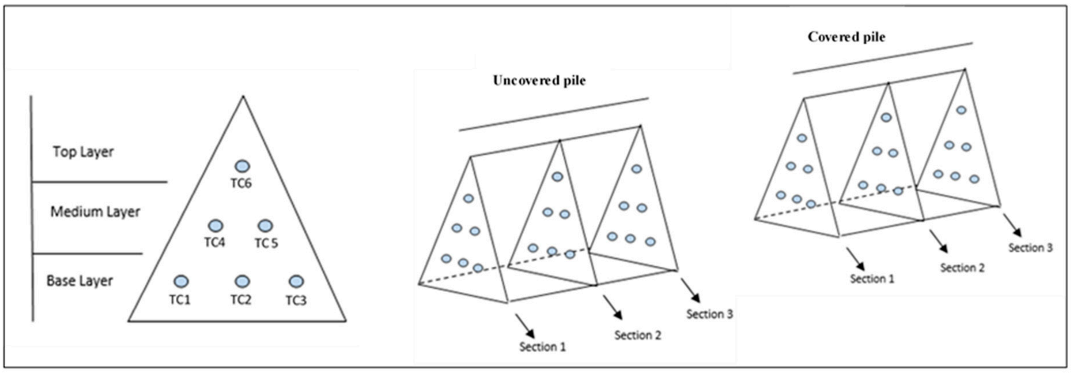

Figure 2. On the left side, the single transversal section of the scheme utilized to set the experiment; on the right side, the full scheme of the experiment with three sections (replicates) in both treatments.

2.3. Physical Characteristics

Near each thermocouple, a plastic net filled with about 1 kg chips (pre-weighed) was placed in order to monitor dry matter losses. After storage, the bags were removed from the piles and weighed before and after drying in a ventilated oven set at 105 ± 2 °C. The calculation of the dry matter losses was performed using the following equation (Equation (1)).

$$DML\ (\%) = \left[1 - \left(\frac{DW_2}{DW_1}\right)\right] \times 100 \quad (1)$$

DML: Dry matter losses (%);
DW_1: Dry weight prior storage (kg);
DW_2: Dry weight after storage (kg).

Moisture content of the chips was determined according to standard ISO 18134-1:2015 [23] at the beginning of storage, taking 10 random samples (500 g each) from the fresh material; at the end of the experiments, the operation was repeated using 10 random samples (500 g each) taken during pile opening. For calculation of moisture content, the following equation (Equation (2)) has been used.

$$MC\ (\%) = \frac{W_{fb} - W_{db}}{W_{db}} \times 100 \quad (2)$$

W_{fb} = Weight of the sample on fresh basis (g);
W_{db} = Weight of the sample on dry basis (g).

In addition, the particle size distribution of the comminuted woody biomass was analyzed according to UNI EN 15149:2010 [24] before and after the storage in piles considering three samples of 8 L volume each.

2.4. Chemical and Energetic Properties

The parameters studied were the following: ash content (*A*), chemical composition (C, H, N, Cl, S), Higher and Lower Heating Values (*HHV* and *LHV*). These parameters were determined according to the respective European standards: ISO 18122:2015 *"Determination of ash content"* [25], UNI EN 15104:2011 *"Determination of total content of carbon, hydrogen and nitrogen content instrumental method"* [26], ISO 16994:2016 Solid biofuels—determination of total content of sulfur and chlorine [27] and UNI EN 14918:2010 *"Determination of Calorific Value"* [28], respectively.

During storage, the dry matter losses and the change in some fuel quality parameters (heating value) can determine variations in the final energetic balance. In fact, as dry matter losses determine energy losses, variation in the heating value can mitigate or worsen the final energy balance. For this reason, an evaluation of the Δ energy, (i.e., the energy available before and after biomass storage) was performed using the following equation (Equation (3)), as reported in previous studies [15].

$$\Delta En.\% = \left\{ \left[\left(1 - \frac{Dry\ Matter\ Losses}{100} \right) \times final\ LHV \right] - initial\ LHV \right\} \frac{100}{initial\ LHV} \quad (3)$$

Final LHV = Lower Heating Value after storage;
Initial LHV = Lower Heating Value before storage.

2.5. Statistical Analysis

For the statistical analysis of the data obtained from the two treatments, the open source statistical package PAST v.3.26 [29] was used in order to check the statistical significance. After checking the data for normality, the software was used to perform T-test or ANOVA, between the means. Considering that the experimental plan was based on only two treatments, the two Paired samples T-test was used when studying the differences only among the treatments (i.e., dry matter losses) while ANOVA was used for the analysis between treatments and pre-storage conditions (i.e., particle size, moisture content).

3. Results and Discussions

3.1. Climatic Data

During the storage period, the main weather parameters were daily recorded. The amount of precipitation was mainly concentrated in May 2018, followed by an anomalous drought period until the end of the experiment, as confirmed by the referring institution on regional climatic data (Servizio Integrato Agrometeorologico della Regione Lazio (SIARL)) [30]. The air humidity followed the same trend of precipitation, with the highest value recorded in May (83%), and a strong reduction until July (59%). After a fluctuation between August and September, as in the case of precipitation, the value of air humidity at the end of the experiment was 67%. The temperature ranged between 17 and 25 °C (average min and max, respectively), recording the warmer month in July 2018 (Figure 3).

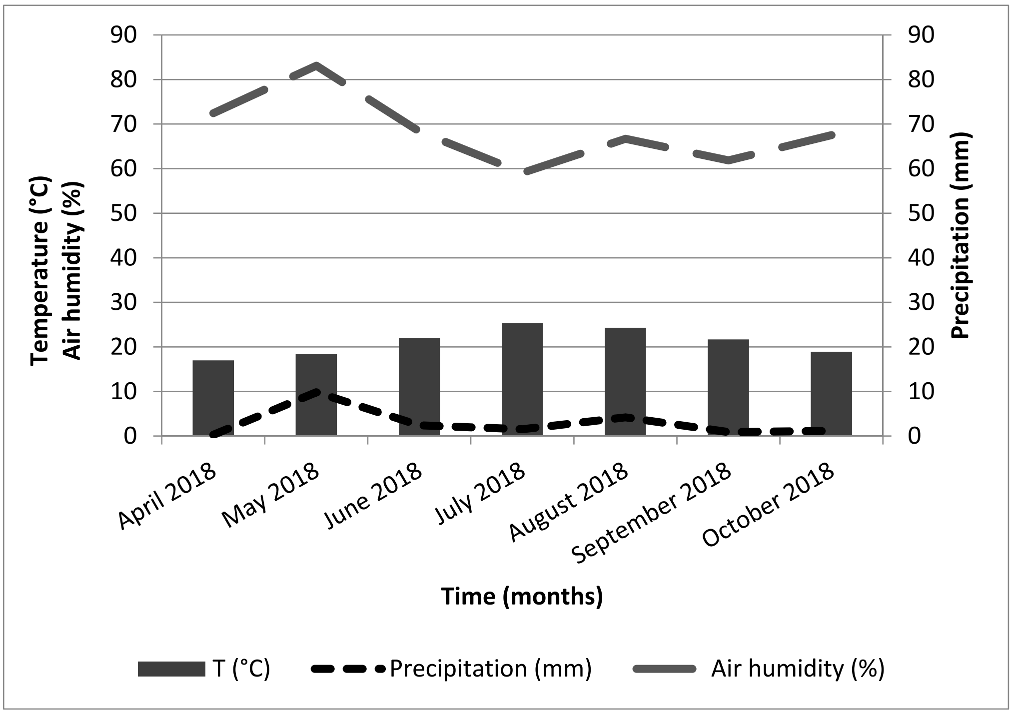

Figure 3. Trend of main climatic parameters: temperature (°C), precipitation (mm) and air humidity (%) recorded during the storage of Eucalyptus from April to October 2018.

The climate can greatly influence the storage performance of the biomass, and precipitation is a very important parameter to be considered, since it determines the increase in air humidity and the re-wetting of the material. The presence of moisture facilitates the microbial degradation activity, especially in the uncovered piles, contributing to dry matter losses. In this regard, the high drought occurred in summer 2018 had probably positively affected the storage performance of this biomass. The results obtained in this study should be therefore interpreted taking into account this general consideration.

3.2. Particle Size Distribution

The particle size analysis shows that the chipper Farmi (Farmi forest corporation, Ahmolantie 674510 Iisalmi) CH260 produced a chip falling in the class of "P16", i.e., the class in which more than 60% of the sample weight is characterized by a chip size between 3.15 and 16 mm according to ISO 17225-1 2014 [19]. The storage did not cause a class variation, so the "P16" was maintained also after the storage in both even if the several-sample test ANOVA confirmed the presence of significant differences among values of same size class between the treatments (data not shown). The coarse fraction above 31 mm was absent, while the fine fraction was among values of 20% and 25% before and after storage (in both treatments), determining the classification of the product as "F25". It should be noted that a small increase in fine fractions was observed in both treatments after storage; from an initial 20.17% of fine fraction in the fresh material, this became, respectively, 22.15% and 23.19% in covered and uncovered chip piles after storage. On the contrary, the size class between 3.15 and 8 mm displayed an opposite trend; form an initial 59.7%, this fraction became 57.31% in covered chips and 56.96% in uncovered chips (Figure 4). Even if the size classification of the product was not affected by storage, the minimal but significant size variation should be attributable to the degradation process of microorganisms. As previous studies confirmed, the small size of the chips determined problems of air circulation in the piles [22], which in turn determine the persistence of moisture in the stored material. This is also confirmed by the final moisture content of the two treatments (31% covered vs. 40%

uncovered). The slowed air-drying allowed microorganisms to continue their activity, and this was also confirmed by the temperature monitored inside the piles, which displayed a more similar trend (with higher temperatures) in the uncovered pile, i.e., more degraded treatment according to dry matter analysis. Another interesting observation that indicates degradation activity is the quantification of the fine fractions, which increased in both treatments after storage, which was slightly higher in the uncovered pile.

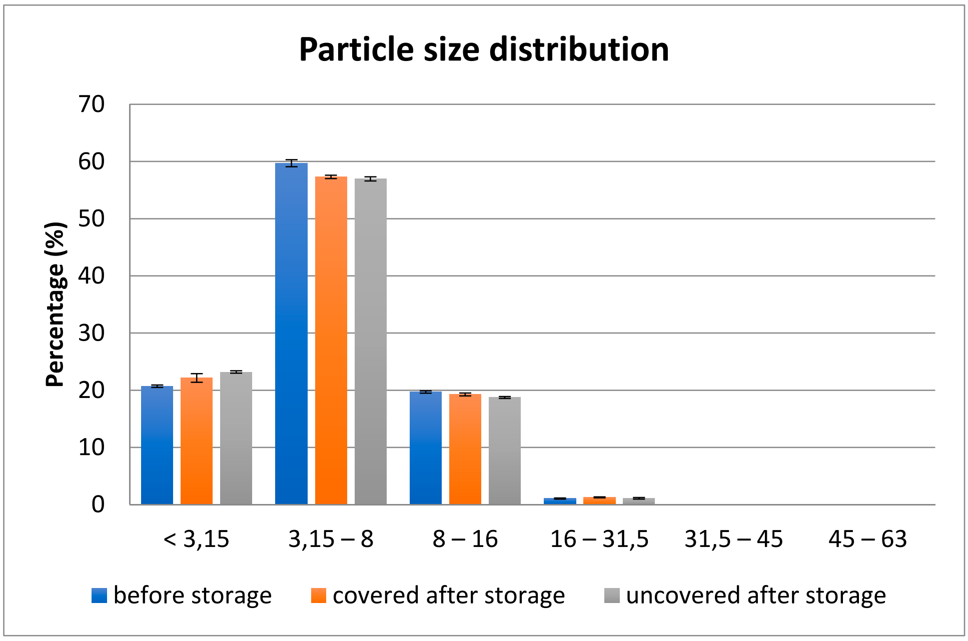

Figure 4. Particle size distribution of the chips before and after storage.

Such a small size of chip can have great influence on the storage dynamics, because the air circulation inside the pile is very limited.

3.3. Moisture Content and Internal Heat Development

At the end of storage, the moisture content of uncovered P16 wood chips was higher than 9% with respect to the chips of the covered pile (Table 1). The several-sample test ANOVA confirmed the presence of significant differences ($p < 0.05$) among fresh chips and post-storage chips and among the material of the two treatments (covered vs. uncovered). In this case, it therefore confirmed the efficacy of the Toptex for small size chips. Despite the initial *MC* values, the fresh woody biomass samples showed a reduced standard deviation (SD ± 0.13), and the moisture of the final samples deviated remarkably in both covered and uncovered piles (from the mean values the SD was ±8.45 in covered pile and ±4.88 in uncovered pile). The moisture behavior inside the wood chip piles of coniferous biomass was recently studied by Wästerlund et al. [31]. In this work, it is explained that the moisture inside the open-air stored pile is not distributed homogenously during storage because of physical dynamics that influence the water movement. For instance, the internal heat development promoted by microbial activity determines the movement of moist air from the internal to the external part of the pile. The precipitation and the air humidity can also influence the moisture of chips, especially in the external layer; indeed, when the chips are handled with a tractor bucket the product is mixed and some regions can be moister than others. Therefore, these high deviations can be explained, as our sampling was performed during pile opening with a tractor bucket, determining a mixing of the pile layers during sample collection; it should be noted that this methodology was followed to resemble the normal conditions that occur in power plant when chips are loaded in the feeding system of the boiler.

Table 1. Moisture content (*MC*) of Eucalyptus covered and uncovered woody biomass pile, expressed in percentage (%), where: MC_i, initial moisture content and MC_f, final moisture content, that is at the end the storage. *MC* values with different letters indicate mean values significantly different ($p < 0.05$) according to the several-sample ANOVA test.

Type of Storage	Replicas	MC_i (%)	MC_f (%)
Covered	10	50 ± 0.13 [a]	31 ± 8.45 [b]
Uncovered	10		40 ± 4.88 [c]

It should be noted that, considering the novelty of the research, comparison with the results found in other studies was based on different species and class size, as reported in the literature.

Effectively, the internal heat development recorded during storage in the two piles may reflect the moisture content deviations between both treatments (Figure 5; Figure 6). The uncovered pile in fact maintained a trend of temperatures higher and constant in all measurement points with respect to the covered piles, indicating a steady fermentation process with respect to the covered treatment. The more rapid heat dissipation occurring in the lower external part of the covered pile (T1 and T3) is a confirmation of the microbial breakdown in this treatment; it should be mainly associated with the vicinity of the material to the ground and to the external environment. Probably, these regions of the pile have lost moisture more rapidly with respect to the others, causing the microbial activity to stop faster. The uncovered pile, on the contrary, has probably suffered the effect of the moist air of the night, which maintained the conditions necessary to keep the fermentation process alive.

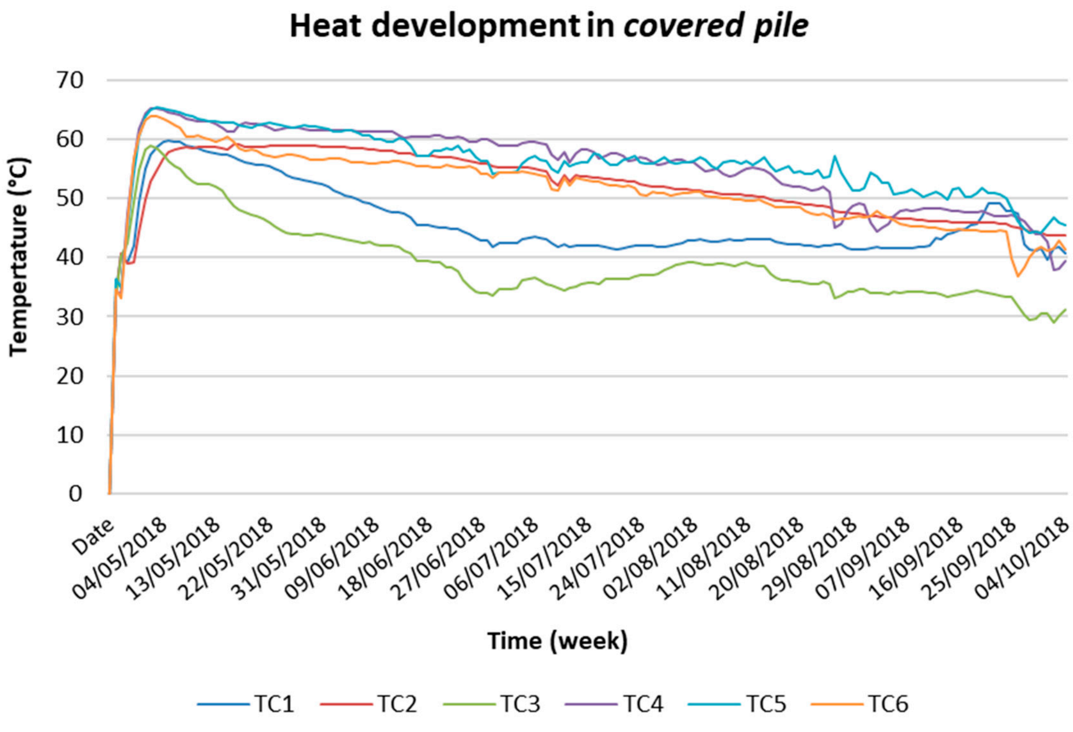

Figure 5. Heat development in covered pile. The numbered letters (TC1, TC2, etc.) indicate the thermocouple location according to the scheme shown in Figure 2.

In general, the difficulties to dissipate heat in both piles should probably be associated with the lack of ventilation [32], which is also due to the small chip size; this has favored the persistence of moisture, and therefore the microbial vitality. The gradual decrease in temperature in some parts of the covered piles that can observed during the time in both treatments is a reflection of the gradual reduction in the fermentation processes, meaning that growing substrate and water availability were decreasing, as verified in other studies [15].

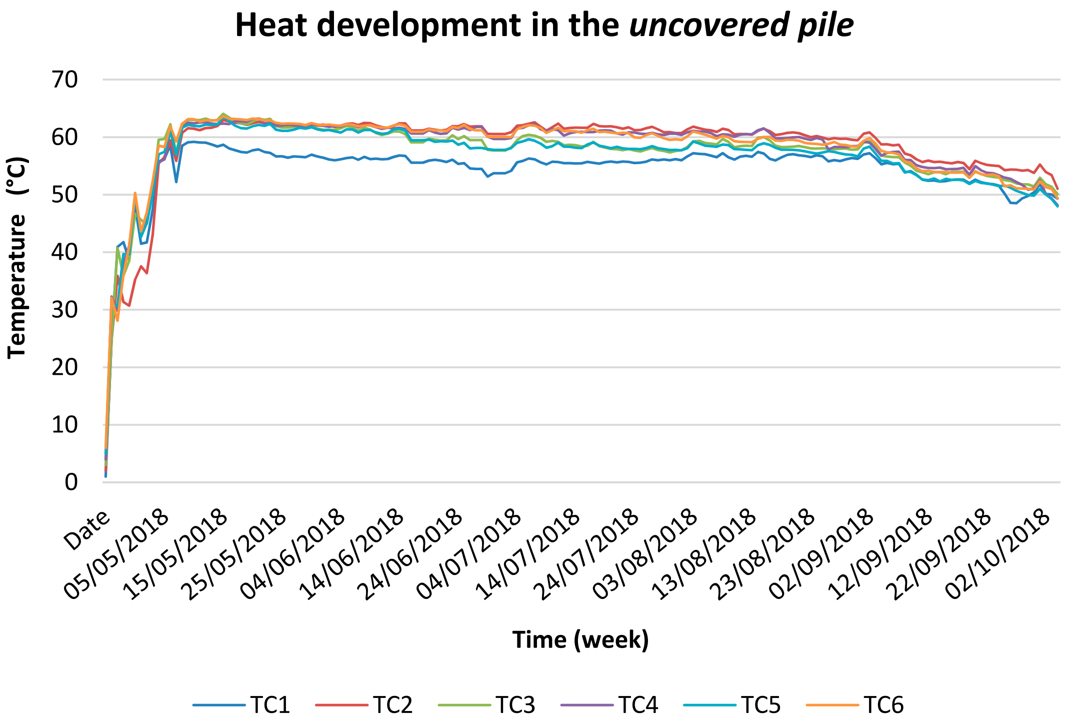

Figure 6. Heat development in uncovered pile. The numbered letters (TC1, TC2, etc.) indicate the thermocouple location according to the scheme shown in Figure 2.

3.4. Dry Matter Loss

Table 2 shows the dry matter losses that occurred during the six-month (April–October 2018) storage in the two piles. Higher losses were observed in uncovered pile. The two paired sample T-tests (equal sample sizes, same variance) performed on the data confirmed the presence of significant differences among treatments ($p < 0.05$). Even in this case, the efficacy of the Toptex was confirmed, as covered wood chips experienced only 2.7% of losses in six months. On the other hand, even if limited, the climatic factors affected the storage performance of uncovered chips. Probably, the precipitations that occurred during storage facilitated the permanence of moisture in the uncovered pile, creating and maintaining the ideal conditions for microorganism to grow and degrade organic matter.

Table 2. Value of dry matter loss (*DML*) of different type of storage of P16 Eucalyptus woodchips, expressed as percentage (%). *DML* value with different letters indicate mean values significantly different ($p < 0.05$) according to the T-test.

Storage	*DML* (%)
Covered	2.7 ± 1.7 [a]
Uncovered	8.5 ± 4.7 [b]

3.5. Fuel Characteristics

In Table 3, some parameters are predicted, such as A, C, H, N, Cl, S, *HHV* and *LHV* of the fresh woody biomass for the two treatments at the end of the trial. The results obtained after the test are characterized by an increase in the heating values in both treatments. This phenomenon was also verified in other studies and could be explained by the degradation of the most susceptible wood fractions to microbial degradation, i.e., cellulose and hemicellulose [32]. From an energetic point of view, these fractions are less powerful, because their heating value is much lower with respect to that of lignin; therefore, a reduction in these compounds in woody material (with the lignin remaining not degraded) determines an increase in the energetic performance of lignocellulosic biomass. Chemical elements (C, H, N, Cl, S) did not show remarkable differences from the fresh material, while ash content slightly increased in both treatments with respect to the start conditions. Regarding this, Lenz et al. [33] found the evidence of a direct relation between the increase in ash content and the total DML. The observation and the trends are also confirmed in this study. On the other hand, another factor that may have affected the increase in ash content is the increasing percentage of fine fractions (<3 mm) at the end of storage. In fact, the same behavior was verified in previous studies by Pari et al. [14].

Table 3. Ash content, elementary compounds and fuel quality parameters of P16 woodchips.

Parameter	Unit	Fresh Biomass	After Storage Uncovered Chips	After Storage Covered Chips
Ash	%	3.0	3.4	3.2
Carbon	%	47.8	47.4	48.0
Hydrogen	%	5.8	5.5	5.6
Nitrogen	%	0.32	0.50	0.30
Chloride	%	0.10	0.13	0.11
Sulfur	%	0.03	0.02	0.01
Heating Value				
Higher heating value	kJ/kg	19.035	19.440	19.439
Lower heating value	kJ/kg	17.773	18.228	18.225

Regarding the energy variations due to storage, in covered biomass the increase in the heating value has almost compensated the dry matter losses that occurred, indicating a final energy balance equal to −0.2%. On the contrary, in uncovered biomass, the heating value increase was not enough to balance the dry matter losses and the final energy content was −6.17% (Figure 7). According to other studies, the increase in the heating value is attributable to the degradation of cellulose and hemicellulose, i.e., the less energetic and more degradable fractions of lingo-cellulosic biomass. Their reduction can favor a relative accumulation of lignin that is reflected in the increase in the heating value after storage [33].

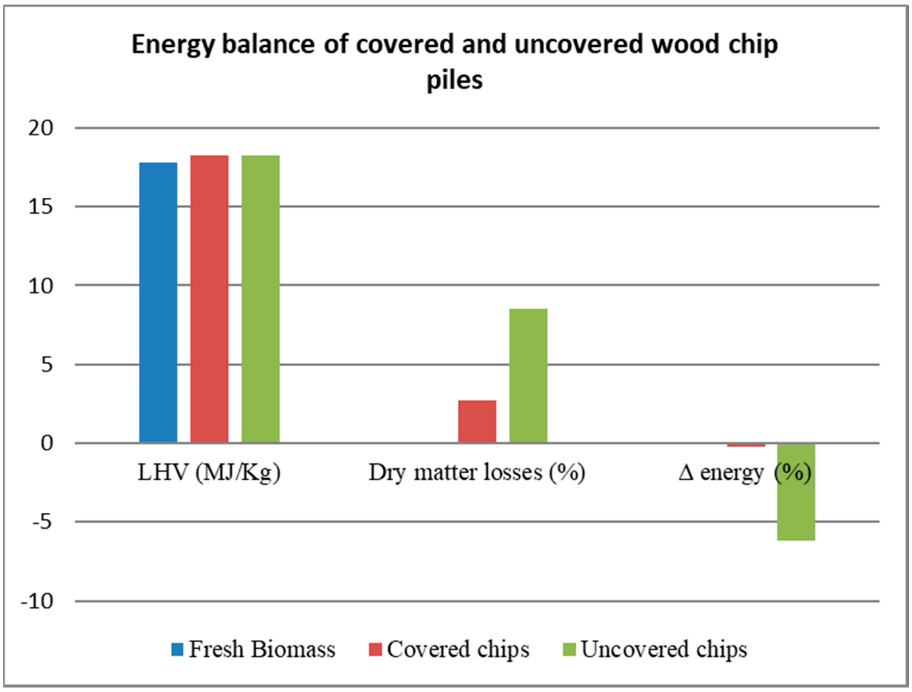

Figure 7. Variations in energy content according to storage systems.

4. Conclusions

The study highlights how it is possible to store P16 woodchips from an MRC Eucalyptus plantation located in central Italy. The results open new rooms of investigation and market opportunities on this class size of Eucalyptus biomass since, to date, according to author experience, no studies have been carried out on this topic. Two types of storage system (covered vs. uncovered) were adopted, and several parameters were monitored for six months in order to ensure a complete study of the dynamics involved. The covered system highlighted the best results regarding dry matter losses and moisture content and energy balance. Although the advantages of using a covering systems are not new, the main interesting finding of this study is the demonstrated storability of small chips, which, despite a limited air circulation achieved, only a 2.7% loss of dry matter and 0.2% loss of energy content using the Toptex covering system. Considering the potential destination of this product (microchip production upon sieving and forced drying), this finding opens the opportunity to improve the logistics in forestry operations, suggesting that handling methods should be based on direct chipping of woody biomass immediately after being cut, also for the microchip chain.

Due to a lack of information in the literature, future research should focus on the economic evaluation of the feasibility of the micro-wood chip supply chain, analyzing how storage could affect the final production costs. In addition, it will be critical to compare the economic sustainability of micro energy supply chains based on both long and short wood chips in order to define the best logistics for this type of solid biofuel.

Author Contributions: Conceptualization, A.S. (Antonio Scarfone) and S.B.; methodology, A.S. (Antonio Scarfone), S.B., P.C., A.S. (Alessandro Suardi), N.R., V.A., G.T. and L.P.; software, P.M.; validation, A.S. (Antonio Scarfone), S.B., P.C., A.S. (Alessandro Suardi), N.R., V.A., G.T. and L.P.; formal analysis, A.S. (Antonio Scarfone), S.B., P.C., A.S. (Alessandro Suardi), N.R., V.A., G.T. and L.P.; investigation, A.S. (Antonio Scarfone), S.B., P.C., A.S. (Alessandro Suardi), N.R., V.A., G.T. and L.P.; resources, L.P. and G.T.; data curation, A.S. (Antonio Scarfone), S.B., and P.C.; writing—original draft preparation, A.S. (Antonio Scarfone), S.B., P.C., A.S. (Alessandro Suardi), N.R., V.A. and G.T.; writing—review and editing, A.S. (Antonio Scarfone), S.B., P.C., A.S. (Alessandro Suardi), N.R., V.A., G.T. and L.P.; visualization, L.P.; supervision, L.P.; project administration, L.P.; funding acquisition, L.P. All authors have read and agreed to the published version of the manuscript.

Funding: The works were performed in the framework of the European project "BeCool" (grant agreement No. 744821). The BeCool project is financed by the EU H2020 programme.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Spinelli, R.; Picchi, G. Harvesting Systems for Poplar Medium Rotation Forestry. In Proceedings of the 19th European Biomass Conference and Exhibition, Berlin, Germany, 6–10 June 2011; pp. 195–197. [CrossRef]
2. He, X.; Lau, A.K.; Sokhansanj, S.; Lim, C.J.; Bi, X.T.; Melin, S. Dry matter losses in combination with gaseous emissions during the storage of forest residues. *Fuel* **2012**, *95*, 662–664. [CrossRef]
3. Goyal, H.B.; Seal, D.; Saxena, R.C. Bio-fuels from thermochemical conversion of renewable resources: A review. *Renew. Sust. Energ. Rev.* **2008**, *12*, 504–517. [CrossRef]
4. Iglesias-Trabado, G.; Wilstermann, D. Des Eucalyptus universalis, Global Cultivated Eucalypts Forest Map 2008. Version 1.0.1, GIT Forestry Consulting's Eucalyptologics: Information Resources on Eucalyptus Cultivation Worldwide. 2012. Available online: http://git-forestry-blog.blogspot.com/2008/09/eucalyptus-global-map-2008-cultivated.html (accessed on 1 November 2019).
5. Mughini, G. Suggerimenti per una eucalitticoltura clonale sostenibile nelle aree a clima mediterraneo dell'Italia centro-meridionale. *Forest@-J. Silvic. For. Ecol.* **2016**, *13*, 47. [CrossRef]
6. Gasparini, P.; Tabacchi, G. *L'Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio INFC2005*; Secondo Inventario Forestale Nazionale Italiano. Metodi e risultati; Edagricole-New Business Media: Milano, Italy, 2012; p. 653.
7. Pignatti, G.; Verani, S.; Sperandio, G. Produzione di legna da ardere da cedui di eucalipto a turno breve: Produttività di lavoro e costi. *Ital. For. Mont.* **2019**, *74*, 218–226. [CrossRef]

8. Lieskovský, M.; Gejdoš, M.; Messingerová, V.; Němec, M.; Danihelová, Z.; Moravčíková, V. Biological Risks from Long-Term Storage of Wood Chips. *Pol. J. Environ. Stud.* **2017**, *26*, 2633–2641. [CrossRef]
9. Haughton, A.J.; Bohan, D.A.; Clark, S.J.; Mallott, M.D.; Mallott, V.; Sage, R.; Karp, A. Dedicated biomass crops can enhance biodiversity in the arable landscape. *GCB Bioenergy* **2016**, *8*, 1071–1081. [CrossRef] [PubMed]
10. Pecenka, R.; Hoffmann, T. Harvest technology for short rotation coppices and costs of harvest, transport and storage. *Agron. Res.* **2015**, *13*, 361–371.
11. Kühmaier, M.; Erber, G.; Kanzian, C.; Holzleitner, F.; Stampfer, K. Comparison of costs of different terminal layouts for fuel wood storage. *Renew. Energy* **2016**, *87*, 544–551. [CrossRef]
12. Civitarese, V.; Spinelli, R.; Barontini, M.; Gallucci, F.; Santangelo, E.; Acampora, A.; Scarfone, A.; Del Giudice, A.; Pari, L. Open-Air Drying of Cut and Windrowed Short-Rotation Poplar Stems. *BioEnergy Res.* **2015**, *8*, 1614–1620. [CrossRef]
13. Manfredi, S. Bilancio di Ciclo di Vita Energetico ed Ambientale di una Filiera Aziendale di Cippato da Short Rotation Forestry: Applicazione. Master's Thesis, Università degli Studi di Parma, Parma, Italy, 2011.
14. Pari, L.; Scarfone, A.; Santangelo, E.; Gallucci, F.; Spinelli, R.; Jirjis, R.; Del Giudice, A.; Barontini, M. Long term storage of poplar chips in Mediterranean environment. *Biomass Bioenergy* **2017**, *107*, 1–7. [CrossRef]
15. Barontini, M.; Scarfone, A.; Spinelli, R.; Gallucci, F.; Santangelo, E.; Acampora, A.; Jirjis, R.; Civitarese, V.; Pari, L. Storage dynamics and fuel quality of poplar chips. *Biomass Bioenergy* **2014**, *62*, 17–25. [CrossRef]
16. Jirijs, R. Effects of particle size and pile height on storage and fuel quality of comminuted Salix viminalis. *Biomass Bioenergy* **2005**, *28*, 193–201. [CrossRef]
17. Kristensen, E.F.; Kofman, P.D. Pressure resistance to air flow during ventilation of different types of wood fuel chip. *Biomass Bioenergy* **2000**, *18*, 175–180. [CrossRef]
18. Spinelli, R.; Pari, L.; Magagnotti, N. New biomass products, small-scale plants and vertical integration as opportunities for rural development. *Biomass Bioenergy* **2018**, *115*, 244–252. [CrossRef]
19. UNI EN ISO 17225-1. Solid Biofuels-Fuel Specifications and Classes-Part 1: General Requirements. 2014. Available online: http://store.uni.com/catalogo/uni-en-iso-17225-1-2014 (accessed on 10 January 2020).
20. Pari, L.; Scarfone, A.; Alfano, V.; Bergonzoli, S.; Suardi, A.; Lazar, S. Produttività dell'eucalipto-Un impianto quinquennale in Italia Centrale. *Sherwood* **2019**, *241*, 70–72.
21. Spinelli, R.; Hartsough, B.R.; Magagnotti, N. Testing mobile chippers for chip size distribution. *Int. J. For. Eng.* **2005**, *16*, 29–35. [CrossRef]
22. Eliasson, L.; von Hofsten Skogforsk, H. Effects of microchip production on chipper efficiency. Track #2–Non Peer-Reviewed Proceedings Paper. In Proceedings of the 41st Annual Council on Forest Engineering Meeting "Revolutionary Traditions, Innovative Industries", Williamsburg, VA, USA, 15–18 July 2018. Available online: https://cofe.org/files/2018_Proceedings/Eliasson%20and%20von%20Hofsten.pdf (accessed on 10 January 2020).
23. UNI EN ISO 18134-1. Solid biofuels—Determination of Moisture Content—Oven Dry Method Total moisture—Reference Method. 2015. Available online: http://store.uni.com/catalogo/uni-en-iso-18134-1-2015?___store=en&___from_store=it (accessed on 10 January 2020).
24. UNI EN 15149-1. Solid Biofuels. Determination of Particle Size Distribution. Part 1: Oscillating Screen Method Using Sieve Apertures of 1 mm and above. 2010. Available online: http://store.uni.com/catalogo/en-15149-1-2010 (accessed on 10 January 2020).
25. UNI EN ISO 18122. Solid Biofuels. Determination of Ash Content. 2015. Available online: http://store.uni.com/catalogo/uni-en-iso-18122-2016 (accessed on 10 January 2020).
26. UNI EN 15104. Solid Biofuels. Determination of Total Content of Carbon, Hydrogen and Nitrose e Instrumental Method. 2011. Available online: http://store.uni.com/catalogo/uni-en-15104-2011 (accessed on 10 January 2020).
27. UNI EN ISO 16994:2016. Solid biofuels—Determination of total content of sulfur and chlorine. Available online: http://store.uni.com/catalogo/iso-16994-2016 (accessed on 10 January 2020).
28. UNI EN 14918. Solid Biofuels. Determination of Calorific Value. 2010. Available online: http://store.uni.com/catalogo/uni-en-14918-2010# (accessed on 10 January 2020).
29. Hammer, Ø.; Harper, D.A.; Ryan, P.D. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol. Electron.* **2001**, *4*, 9. Available online: http://palaeo-electronica.org/2001_1/past/issue1_01.htm (accessed on 10 January 2020).

30. SIARL: Servizio Integrato Agrometereologico (Regione Lazio). Available online: http://www.arsial.it/portalearsial/agrometeo/index.asp (accessed on 1 February 2019).
31. Wästerlund, I.; Nilsson, P.; Gref, R. Influence of storage on properties of wood chip material. *J. For. Sci.* **2017**, *63*, 182–191. [CrossRef]
32. Pari, L.; Scarfone, A.; Santangelo, E.; Figorilli, S.; Crognale, S.; Petruccioli, M.; Suardi, A.; Gallucci, F.; Barontini, M. Alternative storage systems of Arundo donax L. and characterization of the stored biomass. *Ind. Crop. Prod.* **2015**, *75*, 59–65. [CrossRef]
33. Lenz, H.; Pecenka, R.; Hartung, E.; Idler, C. Development and test of a simplified method to calculate dry matter loss during open-air storage of poplar wood chips by analysing ash contents. *Biomass Bioenergy* **2016**, *94*, 258–267. [CrossRef]