Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2008, 4 (3), 307 - 312

Appraisals on Poplar Harvesting Methods Through Energy Conservation Efficiency

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Abstract: As renewable energy demand increases, SRF poplar cultivation is getting more and more important in energy production as a valuable plantation for farmers in Italy. While the consumption of wood fuel is spread during all the year, SRF harvesting takes place normally between December and March: storage between April and November is therefore necessary, pointedly concerning the energetic quality of the material. Today three different harvesting methods are available, turning out respectively whole plants, chunks and chips. Some elements, such as weather conditions and microbiological activities, whose effects are not easily manageable, always produce a dry matter reduction, hence energy loss. Aim of this work is to point out the influence of harvesting method on energy content preservation, through the control of the product dimensions. To evaluate the energy preservation of the products obtained with three different harvesting equipments, piles were built using respectively whole plants, chunks and chips. A measurement of the energy content of the SRF poplar cultivation was made during the harvesting, on late February 2007. Weather conditions during the storage period, temperature, precipitation, humidity and sun radiation were registered. Temperature inside the piles was also monitored at different heights. At the and of October 2007 the piles were opened to get back the weighted samples, to analyze their energy content after eight month storage. At the same time, moisture content, ash content, elementary analyses and heating value were measured. Whole trees and chunks have the lowest energy losses if compared with chips. On the other side, transport and following treatments, more difficult for the whole plants, will have an impact on the economy and energy balance of the productive chain. Both chips and chunks can constitute, in appropriate plants, the final form of fuel, while whole plants must always be processed.
Key words: SRF, harvesting machinery, energy preservation, wood storage.

INTRODUCTION

For economic, strategic as well as environmental reasons, developing alternative energy sources has become a priority for countries that depend mainly on fossil fuels. This is why energy crops have become more widespread in Italy, subsidized by contributions contemplated by national and EC agriculture policies.

Among the energy crops used to produce power and heat, an important role is being played by Short Rotation Forestry (SRF), the cultivation, according to farming models, of rapid growth tree species with high plantation densities (1600-2000 trees per hectare). The trees are felled repeatedly every two to six years for a total cultivation cycle of 10-15 years.

Today these crops represent an interesting opportunity for farmers as well as the energy conversion industry. Currently there are two different harvesting methods: a) immediate mincing after harvest on the field by machines that cut, chop and load the trees; b) harvesting the whole trees and stacking them on the field to let the air naturally dried the trees. Large power plants (>8 MW electricity) and small ones (3 MW) fed by biomass need fuel throughout the year while heating plants need fuel only during the cold season.

The production of chips is scheduled mainly during the months of vegetative rest and this requires storage of the harvested material for periods that vary in duration. It is important to note that the purpose of storage is to obtain fuel with the highest quality possible, low moisture (there is no minimum level), high heating power, low ash content (ash of its own or polluted by inerts). To determine the most advantageous method for obtaining a qualitatively suitable product for power plants we conducted a test to compare pile of whole trees with pile of chips and pile of billets. The latter is an intermediate product between the entire trees and the chips.

The results of this study are shown below.

MATERIAL and METHOD

The CRA – ING ran experiments at Alasia Franco Vivai of Savigliano (CN) on the storage of poplars. Piles of chips, pieces and entire trees were formed and monitored. The main goal was to evaluate the effect of size on final product quality and thereby determine the best conservation method in terms of loss of dried substance (heating power) and the reduction of water content.

The poplars used for the experiment were harvested in the Pavese area and transported by truck to Savigliano. The poplars for the production of chips were harvested with a Jaguar designed by the Claas, while the chunks were produced with machinery developed by Spapperi. The whole trees were felled manually and immediately stacked. The material was collected a few hours before forming the piles, therefore its moisture was relatively high.

When forming the piles we measureed their size, starting material in terms of moisture, size class and volume/mass (table 1).

Table 1. Particle size distribution of the chips used for building the experimental piles

	Billets	*Chip*	***Whole tree***
Dimensions m	6x4x2,5	12x8x4	3x3x2
Moisture %	57,2	63,1	59,2
mass t	73,52	72,56	n.d.

The initial volume of the chip pile was 364 kg/m^3 while the billets pile was 258 kg/m^3.

During the entire storage period (March - November 2007) the internal temperature and moisture of the pile were monitored. We also measured the loss of dried substance and moisture by using bags of a breathing material containing chips or billets placed in different positions in the pile.

Each pile was divided into different levels (three for the uncovered pile; two for the billets) and sensors and bags were placed on each level. We inserted PT 100 electrical resistance sensors inside the piles to measure temperature. The relative moisture was measured by means of a transducer inside the piles. A dedicated weather control unit measured the local microclimate trend during the entire test period.

At the end of the storage (end of October 2007) the piles were sectioned at two points to show the desiccation profiles. Samples were taken and analyzed in the laboratory to evaluate the loss of dried substance. When the data were processed, the samples belonging to the same category, understood as homogeneous humidity conditions, were averaged out. The volume of each pile was estimated and assigned to different categories. Then all the weighted results were averaged out to obtain a median value representing each heap. In other words we decided to evaluate the specific quality of each pile and avoid general judgments. Since we found a high level of contamination from inerts (see the column on ashes) in some cases the data pertaining to the trend of the lower heating power were evaluated on the basis of the ash-free value in order to determine the amount of energy provided by the combustible portion.

RESEARCH RESULTS

Chip pile

Figure 1 illustrates the dynamics of temperatures in the chip pile.

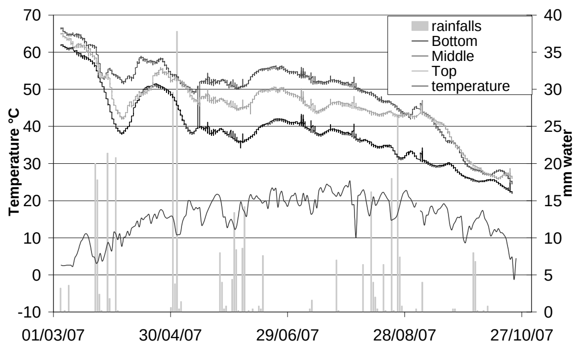

Figure 1. Temperature chip pile

During the first few days of storage we observed a rapid increase in temperatures, which rose to 60-65°C. Then the temperatures started to fall. It should be pointed out that after precipitation temperatures tend to drop suddenly and then rise and recover the downward trend which was occurring before the precipitation. Bear in mind that after about three months a crust forms on the external surface of the pile that presumably allows part of the rainwater to run off without penetrating into the heap.

Said crust could also prevent the evaporation of moist air from the pile. The lowest level (Level 1) is always the coldest (ground effect), while the medium level (Level 2) is the warmest. At the end of the storage period (October) all of levels were 25-28°C.

To evaluate the internal conditions of the material in the heaps at the end of the test, two transversal sections were made, one 5 m long and one 8 m long longitudinally. Figure 2 shows the pile section that is 5 m long and the position of the analyzed samples. The section that was 8 m long had the same characteristic as the first section.

Figure 2. Chip pile section

The following conditions were found:

- A thin layer of dried material on the outside (approx. 3 cm)
- 20-25 cm of wet material
- 3-5 cm in contact with the ground of wet material
- an internal part dried evenly.

The pile has an average weighted humidity of 50% and an LCV of 7000 kJ/kg of raw wood. The initial humidity of the material was 63%.

The storage brought a loss of 27 percentage points of moisture for 59% of the material and a water acquisition of eight percentage points for 41% of the material with a final volume of 195 m3.

The desiccation is interesting because the final moisture of the dried part is 35%, but the moist part has 70% moisture (table 2). The wet layer therefore acquires water from an outside source that we believe is partly from precipitation and partly water from the underlying material that is drying. As regards the part lying on the ground, the increase in moisture can be considered a constant that is inevitable.

The loss of dried substance starts to manifest after 120 days and reaches values of about 10% at the end of storage.

Table 2. Overall quality of uncovered pile

Before storage			
Moisture content %			**62,9**
Lower heat content kJ/kg wt			**4.179**
Lower heat content kJ/kg dm			**15.401**
After storage	**Wet**	**Dry**	**Average**
Volume %	41	59	
Misture content %	70,9	35,5	50,0
Lower heat content kJ/kg wt	3.266	9.669	7.043
Lower heat content kJ/kg dm	14.929	16.9	16.130
Ash content %	8,8	1,6	4,6
MC variation %	8	-27	-13

The pile being tested therefore has an average chip quality that is not exceptional.

Therefore it is reasonable to expect an improvement in the quality of the fuel as pile size increases.

Chunk pile

Figure 3 shows the dynamic of temperatures within the heap.

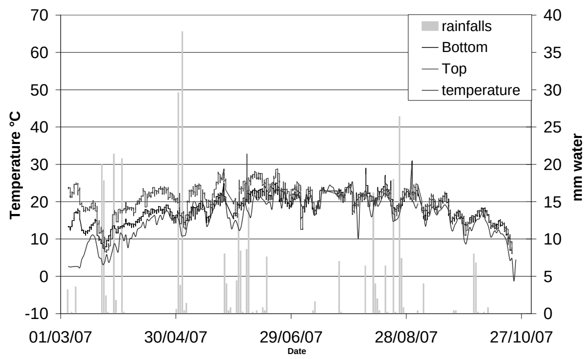

Figure 3. Temperature billet pile.

The temperatures of the low level (Level 1remained lower than those of the high level (Level 2)), at least until halfway through the storage period. However this difference, starting at a temperature of 10°C, decreases gradually and constantly.

The difference with respect to the air temperature at the beginning of the storage is more noticeable for the high level (18°C) than the low level (10°C). After the middle period of storage, this difference becomes the same for both levels and later decreases to a few degrees as the storage time advances and the average temperature of the heap gradually comes closer to the external temperature.

A sudden temperature drop was observed after rainfall, as for the other heaps.

Figure 4 shows the middle section of the pile and the position of the samples.

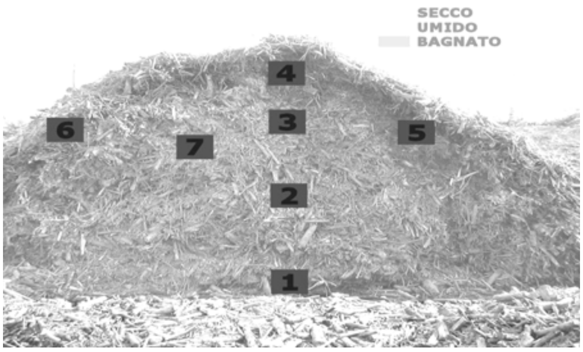

Figure 4. Billet pile section

We can see:

- 10 cm of dried material on the outside (sample 6)
- 40 cm of material between moist and wet under the first layer (samples 4 and 5)
- 20 cm of wet material in contact with the ground (sample 1)
- the inner part evenly dried (samples 2, 3 and 7).

The surface layer of the wet material (samples 4 and 5, 40 cm thick) has an average moisture of 73% and an LCV of raw wood that is a little less than 2800 kJ/kg, (but 19000 kJ/kg dried substance) while the material lying on the ground (sample 1) has a humidity of 71% that corresponds to an ash-free content of 18.150 kJ/kg dried substance.

The dried part (samples 2, 3, 6 and 7; of which sample 6 is the outside layer) has a moisture of 19.5% and an LCV in the raw wood 14,400 kJ/kg a.r., equivalent to 19,600 kJ/kg ash-free dried substance .

As pointed out earlier, given the high content of inerts, it is more reasonable to compare the humidity classes of the material as a function of the LCV of the ash-free dried substance:

- wet surface material (samples 4 and 5): average moisture 73%; LCV 2,850 kJ/kg ash-free dried substance ;
- material on the ground (sample 1); average moisture 71%; LCV 7.170 kJ/kg ash-free dried substance ;
- dried material (samples 2, 3, 6 and 7): average moisture 19.5%; LCV 15,400 kJ/kg ash-free dried substance .

In the overall evaluation the bottom of the pile is kept separate from the moist part though the moisture in play differs by only a few percentage points.

The volume of the wet material (samples 4 and 5) is 28% of the total; the volume of the wet material lying on the ground (sample 1) is 10%; the remaining 62% is dried material (samples 2, 3, 6 and 7).

Considering these data, it turns out that the pile has an average moisture of 40% and the LCV of the raw wood is 10,400 kJ/kg a.r.

The initial moisture of the material was 57%. For a final volume of 38.5 m3, storage brings a loss of 38 percentage points for 62% of the material and a water acquisition of 14-15 percentage points for 38% of the material.

The desiccation is quite interesting because the final moisture of the dried part is 19.6%, a result that can be reached only with whole trees.

The LCV of the raw wood is among the most interesting but the test should be repeated with material that has a minimum of inerts.

Moreover the test should focus on the constancy of the moist layer as a function of the volume of the heap. In other words if said layer remains constant, the increase in the size of the heap could improve the overall quality of the material.

It should be pointed out, however, that the final humidity of the “dried” portion is about 18%. The loss of dried substance is about 10%. The storage system is a compromise between chips and whole trees. It is clear that the material must be processed during the utilization phase.

Whole tree pile

Figure 5 shows the trend of temperatures inside the heap which follow the temperatures of the outside air.

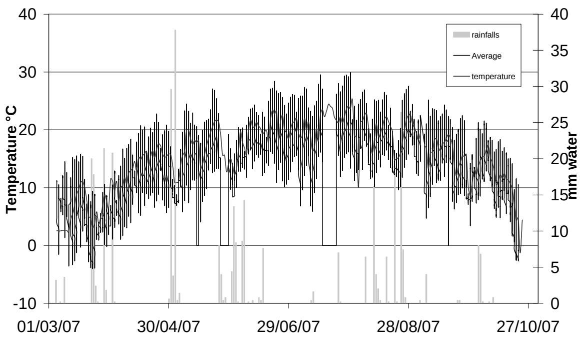

Figure 5. Temperature whole tree pile

The final moisture of the material is about 18%, which confirms the hypotheses that storage of the entire tree, in spite of the problems moving them, is the method that provides the best quality of fuel.

The loss of dried substance is on average 8.5% (table 4).

Table 4 . Whole tree pile characteristics.

Before storage	
Moisture content %	59,2
Lower heat value kJ/kg dm	15.401
Lower heat value ash free kJ/kg	15.775
Lower heat value kJ/kg wt	15.151
After storage	
Moisture content %	17,8
Lower heat value kJ/kg dm	18.452
Lower heat value ash free kJ/kg	19.863
Ash content % wt	6,0
Ash content % dm	7,1
Moisture variation %	**- 41**
Lower heat value variation KJ/kg ash free	**4.088**

These values make the biomass optimal for producing power.

COMPARISON OF RESULTS

Table 5 compares the results of the chip heap, chunk pile and whole tree heap.

Moisture loss was different for each pile, minimum for chips and maximum for whole trees.

The final moisture reached by the whole trees was 17.8%, making this material optimal for energy purposes.

Table 5. Comparison between values of tree different piles

	Chip	*Billet*	***Whole tree***
Moisture before storage %	57,2	62,9	59,2
Moisture after storage %	39,6	50,0	17,8
MC variation %	**-17,6**	**-12,9**	**-41,4**
Lower heat value ash free kJ/kg before storage	15.775	15.775	15.775
Lower heat value ash free kJ/kg after storage	19.315	18.317	19.863
Lower heat value variation KJ/kg ash free	**3.540**	**2.542**	**4.088**
Dry matter loss after storage %	**10**	**10**	**8,5**

The chunks lost 17.6 percentage points and the chips lost 12.9 percentage points of moisture, reaching 40% and 50% respectively. These values are still rather high for utilization in a power plant. However this represent the weighted volume of the outside part (which acquired moisture content) and the internal part. The latter has an average moisture of 19.6% for the chunks (Table 6) and 35.5% for the uncovered pile. Consequently, we can reasonably surmise that, as described above, when the size of the pile is increased there is an improvement in the overall quality of the pile. If we compare the loss of moisture of only the inner parts of the pile, we can see that the chips lost 34.8 percentage points of moisture during the same time that the chunks lost 37.6 percentage points.

This confirms the assumption that the size of the material affects the desiccation process: Whole trees: - 41.4 % of moisture; Chunks: - 17.6 % of moisture; Chips: -12.9 % of moisture. As regards the final weighted LCV of the raw wood pile (directly related to the water content of the mass, among other factors) we can see that chunks have better quality than chips. If we only look at the inner part of the piles, the chip pile reaches values of about 10,000 kJ/kg of raw wood, while the chunks reach almost 14,400 kJ/kg of raw wood. The whole trees, with over 15,150 kJ/kg of raw wood, are the best storage method for energy purposes.

Another interesting consideration derives from comparing the LCV of the ash-free dried substance.

The LCV of the whole trees and the chunks does not differ significantly whereas the chips have a slightly lower LCV. Likewise the mildew count (units forming a colony) decreases with the increase of the LCV of the ash-free dried substance .

Since these microorganisms attack the cellulose first (LCV: 17 MJ/kg dried substance) and only after that do they attack at the lignin (LCV: 28 MJ/kg dried substance), it would seem that the environmental conditions most suitable for microbiological activity persist longer in chips and chunks than in the whole trees.

In other words, the combination of temperatures, the speed of moisture loss and the relative exposed surface for whole trees cause mainly the deterioration of cellulose but not lignin; this phenomena also occurs in the chunks.

At this point we do not yet have the elements needed to formulate a definitive thesis: additional research is needed to give us a more complete vision of the phenomenon.

CONCLUSIONS

The experiment conducted allowed us to identify some of the aspects to take into consideration for the operators of this field and future research projects.

The size of the material plays quite an important role in chip drying speed and preservation from microbiological attacks .

As the size of the stored material was increased, the qualitative characteristics obtained at the end of storage improved in terms of moisture, LCV and loss of dried substance.

To prevent water from rising from the ground under the heap, and ensure a low content of ash in the chips, it is advisable to provide paved areas, or at least stabilized areas, for handling and storage purposes.

From the qualitative point of view, the whole trees provided the best results. This process could be applied to in-field storage. On the contrary this system involves felling, accumulation on site (removal from the forest) loading, transporting, unloading. An alternative method might be chipping on site and transporting the chips.

Qualitatively chunks are a good solution. However it must be verified whether or not increasing the size of the heap makes it possible to reduce the portion of moist outer material with respect to the total.

From the technical point of view it is an intermediate solution between the whole trees and direct chipping on the field. In the latter case the material must undergo a certain number of transfers and pass through the chipping machine before being converted into energy. The chunks are a good compromise, though most likely they would entail high management costs.

The uncovered pile of chips is the simplest solution. The overall quality of the material is affected by heap size because a moist outer layer is formed. Only additional tests will be able to confirm this hypotheses. The chips inside the pile are good quality, with a humidity of about 30-35%. Rain certainly affects conservation of the material.

This solution would probably be feasible only in the case of large piles.