CONSEQUENCE OF SRF POPLAR WOOD HARVESTING METHOD ON ENERGY CONTENT PRESERVATION

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ABSTRACT: As renewable energy demand increases, SRF poplar cultivation is getting more and more important in energy production. 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, that depends by harvesting method and the product dimensions. Today three different harvesting methods are available, turning out respectively whole plants, chunks and chips. Weather conditions and microbiological activities produce a dry matter reduction, hence energy loss. A measurement of the energy content of the SRF poplar cultivation was made during the harvesting. During the storage period were registered temperature, rainfall, humidity and solar radiation. Temperature inside the piles was also monitored at different heights. After the piles opening were measured moisture content, ash content, and heating. Whole trees and chunks have lower 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: SRC, energy preservation, wood storage.

1 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), i.e. 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, i.e. low moisture (there is no minimum level), high heating power, low ash content (ash of its own or polluted by inerts).

In other words, at harvest we have a certain amount of biomass that is not usable right away except in power plants that use fluid bed technology. Consequently the economic value of this type of biomass is only potential. The plants that can use it pay a price that hardly compensates for production costs. Other plants or heat-only plants pay almost nil .

After suitable storage we obtain a product with high energy and high economic value.

To determine the most advantageous method for obtaining a qualitatively suitable product for power plants we conducted a test to compare heaps of whole trees with heaps of chips and heaps of chunks. The latter is an intermediate product between the entire trees and the chips.

The results of this study are shown below.

2 MATERIALS AND METHODS

The CRA – ING ran experiments at Alasia Franco Vivai (Savigliano ,CUNEO, Italy)) on the storage of poplars. Heaps 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 humidity was relatively high.

When forming the heaps we measured their size, starting material in terms of humidity, size class and volume/mass. These values are shown on Table I , II III and figure 1.

The density of the chip and the billets were 364 kg/m3 and 258 kg/m3 respectively.
During the entire storage period (March - November 2007) the internal temperature and humidity of the heaps were monitored. We also measured the loss of dried substance and humidity by using bags of a breathing material containing chips or chunks placed in different positions in the heap.

Table I : Piles charateristics

	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.

Table II: Average particles size distribution of the billets used for the building of the pile

Diameter (mm)	*% dry wt*
0-10	15,7
11-20	20,9
21-30	18,1
31-40	18,0
41-50	15,3
51-60	3,7
61-70	2,0
71-80	6,3

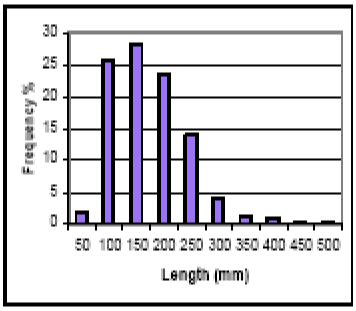

Figure 1 : Particles length distribution (% dry weight) of poplar billets before storage.

Table III : Particles size distribution (% dry weight) of the chips used for the building of the pile

Particle size mm	*Chip*
0-10	36,90
11-25	55,48
26 – 50	7,28
> 50	0,34

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

The data acquisition system consisted of a central unit and waterproof boxes, one for the chips and one shared by the chunks and whole trees. An additional card was inserted in the central unit and connected to the weather control unit to measure rainfall, wind speed, solar irradiation, outside air temperature and humidity .

An internal clock in each box was used to set the acquisition times for each channel (in this case the time set was 40 seconds). A software program inside the central unit was used to adjust all the control parameters of the various sensors, save the data and send it via Internet with a UMTS modem. The entire system was controlled remotely by a VNC software program. A generator provided approximately 2 hours of autonomy for the system itself.

At the end of the storage (end of October 2007) the heaps 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 heap 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 heap 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. However the key data for evaluating the quality of the heap for the purposes of energy utilization are humidity and the LCV of the raw wood

3 RESULTS

3.1 Chip pile

The uncovered chip pile was studied as reference.

Figure 2 illustrates the dynamics of temperatures in this 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. The fluctuations caused by precipitation were less severe over time.

Bear in mind that after about three months a crust forms on the external surface of the heap that presumably allows part of the rainwater to run off without penetrating into the heap.

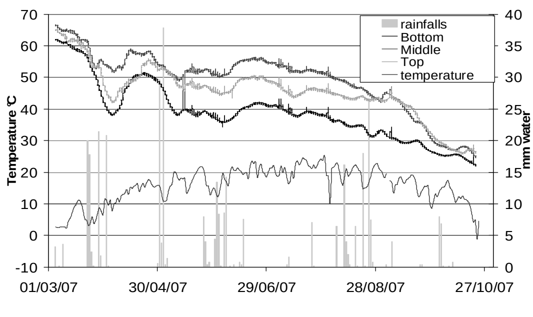

Figure 2 : Temperature trend in chip pile.

Said crust could also prevent the evaporation of moist air from the heap. The lowest level (Level 1) is always the coldest (ground effect), while the medium level (Level 2) is the warmest.

From early September the medium level and high level had the same values and at the end of the storage period (October 2007) 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 3 shows the heap section that is 5 m long and the position of the analyzed sample.

Figure 3 : First section of the chip pile at the end of the storage.

The following conditions were found:

- A thin layer of dried material on the outside (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 section that was 8 m long had the same characteristic as the first section.

The layer of wet material (samples 1, 2, 4, 5) had an average humidity of 71% and consequently, the LCV of the raw wood was significantly low. Moreover samples 1, 2 and 4 had an ash content so high as to indicate a conspicuous presence of inert components because at the time the heap was formed the most external layer was made with material taken from the immediate vicinity on the ground. The middle sample, three, has values congruent with those of the samples taken from the bottom of the heap.

The samples taken from the lowest level (6, 7, 8, 9 and 10) at the end of the storage period had an average humidity of 33% with LCVs of the raw wood that fell within values acceptable to power plants. The ash content was congruent with that of normal ash content in wood.

The heap has an average weighted humidity of 50% and an LCV of 7000 kJ/kg of raw wood. Unfortunately the ash content measurement in the wet part was skewed due to the presence of inerts in the material. The initial humidity of the material was 63%. The storage brought a loss of 27 percentage points of humidity for 59% of the material and a water acquisition of eight percentage points for 41% of the material with a final volume of 195 m^3.

Table IV summarizes the overall quality of the material in the heap.

Table IV : Overall quality of the chip pile

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

The desiccation is interesting because the final humidity of the dried part is 35%, but the moist part has 70% humidity. 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 humidity 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.

The heap being tested therefore has an average chip quality that is not exceptional but it is reasonable to expect an improvement in the quality of the fuel as heap size increase

3.2 Chunk heap

Figure 4 shows the dynamic of temperatures within the heap.

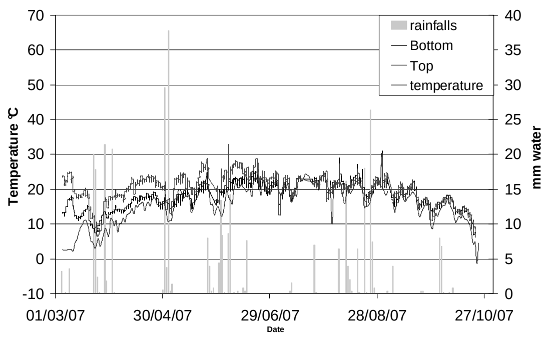

Figure 4 : Temperature trend in chunk pile.

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 5 shows the middle section of the heap and the position of the samples.

Figure 5 : Section of the **c**hunk pile at the end of the storage.

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 humidity of 73% and an LCV of raw wood that is a little less than 2800 kJ/kg, (but 19.000 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 humidity of 19.5% and an LCV 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 humidity 73%; LCV 2.850 kJ/kg ash-free dried substance ;
- material on the ground (sample 1); average humidity 71%; LCV 7.170 kJ/kg ash-free dried substance ;
- dried material (samples 2, 3, 6 and 7): average humidity 19.5%; LCV 15.400 kJ/kg ash-free dried substance.

Table V summarizes the overall quality of the material in the heap.

Table V : Overall quality of billet pile

Before storage			
Moisture content %	57,2		
LHV kJ/kg wt	10.404		
LHV kJ/kg dm	15.401		
After storage	**Wet**	**Dry**	**Average**
Volume %	38	62	
Moisture content %	70,9	35,5	39,6
LHV kJ/kg wt	7.020	14.389	10.404
LHV kJ/kg dm	17.612	18.039	17.850
Ash content %	8,8	1,6	4,9
MC variation %	8	-27	-17.6

In the overall evaluation the bottom of the heap 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 heap has an average humidity of 40% and the LCV of the raw wood is 10.400 kJ/kg a.r..

The initial humidity 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 humidity 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%.

Microbial activity was visible on the material but it was less intensive than that observed on the chipped poplar. A good deal of impurities; e.g. soil and stones, were present in the stored billets which led to an increase in ash content to 7.6 % dry wt basis.

The storage system is a compromise between chips and whole trees. It is clear that the material must be processed during the utilization phase.

3.3 Whole tree heap

Figure 6 shows the trend of temperatures inside the heap which follow the temperatures of the outside air.

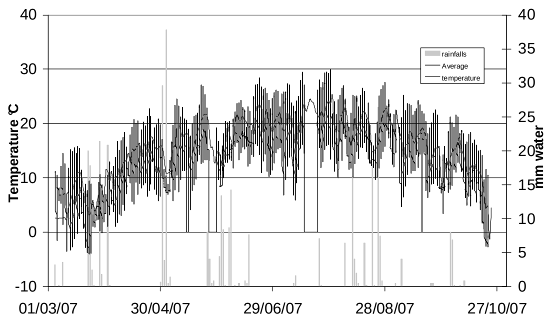

Figure 6 : Temperature trend in whole tree heaps.

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 concerning drying and heating values.

The loss of dried substance is on average 8.5%.

Table VI shows the overall quality of the whole trees pile.

Table V I: Overall quality of whole tree

Before storage	
Moisture content %	59,2
LHV kJ/kg dm	15.401
LHV ash free kJ/kg	15.775
LHV kJ/kg wt	15.151
After storage	
Moisture content %	17,8
Ash content % wt	6
Ash content % dm	7.1
LHV kJ/kg dm	18.452
LHV ash free kJ/kg	19.863
Moisture variation %	-41
LHV variation KJ/kg ash free	4.088

These values make the biomass optimal for producing power.

4 COMPARISON OF RESULTS

Table VII compares the results of the tree piles.

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.

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.

This confirms the assumption that the size of the material affects the desiccation process:

- Whole trees: - 41.4 percentage points of moisture;
- Chunks: - 17.6 percentage points of moisture;
- Chips: -12.9 percentage points 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.

Table VII : Comparison between various storage systems

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

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.

5 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 heap 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 heap 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 heaps.