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Small-scale storage techniques for fuel chips from short rotation forestry

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HIGHLIGHTS

- Five storage techniques were tested on SRF poplar chips stored in small (20 m^3) piles.
- The storage period lasted 170 days, in spring and summer.
- Piles under plastic cover presented opposite trends compared to all other piles.
- Dry matter losses were highest for uncovered piles, and lowest for plastic covered piles.
- These results were closely related to the dry Southern European climate and season.

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ABSTRACT

The experiment determined the technical and financial efficiency of five storage techniques, specifically designed for SRF poplar chips stored at the farm site in small (20 m^3) piles. The treatments on test were: uncovered storage, storage under a temporary roof structure, cover under a semi-permeable fleece sheet, cover under two types of plastic sheet (i.e. white and black). Each treatment was replicated 3 times. Researchers monitored temperature and moisture content trends inside the piles, and determined dry matter losses at the end of the 170 days storage period. In general, piles under plastic cover presented opposite trends compared to all other piles. They acquired moisture rather than losing it, and showed gradual temperature trends instead of a typical peak-and-drop behaviour. Dry matter losses varied from 5.1% to 9.8%, and were highest for the uncovered treatment, and lowest for the plastic cover treatment. Under the conditions of north-western Italy, uncovered storage was a cost-effective option. Protecting the piles with some cover incurred more cost than it saved, resulting in a higher storage cost per unit energy. Although more expensive, sheltering the piles under a simple roof structure offered the benefit of a higher reduction of moisture content, which may turn the chips into a higher quality fuel. Of course, these results were closely related to the Southern European climate, and the specific year of the test. Occasional wetter years may overturn these results.

1. Introduction

Since the first oil crisis in the 1970s, many governments have promoted the use of wood biomass as an effective substitute for conventional energy sources [1]. Substitution has become more urgent in recent years, due to the increased global competition for the finite fossil resource and the need to mitigate climate change [2]. Ambitious new targets have been set for biomass use, boosting the demand for wood fuel [3]. Wood biomass is available in many forms and in all parts of the world, allowing the deployment of bioenergy almost everywhere, once the main sources have been identified and assessed [4].

Substantial amounts of wood biomass can be obtained from dedicated tree plantations, established with fast-growing hardwoods and harvested after 2–10 years, depending on site conditions and product strategy [5]. For decades, short rotation forestry (SRF) has been one of the pillars of the European Union biomass strategy [6], for its capacity to accomplish a balanced mix of technical, ecological and social targets [7]. Over the years, improved cropping and harvesting systems have been developed, which offer a good energy balance [8] and acceptable economic results [9].

However, SRF is generally harvested in winter only, whereas the demand of biomass-fired power stations is steady and sustained all along the year [10]. Diachronic supply and demand create a need for a fuel buffer to secure the energy production at all times [11]. Biomass fuel can be stored in many different ways depending on the type of fuel and the local conditions [12]. Stores can be built

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at the user plant, at wood terminals or near the plantations [13]. In Italy, fuel chips are often stored at the farm site, near the plantations [14]. Therefore, stores tend to be spread over the landscape and represented by relatively small piles, with their specific pros and cons [15]. In particular, when individual stores are relatively small, it is possible to use a variety of storage methods that are normally not available for large quantities, due to technical and economic reasons [16]. While large chip piles are almost always stored outdoors and uncovered, smaller piles can be covered with different materials or placed under a roof, which helps containing quality degradation and dry matter losses [17]. The performance of different storage methods may change with tree species and climatic zone, which justifies a specific study on Southern European SRF tree species, such as poplar (*Populus* sp.) and black locust (*Robinia pseudoacacia* L.). Aside from climate, species selection represents a main difference between Southern and Northern European SRF plantations, where willow is dominant. Furthermore, very few studies deal with fuel chip storage at the farm site, in relatively small piles. In this respect, our study analyses the options for a diffused storage system, which can relieve much of the logistical strain incurred by traditional centralised models. Therefore, the goal of this study was to provide a technical and economical assessment of different techniques used for the diffused storage of chips obtained from SRF poplar, which is the most common species used for the establishment of SRF plantations in Central and Southern Europe [18].

2. Materials and methods

The research was conducted in northwestern Italy between March and September 2010. The test compared five different storage techniques, and namely: uncovered (control), cover by black plastic sheet, cover by white plastic sheet, cover by semi-permeable fleece sheet and cover by simple roof structure. In particular, the semi-permeable fleece is capable to drain off 85% of the precipitation, while remaining permeable to air and steam from inside. The roof structure consisted of a modular steel frame, with a waterproof sheet metal cover.

Each of the 5 treatments was replicated three times, where one replicate consisted of a single pile with a volume of 20 m^3 (6 m long, 2.5 m wide and 2 m tall). The complete experimental design consisted of 15 replicates. The fifteen chip piles were built on the same site in a random sequence. Piles were built on the naked soil and were all aligned with their longer axis in the east–west direction. All poplar trees used for the test belonged to clone I-214, one of the most common and successful Euro-American hybrid poplar clones. Chips were obtained from 6-year-old poplar stems, with an average base diameter of 16.5 cm, and an average height of 10.4 m. Stems were chipped with a commercial drum chipper, model Pezzolato PTH 900 (www.pezzolato.it).

Storage performance is assessed through variations in moisture content and total dry mass. Successful storage achieves the highest moisture content reduction and the lowest dry matter loss. Temperature is a reliable indicator of storage performance, since degradation reaction are exothermic and generate a marked temperature rise [16]. Therefore, moisture content and temperature inside the piles were monitored for the entire storage period, which begun in March with pile building and ended in September with pile removal and chip usage. Temperature was measured by thermocouples, and moisture content with time-domain reflectometry (TDR) prototype sensor, specifically developed for the study by the University of Turin. The TDR sensor system consisted of two probe types: P-type probes were for point measurements, while R-type probes for average measurements. Values were recorded each day during the first month. Thereafter, the recording frequency was reduced to one measurement every 3 days. The high sampling frequency in the first month had the purpose of documenting possible temperature peaks, as reported in previous studies. Later on, temperature and moisture are known to change more gradually, which justified longer sampling delays. The thermocouples and the P-type probes were placed in the mid-section of the pile, at three different heights above the ground (0.5, 1.0, 1.5 m). R type probes were positioned in the middle of the woodchips pile (Fig. 1). The TDR system was calibrated using the gravimetric method.

Losses were determined both in terms of dry matter and bulk volume. Each pile corresponded to one trailer load of chips, and all trailers were scaled at the beginning of trial on a certified weighbridge. At that time, the exact bulk volume was also determined, after levelling the load. At the end of the trial, all piles were reloaded on trailers, and the same procedure was repeated. Fresh weights were corrected for wood moisture content in order to calculate dry weights.

A weather station was also installed in the centre of the storage site in order to monitor air temperature (°C), air humidity (%) and precipitation (mm) at 1 h intervals.

Particle size distribution is known to affect storage properties [12]. Particle size distribution determines the air permeability of chip piles and affects the speed and degree of drying under any given conditions. Nellist [19] calculated the following exponential relationship between average particle size and air permeability:

$$A = 19125\,(\text{Mean particle size, mm})^{-0.874} \quad (1)$$

where "*A*" is a coefficient describing the pressure resistance of the heaped chips to airflow, and therefore provides a good indicator of how readily the chips would dry. Assuming that particle size distribution in any given class is skewed towards the lower size classes, the mean particle size can be calculated using geometric means, which partly compensate for such skew. The mean particle size is therefore obtained by a weighted average of all particle classes, as represented by their geometric mean. The Particle size distribution of the chips used for the experiment was determined with an oscillating screen according to European Standard EN 15149-1: 2011, on ten one-kilogram samples. Chips were divided into the following six length classes: <3 mm, 3–15 mm, 16–45 mm, 46–63 mm, 64–100 mm, and >100 mm.

Finally, storage cost was estimated by summing all the costs incurred to build each pile, including: machine hours, man hours and materials (covers etc.). In particular, we assumed that covers were re-usable for 2 years, and that the simple roof system had a 15-year life cycle. Cost was calculated on an energy base, in Euro GJ^{-1}. To this end, we first calculated the storage building cost per initial green tonne, which was then discounted according to green weight losses. Final tonnes were divided into dry wood tonnes and water tonnes, based on the final moisture content values for each treatment. Dry wood and water weights were used

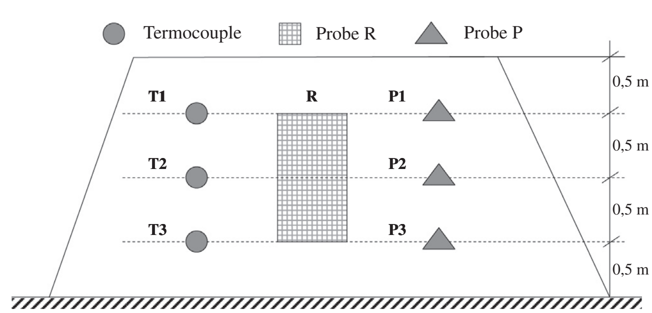

Fig. 1. Position of the probes inside the piles.