



Research paper

Dry matter losses and quality changes during short rotation coppice willow storage in chip or rod form



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ABSTRACT

This study compares dry matter losses and quality changes during the storage of SRC willow as chips and as rods. A wood chip stack consisting of approximately 74 tonnes of fresh biomass, or 31 tonnes dry matter (DM) was built after harvesting in the spring. Three weeks later, four smaller stacks of rods with an average weight of 0.8 tonnes, or 0.4 tonnes DM were built. During the course of the experiment temperature recorders placed in the stacks found that the wood chip pile reached 60 °C within 10 days of construction, but the piles of rods remained mostly at ambient temperatures. Dry matter losses were calculated by using pre-weighed independent samples within the stacks and by weighing the whole stack before and after storage. After 6 months the wood chip stack showed a DM loss of between 19.8 and 22.6%, and mean losses of 23.1% were measured from the 17 independent samples. In comparison, the rod stacks showed an average stack DM loss of between 0 and 9%, and between 1.4% and 10.6% loss from the independent samples. Analysis of the stored material suggests that storing willow in small piles of rods produces a higher quality fuel in terms of lower moisture and ash content; however, it has a higher fine content compared to storage in chip form. Therefore, according to the two storage methods tested here, there may be a compromise between maximising the net dry matter yield from SRC willow and the final fine content of the fuel.

1. Introduction

One of the most challenging aspects of using biomass for energy is preserving dry matter and fuel quality during storage [1]. Due to the limited harvesting window of short rotation coppice (SRC) willow, the crop must be stored between harvesting in late winter/early spring and eventual consumption by a bioenergy facility. Willow is typically harvested at just over 50% moisture content (MC), so it is beneficial to dry and store the material simultaneously in order to provide a suitable quality fuel at the time of demand [1]. Two studies have shown that dry matter (DM) losses of short rotation coppice willow and poplar are around 20% [2,3], when storing in stacks for between three and 9 months, respectively, though periodical sampling in Ref. [3] showed that the DM losses plateaued after four to five months. The wood chip stacks showed rapid increases in temperature to around 60 °C within a few days of establishment, with a corresponding increase in CO₂ concentration within them. The DM losses were found to be higher than in studies on forest-residue chips, which may be due to the higher proportion of bark in short rotation woody chips. Bark contains many plant nutrients and, after comminution, offers an ideal growth medium for

bacteria and fungi [4].

The initial heating phase is suggested to create favourable conditions for microbial and fungal colonisation. The transfer of heat and moisture between the wood chip stack and the outside air is dependent on the equilibrium relationship between them and the rate at which the moisture can diffuse through the stack [5]. Stacks consisting of larger particles should follow ambient temperatures more closely than those formed of smaller particles where self-heating is prevalent [5–8]. Willow can be harvested as chips, as billets (~20 cm pieces) and as whole stems (rods). In the UK, chipping is most commonly carried out, due to a number of modified forage harvesters being available, and this offers multiple use of harvest machinery. There is currently one active billet harvester and no more than two rod harvesters in operation in the UK. There have been no studies examining the DM losses of SRC willow when stored as rods in the UK, although it is hypothesised that such storage will reduce dry matter losses and allow the biomass to dry more effectively due to natural ventilation in the stacks [9]. Unfortunately, rod harvesting increases costs because the material is more difficult to handle than chips and because another processing stage in the supply chain is required, as the rods must be chipped before being combusted.

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This study explores the DM losses and quality of wood chips produced from SRC willow when stored as chips in a large pile, or as rods in smaller piles, which are later chipped.

Dry matter losses can lead to complications, however, as other characteristics may change during storage that affects the combustion properties of the fuel. For example, ash contents have been shown to increase during wood chip storage due to decay of the biodegradable fractions [1]. Also, the washing away of water-soluble components, such as salts and alkali chlorides, by rain can change characteristics of the ash such as ash fusibility [10]. Ash content can also increase due to contamination from soil or from dust particles in wind [11]. Moreover, natural composting processes, can alter the carbon-to-nitrogen ratio (C:N) during storage [12]. This often leads to a higher relative fuel-bound nitrogen composition of the biomass which causes higher emissions of NO_x during combustion [13]. Finally, changes in the quantities of fines (particles less than 3.15 mm) during storage must be assessed, as these tend to burn rapidly and generate very high temperatures in combustion systems. This can lead to ash melting and slagging [14]. Fines can also have important health and safety implications for those handling biomass [15]. Another aim of this study is to explore quality changes during wood chip and rod storage.

2. Materials and methods

2.1. Wood chip stack construction

The material for the wood chip storage pile was harvested from two areas of SRC willow. The sites were established in 2009 and were previously harvested in winter 2011–12. The areas were planted with breeding material from a *S. viminalis* x *S. schwerinii* cross. Both sites were previously cropped in an arable rotation. The SRC willow was treated with a residual herbicide (aminotriazole) and 60 kg ha⁻¹ nitrogen in spring 2012 to encourage re-growth.

The crop was harvested on the 4th March 2015 using a Claas forager harvester with a Coppice Resources Ltd (Retford, UK) header and blown into an accompanying trailer. At this point ten fresh samples of wood chips were taken for MC, ash and composition analysis. The material was immediately transported to a nearby field (coordinates 52.012854, -0.598906) where the stack was built by tipping the chips onto the ground and piling them up using a tractor with a front mounted loader and bucket. The completed stack was approximately 19 m long, 7 m wide and 3 m high and was built in a precise south-westerly to north-easterly orientation (Fig. 1).

The total stack mass was determined by weighing the harvested material during the stack establishment. This was performed by manoeuvring the trailer over a series of portable weight pads (PT Weigh pads, Weightru, Stourbridge, UK) on a concrete standing. Each pad can weigh up to 10,000 kg to the nearest 100 kg. The weight under each axle was recorded, as well as under the drawbar. The readings from the weight pads were validated by comparing the weight of the empty trailers with their known weights from a calibrated weighbridge.

2.2. Rod stack construction

The material for the rod storage stacks was taken from a similar plant breeders trial site, where the two experiments consisted mainly of pure *Salix viminalis* genotypes. Both experiments were situated approximately 40 km from that giving rise to the wood chip. The first experiment was harvested on 4th February 2014 and the second experiment was harvested on 30th March 2015. Both were weighed onsite in batches and placed adjacent to the harvesting site (coordinates 51.812,413, -0.375,903) where one (2014 experiment) and four (2015 experiment) stacks were built. Both the harvesting and building of the piles was performed by hand to mimic the action of a machine such as the Stemster III (Nordic Biomass, Denmark). At this point four samples of rods were chipped and taken for MC, ash and composition

analysis. These samples were chipped by an arboricultural chipper, not by the forage harvester used for the chip storage. Each stack was supported within an area pre-marked with 1.5 m-high wooden stakes approximately 1.5 m apart in a square formation (Fig. 1c), and the rods were placed between the stakes to make the stack. In 2014 the single stack contained 1212 kg of fresh biomass (567 kg DM), whereas in 2015 the stacks contained an average of 763 kg of fresh biomass (358 kg DM), both somewhat less than the 4000 kg that can be accommodated on the bed of a Stemster machine prior to tipping the rods to make a stack.

2.3. Dry matter loss assessment

Dry matter losses were assessed in both the wood chip and rod storage piles by drying weighed samples at 80 °C for 4 days to deduce the change in mass. All reported MCs are on a wet basis. A previous study found a great deal of heterogeneity in terms of DM losses and MCs within two wood chip stacks, therefore a strategic method of assessment was employed to attempt to reduce uncertainty in the results. The same study also found that a ‘crust’ developed on the outer layer of the stack, therefore the current study attempted to examine losses occurring in this layer. For this, the stack was divided into five zones (Fig. 1a). In each zone the dry matter losses occurring in the core, outer layer and top of the stack were tested using weighed, independent plastic mesh bag samples of approximately 3–4 kg of the freshly harvested wood chips. As the pile was being built, three bags were placed in the core area of each zone so that they were at least 2–3 m under the surface (Fig. 1b). In each zone, one bag was placed in the top of the stack. Finally, in each zone, two bags were placed on either side of the outer layer of the stack, about 2 m high, and buried so that they were flush with the outer surface. A temperature recorder (Log Tag[®] Model Trix-8, LogTag Recorders Ltd. Auckland, New Zealand) was added to each core bag to log the temperature on a two-hourly basis throughout the storage period.

In the rod stacks, dry matter losses were measured using small independent bundles (approx. 20 kg) made from randomly selected stems, which were tied together and weighed. In 2014, eight bundles were placed within the central region of the stack, whereas, in 2015, three bundles were placed in the central region of each rod stack, as it was being built. In 2015, a temperature recorder was placed in the centre of each stack.

2.4. Stack breakdown

The wood chip stack was dismantled after 208 days, on 28th September 2015 using a tractor with a front mounted loader. During breakdown, care was taken not to lift soil with the loader bucket so that a bed of chip remained on the ground that was no more than 15 cm in depth. However, this depth ranged across the site and in some instances small amounts of soil were lifted. The lifted chip was loaded onto a series of trailers which were re-weighed on the same concrete hard standing with the portable weigh pads.

The bagged samples were retrieved, and the moisture and ash content was determined for these samples. Due to previously observed heterogeneity in wood chip piles, some extra samples were taken. From each zone, two (technical replicate) samples were taken for moisture content analysis from the crust and the core of the south-eastern (SE) and north-western (NW) sides of the stack, and also from the ‘middle’ of the profile (Fig. 1b). One sample from each technical replicate was taken for ash analysis. Ten random samples of the stack after lifting and re-tipping were taken to assess the overall moisture content change during the experiment, and a large sample was taken to analyse the particle size.

In 2014, the collected chip was then weighed, giving some indication of losses during the handling and chipping process. The rod stacks were dismantled after 156 and 192 days, on 10th July 2014 and 8th October 2015 respectively. The work was conducted by hand, without

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