Choosing between harvest options for short rotation coppice and the consequences for post-harvest management.

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INTRODUCTION

As short rotation coppice developed as a promising cropping option for bio-energy so did a series of machines for harvesting from the coppice stools. SRC was placed between agriculture and forestry, the stems being hard and more difficult to cut with conventional agricultural machinery, but inefficient to cut with forest machinery except in the very largest (longer rotation) crops.

Several manufacturers, ranging from the smallest engineers to large multi-nationals, entered the market. The machines often showing hybridization between agricultural and forestry concepts. It was assumed (largely correctly) that the end product to be marketed would be wood chips. This led to a debate over whether to chip the fresh material as harvested, or dry the cut stems and chip later. Machines were developed capable of achieving both, as well as an intermediate form of billet harvester. The argument was that the larger harvested material (stem or billet) would dry more efficiently, and the counter argument was that the chipping of dry material would require more energy and result in poorer quality chip.

Although there was some data generated around this debate, it was inconsistent and mostly not suitable for a comparative study. The uncertainty simply fuelled the debate. Therefore a more consistent, comparable dataset was generated.

FINANCIAL COSTS

An initial study of a wide range of potential options for harvesting SRC was conducted by calculating the financial cost to clear a single field of SRC willow in the UK. The machines were observed working in many different fields and the data collected used to model their performance in the same field. All options known to be employed by the industry in Europe were included. The data generated are shown in Table 1.

From this exercise it was possible to eliminate several options.

The Biobaler was slow to operate and involved collecting a large number (80 -100) of round bales from the field, a slow operation itself. Round bales could be used in some combustion chambers, but we chose to use the much more widely utilizable wood chips as our end point. Creating chip from round bales would be difficult with a high probability of quality issues.

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During the study period interest in billets as an intermediate form between chips and whole stems was low, so the decision was taken to concentrate on the two extreme forms. More recently we have been made aware of renewed interest in billets.

Whole rod harvesting was clearly the lowest cost method of clearing the field. However, transporting whole rods is difficult, and in unprocessed form not suitable on the public road. Using a forestry brash baler to create neat, higher density, bundles proved very expensive.

TABLE 1. THE FINANCIAL COST (€) OF CLEARING THE FIELD OF STANDING CROP OF SRC WILLOW. COSTS CALCULATED TO THE POINT OF AN ON FARM STORAGE FACILITY.

	Bio-baler	*Small scale forage harvester*	*Medium scale forage harvester*	*Large scale forage harvester*	*Billet harvester*	*Whole rod harvester plus bundler*	*Whole rod harvester Loose rods / stems*
Cost € ha^{-1}	*556*	*604*	*381*	*416*	*624*	*663*	*336*
Speed when harvesting km h^{-1}	*2.2*	*2.6*	*4.5*	*5.6*	*4.5*	*5*	*5*
Fuel used l ha^{-1}	*196*	*231*	*109*	*97*	*101*	*106*	*60*
Time taken h ha^{-1}	*5.0*	*4.2*	*1.7*	*1.4*	*1.7*	*2.9*	*1.8*
No people required	*2.5*	*2.25*	*3.25*	*3.25*	*3.25*	*3.75*	*1*
Capital invested [a] 000 €	*507*	*332*	*713*	*840*	*680*	*987*	*487*
Specific Capital investment [b] 000 €	*193*	*31*	*113*	*173*	*360*	*280*	*280*
Product	*Round bale*	*Chips 3 – 15 mm*	*Chips 3 – 15 mm*	*Chips 3 – 15 mm*	*Billets 120 – 200 mm*	*Whole stems*	*Whole stems up to 8m*

[a] Total capital cost of the machinery regardless of potential on other crops, [b] capital cost of machines only used for SRC harvest.

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Forage harvesters are available at different scales, the smallest scale being slow and relatively expensive to operate, but requiring a low level of specific capital investment allowing small scale producers in isolated areas to enter the wood chip market. We understand that the latest improvements to such small scale machines (documented elsewhere within LogistEC) may have increased the cost to 50k €, but still substantially less than any other option.

FIGURE 1. A SELF-PROPELLED FORAGE HARVESTER FITTED WITH A SRC CUTTING HEADER (COPPICE RESOURCES LTD) PRODUCING WOOD CHIPS (LEFT) AND A TRAILED STEMSTER III (NORDIC BIOMASS) CUTTING WHOLE RODS (RIGHT).

The Bio-baler is slow and expensive to operate. It leaves a more difficult to utilize product (round bales).

The Billet Harvester, if based upon a sugar cane harvester, is expensive to operate largely because it has no alternative use in other crops at other times of the year.

Forest brash balers make whole rod harvested crop transportable on the road, but add considerably to the cost of harvest.

Forage harvesters and whole rod harvesters present the most cost effective methods to clear SRC fields of crop.

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POST-HARVEST MANAGEMENT

As the final wood chip is a low value product most operators choose to rely upon ambient drying to remove moisture from the harvested SRC. The data in Table 2 Indicate how stems (rods) dry more efficiently than chips with fewer losses. The wood chip storage piles contained 84 and 74.5 fresh tonnes of chip in 2014 and 2015 respectively and were therefore representative of smaller scale producers. It was possible to record that the core of the pile dried to a lower moisture content than quoted in Table 2, but mixing of dryer core and wetter outer layers during loading of the lorries gave a mean moisture content that is too high for many users. Larger scale producers build piles of several hundred tonnes of chip, increasing the ratio of core to outer layer and achieving lower mean moisture content at the point of sale. The rod piles consisted 0.8 – 1.1 fresh tonnes and so were smaller than the average pile left at the side of the field by a Stemster harvester (maximum capacity 4.5 fresh tonnes). They were stacked on wooden bearers keeping the rods above the soil surface and allowing a loader to pick them up easily.

TABLE 2. MOISTURE AND DRY MATTER LOSSES DURING STORAGE OF SRC WILLOW CHIPS AND WHOLE STEMS (RODS).

	Storage period (days)		*Moisture content (%) when cut*		*Moisture content after storage, %*		*Dry matter loss in storage, %*		*Loss in handling, % DM*	
	Chip	*Rod*	*Chip*	*Rod*	*Chip*	*Rod*	*Chip*	*Rod*	*Chip*	*Rod*
2014	*97*	*164*	*50.0*	*53.2*	*42.8*	*21.8*	*18.6*	*1.9*	*2.9*	*5.4*
2015	*208*	*156*	*56.4*	*53.1*	*44.4*	*23.8*	*21.4*	*6.6*	*1.6*	*-*

The losses in handling reported in Table 2 have been observed to be greater in conditions were the chip pile was located on poorly drained soil. Soil contamination is both abrasive and corrosive to the intake mechanism and boiler system. Most producers leave a layer of wood chip on the soil surface to avoid problems with rejected loads of wood chip.

To estimate the energy required to chip fresh and part dried rods the fuel used by a tractor driving a standard forestry or arboricultural wood chipper was measured as batches of 0.8 to 1.1 tonnes of rods were chipped. Care was taken to feed the rods evenly to the chipper and avoid downtime, however, it could be seen that there were sources of error in the measurement. In particular there was the flywheel effect of cutting rotor.

TABLE 3. FUEL USE BY THE TRACTOR DRIVING A STANDARD WOOD CHIPPER WHILST CHIPPING WET AND PART DRIED WILLOW RODS.

Chipping date	*Moisture content (%) when cut*	*Moisture content (%) when chipped*	*Fuel used fresh basis (l t^{-1})*
27th January 2014	*52.3*	*52.3*	*3.49*
10th July 2014	*53.2*	*21.8*	*6.52*
6th May 2015	*53.1*	*53.1*	*2.39*
8th October 2015	*53.1*	*23.8*	*3.42*

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FIGURE 2. CHIPPING RODS WITH A FORESTRY / ARBORICULTURAL CHIPPER.

Because the „fuel use“ method above could be seen to introduce some possible errors it was decided to conduct some experimentation in more controlled conditions. ATB Potsdam (Germany) kindly provided access to a test rig that produced the data in Table 4. These data indicated that the 2014 fuel use data may have been reasonably reliable, stored, part dried, rods took approximately twice as much energy to chip.

TABLE 4. ENERGY REQUIRED TO CHIP WET AND PART DRIED WILLOW RODS OF DIFFERENT DIAMETERS.

Stem diameter (mm)	*Moisture content (%)*	*Energy to chip (kWh / fresh tonne)*
10 – 30	*45.2*	*1.48*
20 – 40	*44.8*	*2.21*
10 – 30	*23.7*	*4.43*
20 – 40	*26.5*	*4.19*

In 2015 a comparison was made between wood chips produced by the forage harvester and stored for 208 days in a large outdoor heap and rods chipped fresh or part dried (156 days later). Somewhat surprisingly the forage harvester produced chip with a greater proportion of larger (16 – 45 mm) particles than expected (Table 5), but post storage this had reduced to a more acceptable proportion. The larger particles may be screened out for certain markets, either representing a loss of mass or requiring alternative processing. Left in the mix they threaten to block feed mechanisms to boilers.
Chipping rods once part dried resulted in a doubling of the proportion of “fines”, particles passing a 3.15 mm screen. These fines are considered to be largely responsible for the 5.4% loss recorded when handling the wood chip from the 2014 part dried rods (Table 2). The data in Table 5 suggests that the loss in handling could have been twice as much in 2015 (it was not recorded). Alternatively, if not lost in handling, the fines represent a threat from dust, which can cause human health issues and an explosion risk in a confined space.

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TABLE 5. PARTICLE SIZE DISTRIBUTION (% BY MASS) OF SRC WILLOW CHIPPED FRESH BY A FORAGER AND THEN STORED FOR 208 DAYS AND CHIPPED FRESH AND PART DRIED, AFTER STORAGE AS RODS, BY A WOOD CHIPPER.

	Chipped fresh by forage harvester		*Rods chipped fresh by wood chipper*	*Rods chipped part dried (23.8% moisture)*
Particle size	***Pre-storage***	***Post storage***	***Pre-storage***	***Post storage***
16-45mm	***15.5***	***6.7***	***6.6***	***6.0***
3.15-16mm	***78.4***	***89.2***	***87.5***	***82.8***
<3.15mm	***5.7***	***4.1***	***5.4***	***10.9***

OUTLINE MAJOR POINTS

Rods dry to a lower, more widely acceptable by end users, moisture content and with considerably lower losses than chips.

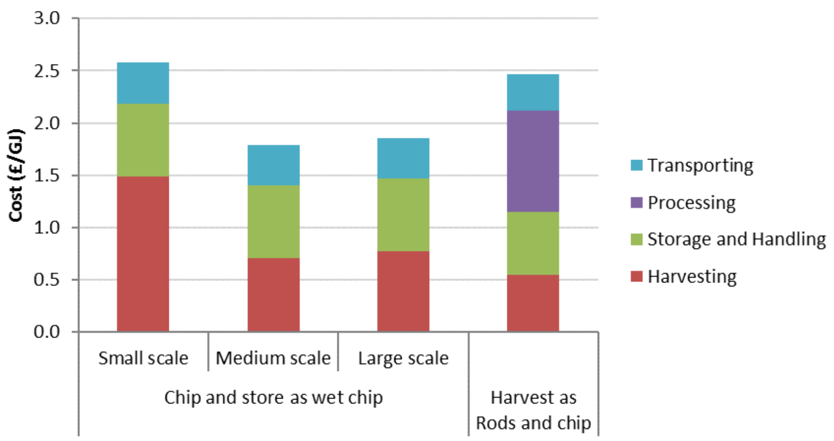
Rods require approximately twice as much energy to chip once part dried than when freshly cut.

Chip quality from part dried rods was poorer than fresh rods, there were greater losses in handling and dust risks from fine particles.

ANALYSIS OF THE WHOLE HARVESTING SYSTEM.

All data collected was combined to make a comparison of the more viable systems identified. The data are presented on the basis of GJ of wood fuel sold. This accounts for losses as well as inputs.

a)



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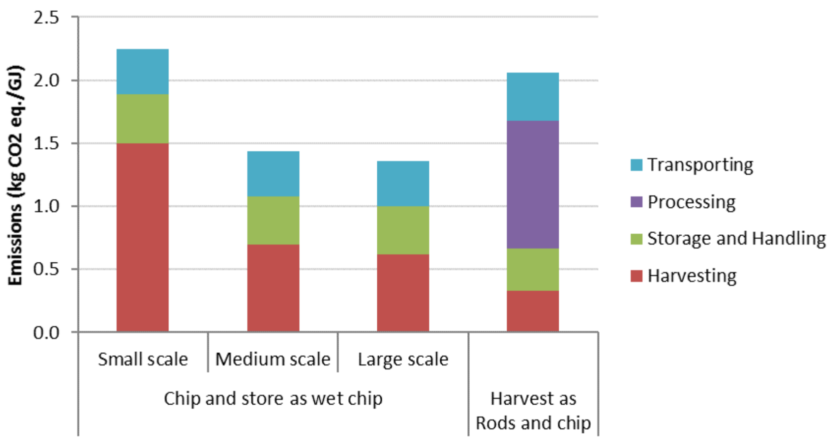
b)



c)

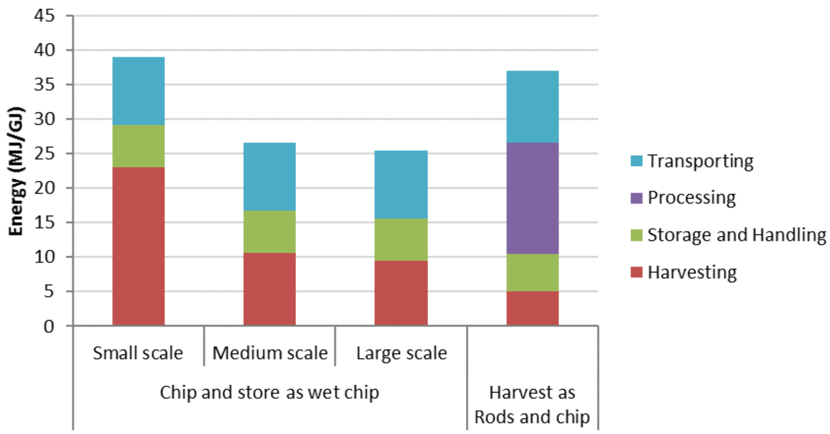


FIGURE 3. THE FINANCIAL (A), GREENHOUSE GAS (B) AND ENERGY (C) COST OF THE ALTERNATIVE METHODS OF HARVESTING SRC WILLOW.

- **Handling and chipping rods adds to the financial, greenhouse gas and energy cost of harvesting SRC willow.**

- **Medium and large scale forage harvesters are the most efficient machines to harvest SRC willow.**

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