# Increasing the Value Recovery from Short-Rotation Coppice Harvesting

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Farmers are reluctant to establish short-rotation coppice because too many uncertainties remain about its economic feasibility. Up to now, most progress has been accomplished by increasing plantation yields through genetic improvement and by reducing management costs through mechanization. In contrast, the potential increase of value recovery has received much less attention. We therefore compared whole-tree chipping with integrated harvesting to test whether more profit could be made by producing pulpwood logs and wood chips, rather than wood chips only. The two systems were compared side-by-side with identical machinery on the same field. Chip production cost was higher for integrated harvesting (15 € $Mg^{-1}$), because the system was less productive (9 Mg $h^{-1}$), as compared with whole-tree chipping (9 € $Mg^{-1}$ and 25 Mg $h^{-1}$). Pulpwood log production only occurred with the integrated harvesting system, at a cost of 8 € $Mg^{-1}$. Integrated harvesting incurred higher production costs, but also accrued better value recovery. Under current market conditions, the two systems offered similar profits, in the vicinity of 5000 € $ha^{-1}$. However, integrated harvesting offered higher flexibility, with a potentially better resilience to market fluctuations.

*Keywords: Integrated harvesting; Poplar; Productivity; Whole-tree chipping; Wood chips*

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## INTRODUCTION

In recent decades, short-rotation coppice (SRC) has become an efficient way of managing tree plantations to meet the growing demand for lignocellulosic feedstock (Coaloa *et al*. 2012; de Wit *et al*. 2013). However, farmers remain reluctant in establishing SRC because no reliable economic assessment of SRC has been made and many uncertainties remain (Faasch and Patenaude 2012; Vanbeveren *et al.* submitted). Over the course of time, many improvements have been achieved to decrease SRC management costs (de Wit *et al.* 2013; Manzone *et al.* 2014). The main management improvements were achieved by mechanization (Spinelli *et al.* 2008) and further improvement of harvesting machinery (Vanbeveren *et al.* submitted). Harvesting is by far the largest cost item in the life of an SRC and can amount to up to half of the production cost, which emphasizes the importance of designing optimized harvesting operations (Spinelli *et al.* 2008; Fiala and Bacenetti 2012; San Miguel *et al.* 2015). At the same time, a lot of research has also addressed the increase of plantation yield, to the benefit of a higher product output. Both approaches – *i.e.*, increased yield and decreased harvesting cost – are eminently quantitative (Mola-Yudego *et al.* 2014). Little attention has been devoted to qualitative approaches, aiming at increasing the value of the product and not just its quantity or cost efficiency. Currently, whole-tree (WT) chipping is the most common harvesting system applied to SRC. This system is simple and fast, but it only offers one single low-priced product, *i.e.*, wood chips. Harvesting and WT chipping of SRC is mostly done according to the cut-and-chip technique, whereby the cut trees are immediately chipped by the same machine (*e.g.* modified forage harvesters), or according to the cut-and-store technique, whereby cut trees are stored before they get chipped by a dedicated chipper (Vanbeveren *et al.* submitted). WT chipping is the only option when rotations are shorter than 4 to 5 years because stems lack the size necessary for producing any other product types. However, more recent SRC plantations are managed according to longer rotations, and the basal part of the stems could be suitable for processing into a higher-value product. Therefore, one might consider applying integrated harvesting (IH), where the basal part of the stems is turned into pulpwood logs, while the treetops are chipped (Verani *et al*. 2008). A precondition for applying IH is a minimum stem diameter of 15 cm at breast height, and thus a minimum rotation length of 5 to 6 years, depending on plantation and site characteristics (Manzone *et al.* 2014). By increasing the rotation length – to minimally five years – the wood chip quality also increases, as the ratio of hardwood over bark and the particle size distribution improve (Manzone *et al.* 2014, 2015). It should also be kept in mind that there must be an interest in the wood logs from the planted species.

With this study, we aimed to determine if applying IH to an SRC may increase profits, as compared with the common WT chipping. Because wood chips have a low market value (Fiala and Bacenetti 2012), we expect that pulpwood logs will generate higher revenues from the harvest of SRC, as they can be used in industry for making modified wood products or packaging (De Somviele *et al.* 2009; Manzone *et al.* 2014).

## EXPERIMENTAL

The study was conducted on an existing five-year-old SRC plantation, planted with poplar (*Populus* spp.) at a density of 1660 ha$^{-1}$ (2 x 3 m planting design). This planting density is typical for Italian SRCs, next to densities of 10000 to 14000 ha$^{-1}$ and 5000 to 6000 ha$^{-1}$. The plantation was split in the middle to obtain two plots with the same shape and a surface area of 0.22 ha each. The average diameter at breast height (1.30 m) of the stems was 14.8 ± 3.3 cm on plot one and 15.5 ± 2.7 cm on plot two. The moisture content of the harvested stems was 45.8% and 43.5%, respectively, for plots one and two. The plantation was located in Cavallermaggiore (Cuneo, Italy) and harvested on 17 November 2015. Felling (and the processing in the case of IH) was done with a GMT 035 saw head (Gierkink Machine Techniek b.v., the Netherlands) attached to a PC110R light excavator (Komatsu Ltd., Japan). Chipping was done in the field, using a PTH 1400-820 ALLROAD all-terrain chipper (Pezzolato S.p.A., Italy). Both machines were operated by professional personnel. Chips were blown directly into silage trailers attached to farm tractors, tasked with moving the chips to the Biopoplar combined heat and power (CHP) plant (in Cavallermaggiore), which was located 2 km away. Plot one was processed as WT chipping, while IH was applied to plot two. When applying IH, one or two 2-m pulpwood logs were produced from the basal part of the stem, and the remaining treetops were chipped (Fig. 1). Working and delay times for felling were recorded in 14 cycles per plot and the working time for chipping was recorded in five cycles for the WT chipping and in two cycles for the IH. Statistical significant differences were tested with non-parametric Mann-Whitney U-tests, as data were not normally distributed.

**Fig. 1.** The end product of plot one (whole trees; left image) and plot two (pulpwood logs and treetops; right image) during the harvest at Cavallermaggiore (Cuneo, Italy). Photo credit: S.P.P. Vanbeveren.

Field stocking was determined by measuring the weight of all trailers on the CHP plant weighbridge at the time of harvesting. Annual yield was calculated by dividing field stocking by plot area and stem age. All weights were reported in Mg of fresh matter. We recorded the time spent on each plot by each machine, separating net felling time from delay time. All delay time that was not caused by the study itself was included in the calculations. Delay times were included in the effective field capacity (EFC; ha $h^{-1}$) and the effective material capacity (EMC; Mg $h^{-1}$), calculated for the felling (or felling-processing in the case of IH) and chipping.

Hourly rates for the machines used in the test were calculated with the method described by Miyata (1980), using costing assumptions provided by the machine owners. The production cost of each system (IH *vs*. WT chipping) was calculated by first multiplying the usage cost with the percent usage time of each machine (feller *vs*. chipper) and then summing these values per harvesting system. The wood chip production cost per harvesting system was calculated by first dividing the feller’s and chipper’s usage cost by their respective EMC and then summing these two values. The pulpwood log production cost was calculated by dividing the feller’s usage cost by its EMC for pulpwood log processing. The total production cost of the WT harvesting system was obtained by multiplying the chipped biomass with the wood chip production cost. For the IH, the total production cost was obtained by the sum of two multiplications: the chipped biomass with the wood chip production cost; and the non-chipped biomass with the pulpwood log production cost. The market prices for wood chips and pulpwood logs from poplar were obtained from the Chamber of Commerce of Alessandria (Italy) (Livraghi 2016).

## RESULTS AND DISCUSSION

The IH of field two required more than double the time for felling (3 h 30 min), but less time for chipping (0 h 55 min) as compared with WT harvesting of field one (1 h 30 min for felling and 1 h 20 min for chipping) (Table 1). The significant difference in felling time ($p < 0.01$) was caused by a higher net felling time, as well as by a higher (non-significant; $p > 0.05$) delay time in the IH system as compared to the WT harvesting. This could be explained by the more extensive handling of the stems in the IH: stems needed to be felled, pulpwood logs needed to be separated from treetops, and then both assortments needed to be piled separately. Additionally, relocating the treetops involved handling small branches, which were more prone to getting stuck in the grapple, hence demanding operator intervention. In contrast, during the WT chipping stems only needed to be cut and windrowed, thereby lowering both the net felling time and the delay time.

**Table 1.** Yield and Field Stocking, Felled and Chipped Amounts of Biomass, Time Needed to Process Both Plots, Feller Effective Field Capacity (EFC), Feller and Chipper Effective Material Capacity (EMC), and Production Costs for Both Studied Plots

| Plot | | 1 | 2 |
|---|---|---|---|
| Processing type | | WT chipping | IH |
| Yield | (Mg ha$^{-1}$ y$^{-1}$) | 35.4 | 30.4 |
| Field stocking | (Mg ha$^{-1}$) | 176.8 | 151.8 |
| Felled biomass | (Mg) | 38.9 | 33.4 |
| Chipped biomass | (Mg) | 38.9 | 23.6 |
| Net felling time | (h:m:s) | 1:28:25 | 3:04:51 |
| Delay time during felling | (h:m:s) | 0:04:57 | 0:27:13 |
| Total felling time | (h:m:s) | 1:33:22 | 3:32:04 |
| Total chipping time | (h:m:s) | 1:18:36 | 0:54:17 |
| Time used for felling | (%) | 54 | 80 |
| Time used for chipping | (%) | 46 | 20 |
| Felling EFC | (ha h$^{-1}$) | 0.14 | 0.06 |
| Felling EMC | (Mg h$^{-1}$) | 25.0 | 9.4 |
| Chipping EMC | (Mg h$^{-1}$) | 29.7 | 26.1 |
| Processing cost | (€ h$^{-1}$) | 123 | 96 |
| Wood chip production cost | (€ Mg$^{-1}$) | 9.04 | 14.81 |
| Pulpwood log production cost | (€ Mg$^{-1}$) | - | 7.97 |
| Total production cost | (€) | 351 | 428 |
| Total revenue | (€) | 1459 | 1550 |
| Profit | (€) | 1107 | 1123 |

WT = whole-tree; IH = integrated harvesting; felling also includes processing in the case of integrated harvesting.

The harvesting EFC (0.14 ha $h^{-1}$) and EMC (25.0 Mg $h^{-1}$ including delay times) for the WT chipping system were more than double the EFC (0.06 ha $h^{-1}$) and EMC (9.4 Mg $h^{-1}$) recorded for IH (Table 1).

The lower chipping time recorded for IH is explained by the lower amount of biomass chipped, as compared with the WT chipping (15 Mg less), as the chipper EMC was almost equal for both processing types (IH 26 Mg $h^{-1}$; WT 30 Mg $h^{-1}$). The small difference in chipper EMC was probably due to the smaller size and, thus, lower density of the biomass chipped under the IH (Manzone 2015). However, it should be kept in mind that harvest losses (*a.o.* due to branches breaking of from the stems during felling) were not taken into account, thereby not generating a difference between felled and chipped biomass for WT chipping. The delay time and fuel consumption during the chipping process were not monitored for this study, but were expected to be higher when handling smaller piece size (Manzone 2015). As a consequence, felling accounts for 80% of the total harvesting time under the IH, and for only 54% under the WT chipping.

The hourly machine cost was higher under the WT chipping treatment than under the IH (123 *vs*. 96 € $h^{-1}$, respectively) because of the higher proportion of chipper use (Table 1). Service life and labor costs were equal for the feller and the chipper. Thus, the difference in hourly cost was mostly due to the higher purchase price, fuel consumption rates, and maintenance cost of the chipper as compared with the feller (Table 2). Given the small scale at which this experiment was conducted, it is suggested not to extrapolate these results to large scale plantations, but rather to keep them as an indication for plantations of a few hectares.

**Table 2.** Economic Data of the Feller (GMT 035 saw head attached to a Komatsu PC110R) and the Chipper (PTH 1400-820 ALLROAD) Used for this Study

| | | Feller | Chipper |
|---|---|---|---|
| Purchase price | (€) | 130,000 | 550,000 |
| Economic lifetime | (y) | 8 | 8 |
| Resale value | (€) | 39,000 | 165,000 |
| Interest rate | (%) | 4 | 4 |
| Fuel consumption | (l $h^{-1}$) | 18 | 40 |
| Crew | (n) | 1 | 1 |
| Depreciation | (€ $y^{-1}$) | 11,375 | 48,125 |
| Interest | (€ $y^{-1}$) | 3,608 | 15,263 |
| Insurance | (€ $y^{-1}$) | 1,000 | 2,500 |
| Fuel and lube | (€ $y^{-1}$) | 36,504 | 81,120 |
| Maintenance | (€ $y^{-1}$) | 5,688 | 24,063 |
| Labour | (€ $y^{-1}$) | 24,000 | 24,000 |
| Annual use | (h $y^{-1}$) | 1,200 | 1,200 |
| 10% overhead | (€ $h^{-1}$) | 6.8 | 16.3 |
| Usage cost | (€ $h^{-1}$) | 75 | 179 |

At a moisture content of 40% to 45%, the market price for poplar wood chips in the studied region was 37.50 € $Mg^{-1}$, and that for pulpwood logs was 43.50 € $Mg^{-1}$. Under such market conditions, IH resulted in an increase of 6% in value recovery (414 € $ha^{-1}$) and a 21% increase in harvesting cost (350 € $ha^{-1}$). In practical terms, that would translate to a very small (1%) increase in profit, which would increase from 5036 € $ha^{-1}$ to 5100 € $ha^{-1}$ passing from WT chipping to IH. It should be kept in mind that this was the net harvesting profit, as the costs to lease the land, as well as to establish and to manage the SRC, were not taken into account.

## CONCLUSIONS

1. Integrated harvesting (IH) of short-rotation coppice (SRC) did not generate a higher profit as compared with whole tree (WT) chipping because the higher market value of the pulpwood logs did little more than offsetting the additional production cost.
2. A higher profit for IH of SRC might arise with changing market conditions, which are relatively volatile, especially when it comes to wood fuel.
3. The main advantage of IH as applied in this study is in the increased product flexibility, which may help coping with sudden market fluctuations.
4. Besides offering financial benefits, SRC remains an important management tool to improve the relationship between agriculture and environment (Verani *et al.* 2015).

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