Cost and Productivity of Harvesting High-Value Hybrid Poplar Plantations in Italy

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Abstract

As the importance of hybrid poplar plantations continues to increase, these stands may soon represent a strategic source of wood products for many temperate-region countries. Financial success from growing these plantations depends on obtaining the highest value recovery at the lowest harvest cost, which has motivated a gradual shift toward mechanized harvesting. This study compared the harvesting efficiency and cost of different harvesting procedures based on manual, semimechanized, and mechanized system configurations. Overall, 25 sites were sampled with time studies. Average site size varied between 0.3 and 2.5 hectares. Total observation time amounted to 787 hours, during which 6,449 trees were harvested. Mechanized harvesting proved significantly faster and cheaper than traditional manual harvesting, allowing an average saving of about 3 €/m^3 for the same tree size. Hence, mechanization may help maintain profitability when harvesting smaller trees, allowing companies to cope with current trends toward shorter rotations for increased cash flow. Semimechanized harvesting did not involve fewer work steps, nor was it less expensive than traditional manual harvesting; its only benefit was a substantial reduction of labor requirements. The concern about reduced value recovery is still the main obstacle to the extensive application of mechanized poplar harvesting.

Hybrid poplar (*Populus* ×*euroamericana*) plantations represent a traditional and important wood source in many European countries as well as in North America and in Asia (Heilman 1999). With about 4 million hectares worldwide, hybrid poplar plantations are still minor contributors to the global wood market, but their importance in temperate areas is rapidly increasing, and poplar may soon represent a strategic source of wood products for many countries (Verani et al. 2008). In fact, poplar plantations already play a key role in the industrial wood supply of such countries as China, France, India, Italy, and Turkey—each producing more than 1 million m^3 of poplar wood from specialized plantations (International Poplar Commission 2004).

Poplar wood has many potential uses, and even the longest rotations are short compared to those of most other trees, favoring their integration with agricultural systems (Britt 2000). Farmers perceive that a robust value-added market for poplar products may be developed, providing poplar cultivars are properly selected and managed (Cardias-Williams and Thomas 2006). In turn, the afforestation of degraded agricultural land with tree crops is an effective way to increase wood supply (Sutton 1999) and enhance environment quality (Sedjo 1999).

Selected poplar clones can produce veneer-grade logs, which represent the main target product for the French (Association forêt cellulose 2004), Italian (Hongyuan 1992), and Chinese (Ye and Wang 2003) plantations. Even where poplar was originally planted for exclusive pulp production, there is an interest in adapting the growing and harvesting systems to a more diversified product strategy (Spinelli et al. 2008). In Italy, the economic success of these plantations depends on producing the largest possible amount of top-grade veneer logs whose value can compensate for the high establishment and management costs incurred. Hybrid poplar is grown on valuable agricultural land and managed very intensively through irrigation, harrowing, and pruning during the early plantation stages. The financial viability of hardwood plantations grown under these circumstances has

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already been questioned (Venn 2005), and there is a need to maximize revenues and reduce management and harvesting costs where feasible.

Harvesting represents a major cost that could be reduced by mechanizing all operations (Spinelli et al. 2009). Poplar plantations offer very favorable conditions for mechanizing harvesting operations (Spinelli et al. 2005). However, any new harvesting procedure introduced to Italy will need to follow the mainstream cut-to-length system, where trees are processed into commercial log assortments at the stump (Cielo and Zanuttini 2004). The main reason for adopting this system is the desire to minimize the value losses that may occur during skidding as a result of the rougher handling (Favreau 1998), which is especially a concern for species with brittle wood (McNeel and Copithorne 1996), such as poplar. Breakage concerns exclude the application of whole-tree harvesting, which is popular in other hardwood plantations, such as Eucalypt (Spinelli et al. 2008) and Gmelina (Ladrach 2004). Compared with motor-manual felling and processing (i.e., felling and processing performed with a chainsaw), mechanized cut-to-length harvesting offers increased productivity and reduced production costs, which may justify rapid full-scale mechanization of the largest operations (Verani and Sperandio 2004). Nevertheless, a recent survey indicated that only 20 harvesters and processors currently work in the Italian plantations, harvesting approximately 150,000 m^3 of poplar roundwood per year, or about 10 percent of the total harvest (Spinelli et al. 2010b).

Apparently, most forest owners do not trust mechanized harvesting with extracting the maximum value from their crops (Spinelli et al. 2010a). In particular, they are afraid that the machine may not respect length tolerance, that it may damage the wood surface, and that the operator on the machine may prove unable to correctly assess stem quality, thus performing suboptimal grading. As a consequence, all mechanization levels seem to coexist in Italian poplar plantations, with variable results in terms of value recovery and cost reduction. This means that most forest landowners are still guessing what could be the best harvesting system configuration, lacking clear indications about the benefits and the limitations of each option. Solving the problem requires (1) determining the actual value recovery obtained with manual and mechanized operations and (2) determining the costs incurred by each operational choice.

The goal of this study was to determine the cost incurred by a range of felling and processing techniques used in Italian hybrid poplar plantations in order to answer the second question, namely, what is the cost saving potentially obtained through mechanized harvesting? A separate study has already been devoted to answering the first question about the eventual difference in terms of value recovery (Spinelli et al. 2010a).

This study is limited to felling, processing, and handling because these are the steps where mechanization is most common. Extraction in Italy is already mechanized, and the choice between different options depends mainly on soil conditions. If mechanized harvesting proves cost effective in Italian hybrid poplar plantations where multiple products are sorted, then forest landowners will be encouraged to apply it, and poplar cultivation may further expand. Even where motor-manual harvesting techniques are still competitive because of cheap labor, mechanization would allow streamlining production, anticipating future labor shortages (Spinelli et al. 2001) and increasing work safety (Bell 2002).

Materials

The study analyzed 25 commercial harvesting sites, collecting time-motion data about all the work steps necessary to transform standing poplar trees into manufactured logs, stacked and ready for extraction to the roadside. Study sites were scattered across northern and central Italy, covering all the main areas where Italian poplar plantations are concentrated (Fig. 1). The sample consisted of 6,449 trees grown on 21.9 hectares. Total observation time amounted to 787 hours (98 work days), during which 5,564 m^3 of poplar roundwood were produced. A complete description of the study plantations is reported in Table 1.

All stands were traditional monoclonal plantations, established at a large spacing and harvested after 10 to 23 years. The traditional Italian clone I-214 was the most represented, as it still enjoys much success in Italy and abroad. All study sites yielded up to three different veneer log grades, two different sawlog grades, and one grade of pulpwood logs or chips.

The following three system configurations were assessed: manual, mechanized, and semimechanized. The manual system included between 6 and 11 different steps, as follows. First, two or three rows of trees were directionally felled with a chainsaw while a tractor or an excavator pushed the cut tree toward the intended direction of fall (Step 1). The same tractor or excavator aligned the butts of severed trees next to each other in order to facilitate processing (Step 2). An operator would delimb them with a chainsaw (Step 3). Then a professional grader would come to the site and mark the bucking points for the veneer bolts (Step 4). The chainsaw operator would return and buck the logs to produce veneer bolts (Step 5). Veneer bolts would be stacked with an excavator, an independent loader or a loading arm fitted to a farm tractor (Step 6). The remaining trees and tree sections were indexed again with a grapple arm, and sawlogs were produced by delimbing and bucking the remaining stem portions to a minimum diameter of about 15 cm with a chainsaw (Steps 7 and 8). No professional grader was needed at this stage. Sawlogs were then stacked and the tops indexed again (Step 9). If roundwood was produced from the tops, the chainsaw operator would delimb and crosscut them to produce pulpwood logs (Step 10). These were also stacked with the same method used for the sawlogs (Step 11). Some steps could be combined, thus reducing the total count of independent phases to a minimum of six.

Mechanized harvesting was performed with a harvester head affixed to a dedicated prime mover or an excavator. In one single pass, this machine felled, delimbed, measured, bucked, and separately stacked all the different products.

In the semimechanized harvesting system, trees were felled and aligned with a feller-buncher or with the same harvester later used for manufacturing the sawlogs and the pulpwood. However, veneer logs were still produced motor manually, using a chainsaw and the assistance of a professional grader, for fear that the harvester could damage the valuable veneer logs or miss their stringent length and quality specifications. At the minimum, semimechanized harvesting consisted of the following three steps: mechanized felling and alignment, manual processing of veneer logs with a chainsaw, and mechanized processing of

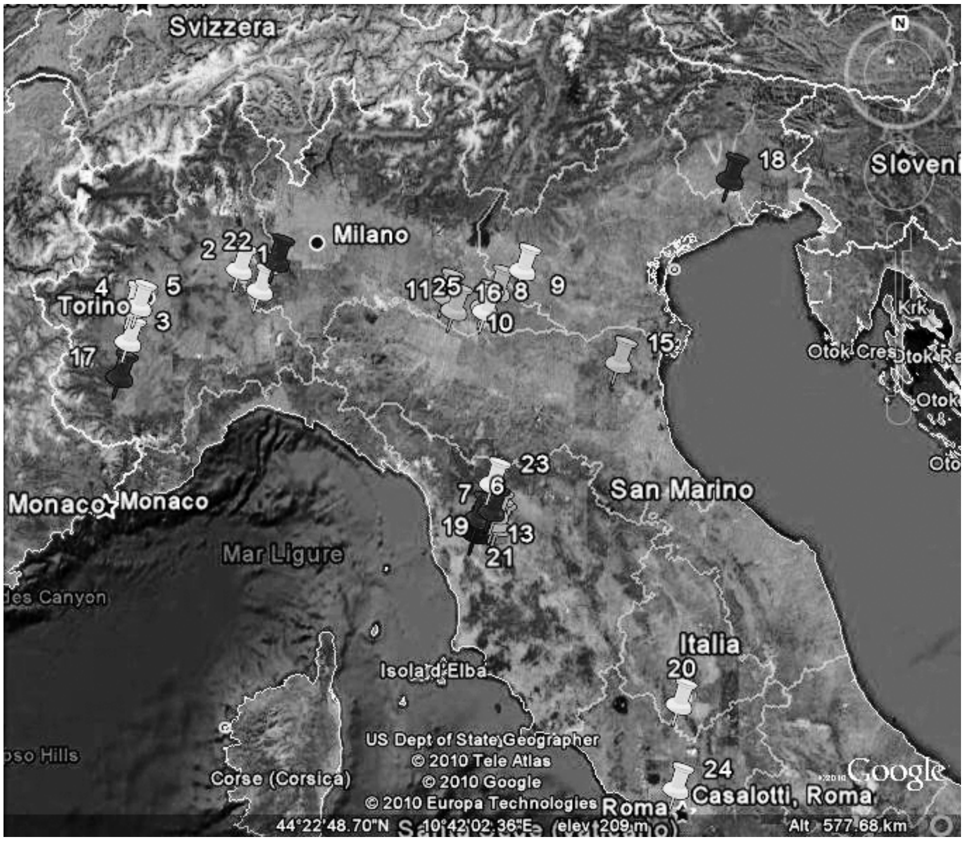

Figure 1.—Location of the harvesting sites (numbers on pins correspond to sites).

Table 1.—Summary of characteristics of the study sites.[a]

Site no.	Area (ha)	Trees (n)	Clone	Age (y)	Spacing (m)	Density (n/ha)	DBH (cm)	Volume (m^3/tree)	Harvest (m^3/ha)	Yield (m^3/ha/y)	Harvesting
1	2.25	624	I-214	18	6 by 6	278	38	1.97	547	30	Manual
2	1.09	303	I-214	11	6 by 6	278	28	0.66	183	17	Manual
3	1.77	505	I-214	16	7 by 5	286	36	1.71	489	31	Manual
4	0.56	140	I-214	15	8 by 5	250	41	2.11	528	35	Manual
5	0.40	101	I-214	19	8 by 5	250	43	2.20	550	29	Manual
6	1.17	586	I-214	11	4 by 5	500	25	0.39	195	18	Semimechanized
7	1.28	641	Avanzo	11	4 by 5	500	32	0.92	460	42	Semimechanized
8	0.53	146	Local	11	6 by 6	278	30	0.90	250	23	Manual
9	0.53	177	Adige	11	6 by 5	333	29	0.79	263	24	Manual
10	1.55	430	Boccalari	12	6 by 6	278	33	0.83	231	19	Semimechanized
11	1.44	343	I-214	11	6 by 7	238	32	0.96	229	21	Semimechanized
12	1.18	393	Avanzo	12	6 by 5	333	32	1.05	350	29	Mechanized
13	0.24	150	Local	15	4 by 4	625	23	0.48	303	20	Mechanized
14	0.35	174	I-214	11	4 by 5	500	28	0.69	347	32	Mechanized
15	0.89	211	Local	12	6 by 7	238	29	0.75	178	15	Semimechanized
16	0.61	170	Patrizia	11	6 by 6	278	29	0.70	194	18	Semimechanized
17	2.42	605	I-214	12	8 by 5	250	32	0.88	220	18	Semimechanized
18	1.37	326	I-214	13	7 by 6	238	34	0.80	190	15	Semimechanized
19	0.38	150	I-214	14	5 by 5	400	36	1.30	520	37	Mechanized
20	0.52	144	Avanzo	18	6 by 6	278	32	1.08	300	17	Manual
21	0.40	160	Neva	12	5 by 5	400	29	0.79	315	26	Mechanized
22	0.54	150	I-214	10	6 by 6	278	27	0.87	243	24	Mechanized
23	0.43	120	Local	23	6 by 6	278	39	1.75	486	21	Manual
24	0.40	110	Avanzo	18	6 by 6	278	34	1.38	384	21	Manual
25	0.36	100	I-214	12	6 by 6	278	26	0.70	195	16	Semimechanized

[a] All clones are hybrid *Populus ×euroamericana*; all volumes are inclusive of bark (outside bark); all volume figures refer to total tree volume, including branches.

sawlogs and pulpwood after veneer bolts had been stacked with the processor.

Methods

For the duration of the study, time-study data were recorded separately for each step, using stopwatches or handheld field computers running dedicated time-study software (Kofman 1995). Productive time was always separated from delay time (Björheden et al. 1995). Observations were associated with volume output (cubic meters outside bark), obtained from appropriate volume tables, after recording the diameter at breast height (DBH) of harvested trees. About 20 total tree height measurements were taken for each stand in order to produce a DBH–height curve and increase the accuracy of volume estimates. Because of the monoclonal character of study plantations, DBH and height variability was very limited, increasing the accuracy of this method.

The study evaluated 14 different professional operators, generally experienced and proficient. Each operator, however, was a potential source of individual variability, which must be taken into account when evaluating the results of the study (Gellerstedt 2002). No attempt was made to normalize individual performances by means of productivity ratings (Scott 1973), recognizing that all kinds of corrections can introduce new sources of error (Gullberg 1995) and that operator effect is indeed very difficult to control (Lindroos 2010).

Hourly machine rates for the units involved in the different harvesting steps were calculated using the method described by Miyata (1980), assuming an estimated annual usage between 500 and 1,200 scheduled machine hours (SMH), depending on machine type. These values were much lower than those typically reported for industrial operations (Brinker et al. 2002), and they were chosen to represent the reality of European plantation forestry, where plantations are fragmented and interspersed into the rural landscape. Ownership fragmentation is known to dramatically reduce machine usage and in general the profitability of forest operations (Cubbage and Harris 1986, Kittredge et al. 1996). The annual usage figures used in the study are a rounded average of the figures reported by the operators actually involved in the study. Labor cost was set to 15 €/SMH, inclusive of indirect salary costs. The costs of fuel, insurance repair, and service were obtained directly from the operators. The calculated operational cost was increased by 20 percent in order to include administration and move costs between harvest sites (Hartsough 2003), the former already capable of representing up to 10 percent of the total hourly cost (Väätäinen et al. 2006). While this may not be a very accurate way of representing administration and move costs, data are not available on their exact amount, especially for the conditions of Italian poplar harvesting. Cost calculation details are shown in Table 2. Data were analyzed with analysis of variance and regression analyses to detect significant differences and trends (SAS Institute Inc. 1999).

Results

The stands sampled in this study were all very productive, with yields between 15 and 42 m^3/ha/y (average, 24 m^3/ha/y) after 10 to 23 years (Table 1). Over 50 percent of the stands had been established with the I-214 clone, whereas traditional local clones and new clones (Avanzo, Neva, and Patrizia) both represented 25 percent of the stands. The new clones in the sample were concentrated in central Italy, whereas none of the stands sampled in the Po valley presented these clones. In fact, the tradition for poplar cultivation is strongest in the Po valley, which may explain the attachment to traditional clones. The data hint at a slightly shorter rotation and higher yield for newer clones, but differences are not statistically significant.

Table 3 shows the product breakdown obtained from the different sites. Veneer logs represented from 0 to 80 percent of the total tree mass, with average and median values of 40 and 46 percent, respectively. No correlation was found between percent veneer recovery and total tree volume ($r^2 = 0.038$), or clone category ($P = 0.228$). Analysis of variance at the 10 percent level could not detect any significant difference in the percentage of veneer recovery between the manual, semimechanized, and mechanized harvesting systems. On the other hand, manual harvesting was systematically applied to older and larger trees (1.25 m^3 roundwood per tree) than handled with either the semimechanized (0.58 m^3 roundwood per tree) or the mechanized system configurations (0.73 m^3 roundwood per tree). This difference was statistically significant (manual vs. semimechanized, $P = 0.001$; manual vs. mechanized, $P = 0.043$). No statistical difference was found in the average tree sizes harvested with the semimechanized and the mechanized system configurations ($P = 0.333$).

Table 2.—Summary of assumptions made for determining machine cost.[a]

Factors	Units	Chainsaw	Excavator	Tractor	Self-propelled loader	Excavator-base harvester	Light harvester	Medium harvester	Heavy harvester
Purchase price	€	700	80,000	65,000	130,000	200,000	300,000	385,000	430,000
Service life	years	4	10	10	10	8	8	8	8
Salvage value	% new	0	30	30	30	30	30	30	30
Depreciation	€/y	175	5,600	4,550	9,100	17,500	26,250	33,688	37,625
Annual usage	SMH	500	800	800	800	1,000	1,200	1,200	1,200
Total fixed cost	€/SMH	0.5	17.3	14.0	28.1	38.3	47.9	61.5	68.6
Repair and maintenance	€/SMH	0.4	3.5	4.6	5.7	8.8	10.9	14.0	15.7
Fuel and lubricant	€/SMH	1.0	12.1	9.0	16.6	22.6	13.6	18.1	22.6
Personnel cost	€/SMH	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Total variable cost	€/SMH	16.4	30.6	28.6	37.3	46.4	39.5	47.1	53.3
Overhead (20%)	€/SMH	3.4	9.6	8.5	13.1	16.9	17.5	21.7	24.4
Total hourly rate	€/SMH	20.3	57.4	51.2	78.4	101.6	104.9	130.3	146.3

[a] SMH = scheduled machine hours; interest rate = 8 percent; exchange rate, February 16, 2011: 1 Euro = USD 1.35; all machines are manned by one operator only.

Table 3.—Summary of the average product breakdown at the various study sites.

Site no.	Veneer (%)	Sawlogs (%)	Pulpwood (%)	Chips (%)	Harvesting system configuration
1	65	4	13	18	Manual
2	53	0	28	19	Manual
3	46	19	13	22	Manual
4	45	16	21	18	Manual
5	33	19	31	17	Manual
6	0	55	0	45	Semimechanized
7	0	55	0	45	Semimechanized
8	54	13	0	33	Manual
9	50	15	22	13	Manual
10	50	0	0	50	Semimechanized
11	51	0	36	13	Semimechanized
12	48	24	0	28	Mechanized
13	0	55	0	45	Mechanized
14	14	40	0	46	Mechanized
15	33	27	30	10	Semimechanized
16	58	9	19	13	Semimechanized
17	62	0	25	13	Semimechanized
18	47	0	17	36	Semimechanized
19	46	20	15	19	Mechanized
20	50	30	20	0	Manual
21	30	50	0	20	Mechanized
22	80	0	20	0	Mechanized
23	30	40	0	30	Manual
24	0	80	20	0	Manual
25	40	0	40	20	Semimechanized

Total felling, processing, handling, and marking time per tree was reduced two-thirds under semimechanized harvesting as compared with manual harvesting (Table 4). When harvesting was completely mechanized, total time per tree was reduced to one-sixth of manual harvesting. These differences were statistically significant. Mechanized harvesting was significantly more productive than both semimechanized and manual harvesting (Table 4). Mechanized harvesting also required fewer separate steps and incurred a much lower incidence of delay time.

The data in Table 4 indicate that the higher productivity of the mechanized harvesting system was not enough to offset its higher hourly cost. However, there was a significant difference between the average tree size handled with the different systems. Tree size has a strong effect on harvesting productivity (Holtzscher and Lanford 1997), and a more appropriate comparison should be conducted after normalizing tree size. This was obtained by regression analysis, using indicator variables to represent the semimechanized and mechanized treatments (Olsen et al. 1998). The result is presented in Figure 2, which shows the significant effect of mechanization in reducing the cost of roundwood harvesting, all along the explored tree volume range. The cost reduction obtained through mechanization amounted to about 3 €/m^3, that is, 25 to 50 percent of the original cost for both manual and semimechanized harvesting. The indicator variable for the semimechanized harvesting treatment did not prove significant ($P = 0.79$), so the application of this procedure may not reduce roundwood harvesting costs below the level common for manual harvesting. On the other hand, semimechanized harvesting allowed reducing personnel requirements to 65 percent of the level necessary for manual harvesting (Table 4), and the difference in labor intensity was statistically significant ($P = 0.02$). Full mechanization resulted in an even more dramatic fourfold reduction of labor needs compared to manual harvesting.

Table 4.—Summary of the average time spent, incidence of delays and unit cost for the three harvesting systems.[a]

Factors	Manual	Semimechanized	Mechanized
Felling (min/tree)	1.7 A	0.9 B	0.7 B
Processing (min/tree)	6.3 A	1.8 B	1.1 B
Handling (min/tree)	2.9 A	0.8 B	0.2 B
Marking (min/tree)	1.2 A	0.7 A	0.1 B
Total (min/tree)	12.1 A	4.2 B	2.1 C
Productivity (m^3/SMH)	6.3 A	8.4 A	21.1 B
Delays (% total)	29.6 A	28.7 A	13.0 B
Steps (n)	7.5 A	5.6 A	1.5 B
Financial cost (€/m^3)	5.06 A	9.19 B	5.55 A
Personnel cost (worker h/m^3)	0.21 A	0.13 B	0.05 C

[a] Productivity and cost refer to commercial roundwood only, excluding tops and branches (later chipped for biomass fuel). Different letters for average values in the same row indicate statistical significance at the 5 percent level.

Discussion and Conclusions

The study was conducted on commercial operations, hence its relatively low resolution and the capacity to highlight macroscopic differences only. Different site conditions may explain the absence of any significant differences in yields and veneer recovery rates between clones (Pinno et al. 2010): it is very likely that growers used the most suitable clone for each different site, which may have obscured differences in yield potential between clones. Besides, not all growers may have paid the same attention to tending care, thus actualizing the yield potential of their crops to different degrees.

Productivity and time-study data presented a high variability because the same treatment category grouped different operators, different machines, and different

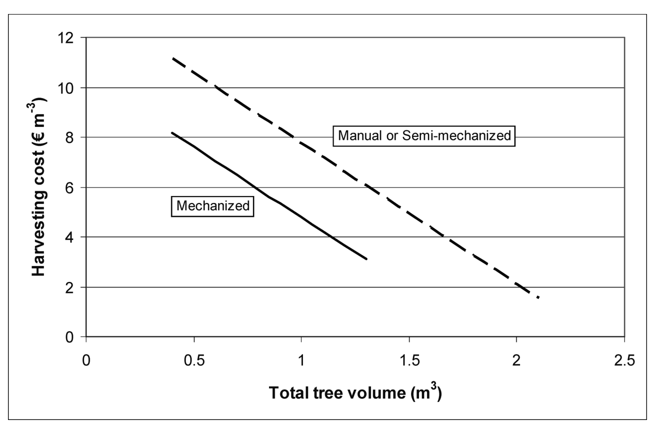

Figure 2.—Harvesting cost of roundwood as a function of tree size and level of mechanization. Harvesting cost (in €/m^3) = 13.392 − 5.637TV − 2.969MECH, where TV = average tree volume (total, including branches) in cubic meters over bark, and MECH = indicator variable (0 if harvesting is manual or semimechanized, 1 if harvesting is mechanized). $r^2 = 0.551$, $F = 13.4$, $P = 0.0002$, $N = 25$.

individual versions of the manual, semimechanized, and mechanized harvesting configurations. As a result, this study could detect only primary effects, so strong as to dominate all other sources of variability. That may also explain the static effect of system configuration, which appeared independent from tree size. In fact, during model building, we tested an interaction variable combining the effects of tree size and system configuration. This variable proved less significant than the two origin variables taken separately and lost all significance once added to them in a multiple regression, hence the decision to adopt the model in Figure 2, which was conceptually debatable yet stronger than the alternatives. Eventually, all analyses pointed at the dominant effect of mechanization level, further confirmed by the significant differences (5% level) reported in Table 4.

Mechanized harvesting was faster and cheaper than traditional manual harvesting, allowing an average saving of about 3 €/m^3 for the same tree size. It is also interesting to note that mechanized harvesting was systematically applied to smaller trees than normally harvested with the traditional manual technique. As machines are capable of handling trees with the individual size of 2 m^3 and larger, the lack of capacity is not the reason machines tended to operate on sites with smaller trees. Therefore, the systematic difference in tree size may indicate a deliberate selection of sites with larger trees on the part of manual operators, incapable of reaching adequate productivity when handling smaller trees. Labor cost in Italy is very high, and the survival of manual operations depends on their capacity to reach a very high productivity, which in the case of poplar harvesting may be possible only when trees are very large. In practice, manual operators may avoid purchasing stands with smaller trees, or mechanized operators may be specifically targeting stands with smaller trees, where they can systematically outbid manual competitors. This is the more important in the light of the current trends toward reducing the rotations of forest plantations to increase cash flow (Manley and Niquidet 2010, Pinno et al. 2010). If rotations are being shortened, tree size will be reduced, and the future of plantation forestry in industrial countries will depend on the massive introduction of mechanized harvesting.

Mechanized harvesting is also inherently simpler than manual harvesting, involving a smooth flow between different phases that are integrated in one single pass. That also explains the very low incidence of delays found in this study, with figures that closely match what was reported in a previous study (Spinelli and Visser 2008).

On the contrary, semimechanized harvesting is not significantly simpler or less expensive than traditional manual harvesting. Its only benefit is a substantial reduction of personnel, and its application may be related to the severe labor shortage experienced in Italian forestry. Semimechanized harvesting can keep the companies running even if they cannot find new recruits, but it does not reduce harvesting cost. In any case, by removing personnel from potentially dangerous occupations, semimechanized harvesting is likely to result in an increase in work safety. Hence, the concern about reduced value recovery remains the main obstacle to the extensive mechanization of poplar harvesting.

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