Strategies for the Processing of Tree Tops from Hybrid Poplar Plantations

RAFFAELE SPINELLI* AND NATASCIA MAGAGNOTTI
CNR IVALSA, Via Madonna del Piano 10, Sesto Fiorentino (FI) - Italy
**corresponding author: Tel.: +39 055 5225641, Fax.: +39 055 5225643; spinelli@ivalsa.cnr.it*
magagnotti@ivalsa.cnr.it

Spinelli, R. and Magagnotti, N. 2011. Strategies for the Processing of Tree Tops from Hybrid Poplar Plantations. *Baltic Forestry* 17(1): 50–57.

Abstract

Industrial poplar plantations represent a strategic source of wood products for many countries. Harvested after 10 to 30 years, they yield about 200 t ha^{-1} of timber and 100 t ha^{-1} industrial wood. The latter is obtained from poplar tops, which can be converted into chips, or a mix of pulpwood and chips. The study compared four options to process poplar tops. Alternatives derived from the intersection of two product strategies (pulpwood and chips, or chips only) with two pulpwood processing methods (manual or mechanized). Both mechanization and simplification (only one product) succeeded in reducing production cost, but the former had a stronger effect. The tests demonstrated that all options were cost-effective and could return some profits. However, the exclusive production of chips offered lower profits, compared to an articulate product strategy aimed at maximising value recovery. In the case of Italian poplar plantations, the price difference between pulp and chips is generally larger than the cost reduction obtained with integral chipping. Similar conclusions were reached by other authors working with spruce and beech in Central Europe. Of course, this is only true for the current price levels of pulpwood and chips: results may change, if this price balance will be altered by the growing demand for biomass fuel.

Key words: biomass, poplar, plantation, mechanization

Introduction

With about four million hectares worldwide, 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 specialised plantations (IPC 2004). Poplar wood has many potential uses, and even the longest rotations are short compared to those of most other trees, which favours their integration with agricultural systems (Britt 2000). Managed on 10 to 30 years rotations, selected poplar clones can produce veneer-grade logs, which represent the main product of the French (AFOCEL 2004), Italian (Hongyuan 1992) and Chinese (Ye and Wang 2003) plantations. In fact, the economic success of these plantations often depends on obtaining the largest possible amount of top grade veneer logs, whose value can compensate the high establishment and management costs incurred by the owners. Table 1 shows the product specifications and the current delivered price for poplar assortments in Italy.

Table 1. Assortment specifications and price of the product delivered at the user plant

Assortment Type, grade	Length m	Diameter min. cm	Acceptable defects	Price min. € t^{-1}	Price max. € t^{-1}
Veneer 1st	1.3-2.6	25-22	None	125	185
Veneer 2nd	1.3-2.6	22-20	except dry knots and cracks	95	122
Veneer 3rd	1.3-2.6	22-20	except cracks	75	100
Saw logs	2	15-18	except cracks	60	80
Pulpwood	2	10	All	50	58
Chip wood	any	any	All	35	50

Notes: all weights are considered fresh, at a moisture content commonly around 50%; Diameter is measured over bark. Chipwood = all timber processed to produce chips or chip products

Of course, no tree can be entirely processed into high-value timber products, and a part of the harvest will always consist of low-quality assortments and residues, with a potential for conversion into chipped biomass products. In fact, Italian companies have been producing industrial chips from poplar harvesting residues for at least 20 years (Spinelli and Hartsough 2001). Chipping has been introduced to poplar plantations earlier than to any other Italian forest stand, because these plantations offer very favourable conditions to mechanization, and especially easy access and industrial management (Spinelli et al. 2005). A similar process is now developing in Spain, where industrial companies are tapping poplar harvesting residues for the expanding bioenergy market (Tolosana et al. 2010). At the beginning, operators only chipped tree parts that could not be converted into any other types of commercial assortments, while trying to extract from their trees the largest possible amount of conventional round wood products. However, the steady increase of chip prices is making them wonder whether it would be best to sacrifice the lowest round wood grades to chip production. That especially applies to pulpwood logs, which take much effort to process while carrying a relatively low price. Diverting this tree portion towards the chip flow may result in a reduction of both revenue and cost, which will accrue a profit if cost decreased more than revenue. Hence the interest in determining with some accuracy the costs associated with both options, and the break-even price ratio between pulpwood and chips, below and above which one option becomes more interesting than the other. This is the goal of the study, which aims at directing poplar harvesting companies towards the most profitable product strategy under given market price conditions.

Of course, alternative tree top processing procedures must be integrated within the larger context of poplar harvesting. Italian companies harvest poplar according to the cut-to-length (CTL) system, where trees are processed into commercial log assortments at the stump site (Cielo and Zanuttini 2004). The main reason for adopting this system is the desire to minimize the value losses caused by whole-tree skidding, as a consequence of the rougher handling (Favreau 1998). This is especially harmful to those species with brittle wood such as poplar (McNeel and Copithorne 1996). Furthermore, most forest owners require that veneer logs are processed manually, under the direction of a grading specialist, because they do not trust mechanical processors with extracting the maximum value from their crops. In particular, they are afraid that mechanized processing 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 sub-optimal grading (Spinelli et al. 2010a). A recent survey indicated that only 20 harvesters and processors currently work in the Italian plantations, harvesting approximately 150 000 m^3 of poplar round wood per year, i.e. about 10 % of the annual harvest (Spinelli et al 2010b). Hence, both manual and mechanized harvesting should be considered when comparing alternative product strategies. Direct observation of sample operations allowed describing the alternative tree top processing procedures described below. These include all work steps necessary for transforming tree tops into pulpwood and/or chips, loaded onto the extraction vehicles. The four treatments on comparison derive from the intersection of two product strategies (pulpwood and chips, or chips only) with two pulpwood processing methods (manual or mechanized). They all take place at the stump site, and are described as follows:

Pulp and Chips, Manual. 1) after the forwarding of veneer and sawmill logs, poplar tops are aligned with a loader; 2) pulpwood logs are processed by two operators with chainsaws; 3) pulpwood logs are loaded onto extraction vehicles with the same loader as above; 4) residues are bunched with a bulldozer equipped with front rake, which pushes them into large piles; 5) residues are chipped, and chips are blown directly onto the extraction vehicles.

Pulp and Chips, Mechanized. 1) after the forwarding of veneer and sawmill logs, poplar tops are grabbed by a processor and manufactured into pulpwood logs. The processor can easily reach tree tops as they are, and handle them without any need for pre-bunching. Similarly, the processor leaves the residue in bunches, so that there is no need for piling them with a bulldozer and rake; 2) pulpwood logs are loaded onto extraction vehicles with a loader; 3) residues are chipped, and chips are blown directly onto the extraction vehicles.

Chips only, Manual. 1) after the forwarding of veneer and sawmill logs with manual methods, poplar tops are bunched with a loader; 2) tops are chipped, and chips are blown directly onto the extraction vehicles.

Chips only, Mechanized. 1) after the forwarding of veneer and sawmill logs with mechanical methods (which leave the tops bunched), poplar tops are chipped and chips are blown directly onto the extraction vehicles.

Materials and methods

First of all, 18 commercial operations were analyzed in order to determine the pulpwood to chip ratio deriving from the two alternative product strategies. From each operation, 20 trees were scaled with tape and calliper, and volumes allocated to different products. Volume measurements were converted into weight figures using an average density of 700 kg m^{-3} (Giordano 1986). Due to the mono-clonal character of study plantations, DBH, height and form variability were very limited, which increased the accuracy of this method.

Time-and-motion studies were conducted on sample operations in order to determine the productivity of each work step. Each sample was extracted from operations considered representative for the specific process step, based on observation of the 18 operations previously surveyed. In particular, a 13-ton excavator was chosen for the alignment of tops and the loading of pulpwood logs; two chainsaw-equipped operators for motor-manual pulpwood processing; a 20-ton excavator-base processor for mechanized pulpwood processing; a 7-ton bulldozer with front rake for residue bunching. In all these cases, repetitions were represented by individual work cycles, each corresponding to one or more tops or logs being handled, processed or loaded, depending on the specific type of work being considered. Chipping productivity was obtained from 18 commercial operations, each representing a repetition. Time consumption was recorded separately for each step, using stopwatches or handheld field computers running dedicated time-study software (Kofman 1995). Observations were associated to volume (m^3 over bark) or weight (fresh tons) output, obtained by applying an average piece volume or weight to the respective piece counts. The average piece volume or weight was estimated by scaling a sample of tops, logs and chip loads, depending on the specific operation considered. All figures were eventually transformed into fresh tonnes, using the 700 kg m^{-3} average density, reported above.

The data base represented 20 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). It order to contain operator effect, the same sample was used to represent the same operation occurring in different treatments, for instance: pulpwood log loading in the motor-manual and mechanized pulpwood treatments; tree top alignment in the motor-manual pulpwood and chip, and chip only treatments.

Hourly rates for the teams involved in the different harvesting steps were calculated with the method described by Miyata (1980), on an estimated annual usage of 1200 scheduled machine hours (SMH). These values were 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 reduce machine usage, and in general the profitability of forest operations (Kittredge et al. 1996). Labour cost was set to 15 Euro SMH^{-1}, 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% in order to include relocation and administration costs (Hartsough 2003), the former already capable of representing up to 10 % of the total hourly cost (Väätäinen et al. 2006). This is not a very accurate way of representing relocation and administration costs, but no data are yet available on their exact amounts, especially for the conditions of Italian poplar harvesting. Results are reported in Table 2.

Data were checked for normality and analyzed with parametric and non-parametric techniques, depending on the outcome (SAS 1999). Readers must note that the study was based on sampling commercial operations, and therefore lacked a strict study design to balance operational, stand or operator factors: therefore, its results should be considered indicative not definitive, and are analyzed for indications of trends.

Table 2. Costing assumptions and machine cost

Operation		Chainsaw	Excavator	Bulldozer and rake	Excavator-base processor	Tractor-mounted chipper	Self-propelled chipper
Purchase price	Euro	700	80000	50000	200000	250000	500000
Service life	years	4	8	8	8	8	8
Salvage value	% new	0	30	30	30	30	30
Interest rate	%	8	8	8	8	8	8
Fuel consumption	l SMH	0.4	8	6	15	25	35
Crew	n	1	1	1	1	2	1
Depreciation	Euro $year^{-1}$	210	7000	4375	17500	21875	43750
Annual usage	SMH	600	1200	1200	1200	1200	1200
Total fixed cost	Euro SMH^{-1}	0.5	12.8	8.0	31.9	39.9	79.8
Repair and maintenance	Euro SMH^{-1}	0.4	2.9	2.9	7.3	9.1	18.2
Personnel cost	Euro SMH^{-1}	15.0	15.0	15.0	15.0	30.0	15.0
Total variable cost	Euro SMH^{-1}	16.4	30.0	27.0	44.9	76.8	86.0
Overhead (20%)	Euro SMH^{-1}	3.4	8.5	7.0	15.4	23.3	33.2
Total	Euro SMH^{-1}	**20.3**	**51.3**	**41.9**	**92.2**	**140.1**	**199.0**

Notes: SMH = Scheduled Machine Hours

Results

All stands were traditional mono-clonal plantations, established at a large spacing and harvested after 11 to 23 years. Test stands yielded up to three different veneer log grades, two different saw log grades and one grade of pulpwood logs or chips. Stands were very productive, offering yields between 10 and 26 fresh t ha^{-1} year^{-1} (average 17.6 fresh t ha^{-1} year^{-1}).

Table 3 shows that there were no significant differences between treatments concerning average stand age, yield, tree size, total stocking and proportion of timber assortments. As an average, tree mass consisted of timber assortments (veneer and saw logs) for about 60%. The remaining 40% could all be converted into chips, or into a mix of pulpwood and chips. In the latter case, the average pulp-to-chip ratio was 60:40, and this value was taken as a reference when calculating the effect of different price and cost levels on operation profitability. The average amount of wood recovered from tree tops varied between 85 and 95 fresh t ha^{-1}.

Table 3. Characteristics of sampled operations

Test	Clone	Age	Spacing	DBH	Tree mass	Harvest	Timber		Pulpwood		Chips	
#	Name	years	m	cm	t tree^{-1}	t ha^{-1}	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%
1	Neva	12	5 x 5	29	0.55	221	177	80	0	0	44	20
2	Canadian	11	6 x 6	30	0.63	175	117	67	0	0	58	33
3	I-214	11	4 x 5	25	0.27	137	76	55	0	0	61	45
4	Avanzo	12	6 x 5	32	0.74	245	176	72	0	0	69	28
5	Boccalari	12	6 x 6	33	0.58	162	80	50	0	0	81	50
6	Canadian	15	4 x 4	23	0.34	212	116	55	0	0	96	45
7	Canadian	23	6 x 6	39	1.23	340	238	70	0	0	102	30
8	I214	11	4 x 5	28	0.49	243	132	54	0	0	111	46
9	Avanzo	11	4 x 5	32	0.64	322	176	55	0	0	146	45
10	Patrizia	11	6 x 6	29	0.49	136	91	67	26	19	18	13
11	I-214	11	6 x 6	28	0.46	128	68	53	35	28	25	19
12	Canadian	12	6 x 7	29	0.52	125	75	60	37	30	12	10
13	I-214	12	8 x 5	32	0.62	154	95	62	39	25	20	13
14	Adige	11	6 x 5	29	0.55	184	120	65	40	22	24	13
15	I-214	16	7 x 5	36	1.20	342	223	65	45	13	74	22
16	I-214	14	5 x 5	36	0.91	364	240	66	55	15	69	19
17	I-214	15	8 x 5	41	1.48	369	225	61	77	21	67	18
18	I-214	19	8 x 5	43	1.54	385	199	52	120	31	66	17
Avg. Chips only		13.1		30.1	0.61	228	143	62	0	0	85	38
Avg. Pulp + Chips		13.4		33.7	0.86	243	149	61	53	23	42	16
Mann Whitney p =		0.56		0.20	0.35	0.96	0.96	0.82	< 0.01	< 0.01	0.02	< 0.01

Notes: Clones "Adige" and "Boccalari" are also Canadian; all weights are considered fresh, at a moisture content commonly around 50%; total tree mass includes tops and branches; obviously, tests 1 to 9 refer to the conversion of tree tops into chips only, whereas tests 10 to 18 refer to the processing of tree tops into a mix of pulpwood and chips

Table 4 shows both the source data and the results obtained for chipping. All residue chipping operations adopted tractor- or trailer-mounted chippers, fed by a separate loader and manned by two operators. These machines were less powerful and productive than the industrial self-propelled chippers used for dealing with whole tops. As expected, the average piece size of residue material was much smaller (4 times) than the average piece size for whole tops. All these differences proved statistically significant.

Table 5 reports the average productivity and cost figures obtained from the field studies. Simpler tasks such as aligning, bunching and loading were more productive and less expensive than other more complex tasks.

The average values reported in Table 5 were used for composing Table 6, which shows the unit cost incurred by each of the four treatments on test, separated according to the different process stages. The upper half of the table reports raw unit cost figures, and allows quantifying the actual cost of the products obtained from each specific operation. The chipping of branches was more expensive than the chipping of whole tops, because the smaller piece size and the less efficient machinery determined a dramatic drop in chipping productivity, which was not offset by the lower hourly cost of the simpler tractor-mounted chippers. The same table seems to indicate that mechanized processing was more expensive than manual processing. However, one must consider that the mechanical processor avoided the cost of aligning the tops and of bunching the residue. Therefore, a fair comparison should weigh the cost of mechanical processing against the combined costs of aligning, manual processing and residue bunching. In that case, mechanical processing was 30 % less expensive than manual processing.

In the lower half of the same table, raw cost values have been pro-rated according to the respective incidence of different final products. This allowed estimating a final processing cost per ton of wood prod-

Table 4. Description and performance of the chipping operations

Test #	Machine Type	Power kW	Loader type	Piece size t	Productivity t SMH^{-1}	Cost € t^{-1}	Treatment Type
1	Self-propelled	383	built-in	0.167	14.2	14.1	Chips only
2	Self-propelled	383	built-in	0.231	20.0	9.9	Chips only
3	Self-propelled	383	built-in	0.171	13.7	14.5	Chips only
4	Self-propelled	380	built-in	0.180	27.0	7.4	Chips only
5	Self-propelled	346	built-in	0.167	19.2	10.3	Chips only
6	Self-propelled	440	built-in	0.164	19.5	10.2	Chips only
7	Self-propelled	380	built-in	0.140	24.4	8.2	Chips only
8	Self-propelled	346	built-in	0.130	14.5	13.7	Chips only
9	Self-propelled	346	built-in	0.129	19.1	10.4	Chips only
10	Tractor-powered	137	Tractor	0.064	9.1	15.4	Pulp + Chips
11	Tractor-powered	137	Tractor	0.056	8.1	17.3	Pulp + Chips
12	Towed	221	Excavator	0.053	8.8	15.9	Pulp + Chips
13	Tractor-powered	206	Tractor	0.052	8.9	15.8	Pulp + Chips
14	Tractor-powered	206	Tractor	0.040	8.1	17.3	Pulp + Chips
15	Tractor-powered	120	Tractor	0.036	8.7	16.1	Pulp + Chips
16	Tractor-powered	118	Tractor	0.029	6.8	20.5	Pulp + Chips
17	Tractor-powered	110	Excavator	0.029	7.1	19.7	Pulp + Chips
18	Tractor-powered	118	Tractor	0.025	9.1	15.4	Pulp + Chips
Mean Chips only		376		0.164	**19.1**	**11.0**	
Mean Pulp + Chips		152		0.043	**8.3**	**17.1**	
Mann Whitney p =		< 0.01		< 0.01	< 0.01	0.01	

Notes: All weights are considered fresh, at a moisture content commonly around 50%; piece size represents the weigh of individual pieces, not of the total top and branch part of one individual tree, as this is often divided into two or more pieces; test identification numbers are specific to the chipping study and do not necessarily match the test identification numbers for the mass breakdown study, reported in Table 3

Table 5. Productivity and cost of the different processing steps

Task Type	Equipment Type	Repetitions count	Productivity t SMH^{-1}	Productivity Std. Dev.	Production cost € t^{-1}	Production cost Std. Dev.
Aligning Tops	Excavator	17	13.8	7.2	**4.8**	2.7
Processing	Chainsaw	42	6.8	2.2	**6.9**	2.8
Processing	Processor	62	11.4	4.3	**9.3**	3.3
Loading logs	Excavator	64	20.7	0.6	**2.5**	0.1
Bunching residues	Bulldozer	8	28.1	6.7	**1.6**	0.4
Chipping residues	Tractor-mounted chipper	9	8.3	0.8	**17.0**	1.9
Chipping tops	Self-propelled chipper	9	19.1	4.6	**11.0**	2.6

Notes: All weights are considered fresh, at moisture content commonly around 50%

uct, regardless of its destination – pulp or chip. Conversion into pulpwood and chips incurred a cost of 18 and 13.9 Euro fresh t^{-1} for the manual and the mechanized option, respectively. The exclusive production of chips incurred a cost of 15.8 and 11 Euro fresh t^{-1} for the manual and the mechanized option, respectively. Hence, for the same product strategy, mechanization allowed reducing tree top processing cost between 23 and 30%. In contrast, process simplification as obtained by integral chipping only allowed a cost reduction between 12 and 20 %, for the same level of mechanization. Mechanizing and simplifying at the same time allowed for the highest cost reduction, equal to 38 %.

The last line in Table 6 shows the overall labour intensity of the four treatments on test. For the same product strategy, mechanization allowed reducing the labour intensity of tree top processing from 50 to 60%. Process simplification allowed an even more dramatic reduction, between 60 and 70 %, for the same level of mechanization. Mechanizing and simplifying at the same time reduced labour needs by factor 7.4.

Of course, potential cost reductions must be weighed against value recovery, which depends on the price of both pulpwood and chips – both highly variable. Table 7 shows the revenues obtained for different price level combinations. Adopting the more articulate pulp and chip strategy generally allows higher revenues than the exclusive production of chips. The gain ranges from 0 to 13.8 € fresh t^{-1}. Conversely, the data shown in Table 6 indicate that process simplification as obtained by integral chipping only allows a cost reduction between 2.2 and 2.9 € fresh t^{-1}, for the same level of mechanization. Hence, integral

Table 6. Unit production cost in € t-1, separated by process stage

	Pulp + Chips		Chips only	
	Manual	Mechanized	Manual	Mechanized
	Raw cost			
Aligning Tops	4.8	0.0	4.8	0.0
Processing	6.9	9.3	0.0	0.0
Loading logs	2.5	2.5	0.0	0.0
Bunching residues	1.9	0.0	0.0	0.0
Chipping residues	17.0	17.0	0.0	0.0
Chipping tops	0.0	0.0	11.0	11.0
Pro-rated cost (60% pulp: 40% residue; or 100% chips)				
Aligning Tops	4.8	0.0	4.8	0.0
Processing	4.1	5.6	0.0	0.0
Loading logs	1.5	1.5	0.0	0.0
Bunching residues	0.8	0.0	0.0	0.0
Chipping residues	6.8	6.8	0.0	0.0
Chipping tops	0.0	0.0	11.0	11.0
Total	**18.0**	**13.9**	**15.8**	**11.0**
Labour (h worker t^{-1})	0.389	0.178	0.125	0.052

Notes: costs refer to fresh tons, at a moisture content commonly around 50%; the total cost has only been calculated after prorating, as a sum of raw costs would make little economic sense

Table 7. Revenues obtained with different product strategies as a function of price levels

Price conditions	Pulp and Chip	Chip only	Difference
Lowest pulp + lowest chip	44	35	9.0
Lowest pulp + highest chip	50	50	0.0
Highest pulp + lowest chip	49	35	13.8
Highest pulp + highest chip	55	50	4.8

Notes: all figures are in € t^{-1} and refer to fresh tons, at a moisture content commonly around 50%; price levels obtained from Table 1; Difference = Pulp and chips - Chip only

chipping is profitable only if pulpwood prices drop to minimum levels.

Discussion and conclusions

The study was conducted on commercial operations, hence its relatively low resolution and the capacity to highlight macroscopic differences only. Varying site conditions may explain the absence of any significant differences in yields and timber 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.

In all cases, poplar tops represent a substantial source of wood biomass. If one excludes the portion eventually converted into pulpwood, the residue amounts to over 40 fresh t ha^{-1}, not much less than normally obtained from softwood thinnings (Kojola et al. 2005) or from softwood slash after a final cut (Nurmi 2007). What is more, poplar residue must be disposed of, because the fields are being recultivated. Hence, leaving the residue on the ground is not a viable option. Under these circumstances, chipping proves a cost-effective alternative to mulching or burning – the latter generally forbidden. In fact, this study demonstrates that chipping poplar residue always returns some profit, even with chip price at its lowest. It also confirms that productivity is higher and cost lower when chipping larger pieces with powerful machines, compared to chipping small-size wood with smaller machines (Spinelli and Magagnotti 2010). In this respect, one must notice that whole tops and residues were chipped with different machine types: more powerful for whole tops, less powerful for residues. In fact, the smaller chippers used for the residues were capable of handling whole tops, and the larger chippers used for whole tops could certainly handle the residues. If the same machines had been used to chip both material types, the comparison between alternatives may have produced different results. However, a comparison of systems based on the same chipper type might prove unrealistic, because commercial operations have already differentiated as described in this study: those who bought the large chippers generally chip whole tops, in order to maximize the potential of their newer and expensive machines. On the other hand, operators who chip residues prefer to stick with smaller chipping units, because the small size of the feedstock would prevent a larger chipper from expressing its full productive potential.

The study also shows the obvious benefits of simplification. It is well known that the cost of a given process grows with the number of steps involved, and Table 6 demonstrates that quite clearly. Fortunately, this study does something more than just demonstrating the obvious: it tries to draw a balance between the benefits of simplification and those of mechanization. Its data indicate that mechanization has a stronger effect than simplification, and entails a sharper cost reduction.

Mechanization also allows a dramatic reduction of labour needs, and its application can be interpreted as a response to the severe labour shortage experienced in Italian forestry. Mechanization can keep the companies running even if they cannot find new recruits, and it is also likely to increase work safety, by removing manual labour from potentially dangerous occupations (Bell 2002). Together with a strategic concern for cost reduction, these factors can explain the widespread interest in mechanizing hardwood operations (Salila and Kärki 2006, Spinelli et al. 2009).

The choice between alternative product strategies must weigh cost reduction against value recovery (Sadauskienė 2006). That is made especially difficult by fluctuating product prices (Spinelli and Magagnotti 2010). In the case of Italian poplar plantations, the price difference between pulp and chips is generally larger than the cost reduction obtained with integral chipping. The same conclusion was reached for adult spruce stands in Germany (Cremer and Velazquez-Marti 2007) and Denmark (Suadicani 2004). In contrast, Suadicani and Talbot (2010) found that neither option was clearly superior to the others, when thinning Danish beech. As a common denominator, all these studies indicate that the exclusive production of chips offers lower profits, compared to an articulate product strategy aimed at maximising value recovery. That does not rule out the exclusive production of chips, which can be justified by a number of reasons other than pure profit – for instance, the shortage of labour associated with the lack of capital for acquiring mechanical equipment, or the need to complete the job as quickly as possible. Of course, this is only true for the current price levels of pulpwood and chips. The growing demand for renewable fuel may determine a significant increase of chip prices, potentially reducing the profit margin of integrated pulp and chip harvesting, and opening new perspectives to integral chipping.

References

AFOCEL 2004. Memento. Nangis – France 29 pp.

Bell, J. 2002. Changes in logging injury rates associated with use of feller-bunchers in West Virginia. *Journal of Safety Research* 33: 436-471

Brinker, R., Kinard, J., Rummer, B. and Lanford, B. 2002. Machine rates for selected forest harvesting machines. Circular 295 (Revised). Alabama Agricultural Experiment Station, Auburn University, AL, USA. 32 pp.

Britt, C. 2000. Poplars: a multiple-use crop for European arable farmers. In: Poplar and willow culture: meeting the needs of society and the environment. GTR-NC-215, USDA Forest Service, St. Paul, MN, USA. 24 pp.

Cielo, P. and Zanuttini, R. 2004. la raccolta del legno nei pioppeti [Wood harvesting in poplar plantations]. *Italia Forestale e Montana* 59: 467-482 (In Italian, Engl. Summary).

Cremer, T. and Velazquez-Marti, B. 2007. Evaluation of two harvesting systems for the supply of wood chips in Norway spruce forests attacked by bark beetles. *Croatian Journal of Forest Engineering* 28, 145-156.

Favreau, J. 1998. Stem breakage during harvesting: a summary of FERIC's studies. FERIC Field Note 68, Pointe Claire, Canada. 2 pp.

Gellerstedt, S. 2002. Operation of the single-grip harvester: motor-sensory and cognitive work. International *Journal of Forest Engineering* 13: 35-47.

Giordano, G. 1986. Tecnologia del Legno [Wood Technology]. III Ed. Vol.3, UTET, Turin, Italy.

Gullberg, T. 1995. Evaluating operator-machine interactions in comparative time studies. *Journal of Forest Engineering* 7: 51-61.

Hartsough, B. 2003. Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. *Western Journal of Applied Forestry* 18: 133-142.

Hongyuan, X. 1992. The culture history and breeding strategy of poplar in Italy. *Journal of Forestry Research* 3: 95-100.

IPC 2004. The contribution of poplars and willows to sustainable forestry and rural development. Synthesis of Country Progress Reports. Working Paper IPC/3, FAO, Rome, Italy. 39 pp.

Kittredge, D., Mauri, M. and McGuire, E. 1996. Decreasing Woodlot Size and the Future of Timber Sales in Massachusetts: When Is an Operation Too Small? *Northern Journal of Applied Forestry* 13: 96-101.

Kofman, P. 1995. Siwork 3: User Guide. Danish Forest and Landscape Research Institute, Vejle, Denmark. 37 pp.

Kojola, S., Penttilä, T. and Laiho, R. 2005. First Commercial Thinnings in Peatland Pine Stands: Effect of Timing on Fellings and Removals. *Baltic Forestry* 11: 51-58.

Lindroos, O. 2010. Scrutinizing the theory of comparative time studies with operator as a block effect. *International Journal of Forest Engineering* 21: 20-30.

Mc Neel, J. and Copithorne, R. 1996. Yarding systems and their effect on log quality and recovery levels in coastal timber of British Columbia. Proceedings of Forest Products Society, Portland, Oregon.

Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. General Technical Report NC-55. Forest Service North Central Forest Experiment Station, St. Paul, MN, USA. 14 pp.

Nurmi, J. 2007. Recovery of logging residues for energy from spruce (Picea abies) dominated stands. *Biomass and Bioenergy* 31: 375-380.

Pinno, B., Thomas, B. and Bélanger, N. 2010. Predicting the productivity of a young hybrid poplar clone under intensive plantation management in northern Alberta, Canada using soil and site characteristics. *New Forests* 39: 89-103.

Sadauskienė, L. 2006. The Top Diameter Limits in Integrated Forest Fuel Procurement System: Lithuanian Case Studies. *Baltic Forestry* 12: 227-233.

Salila, T. and Kärki, T. 2006. Mechanical Hardwood Processing Potential in New EU Countries. *Baltic Forestry* 12: 192-199

SAS Institute Inc. 1999. StatView Reference. SAS Publishing, Cary, NC. p. 84-93. ISBN-1-58025-162-5.

Scott, A. 1973. Work measurement: observed time to standard time. In: Wittering, W. 1973. Work study in forestry. *Forestry Commission Bulletin* n. 47: 26-39.

Spinelli, R., Magagnotti, N., and Nati, C. 2010a. Work quality and veneer value recovery of mechanised and manual log-making in Italian poplar plantations. Manuscript accepted by *European Journal of Forest Research* on 25-11-2010.

Spinelli, R., Magagnotti, N. and Picchi, G. 2010b. Deploying Mechanized Cut-to-Length Technology in Italy: Fleet size, Annual Usage and Costs. Manuscript accepted by *International Journal of Forest Engineering* 21 (in press).

Spinelli, R. and Magagnotti, N. 2010. Comparison of two harvesting systems for the production of forest biomass from the thinning of *Picea abies* plantations . *Scandinavian Journal of Forest Research* 25: 69-77.

Spinelli, R. and Magagnotti, N. 2009. A tool for productivity and cost forecasting of decentralised wood chipping. *Forest Policy and Economics* doi. 10.1016/j.forpol.2009.10.002.

Spinelli, R., Magagnotti, N. and Nati, C. 2009. Options for the mechanized processing of hardwood trees in Mediterranean forests.*International Journal of Forest Engineering* 20: 30-35.

Spinelli, R., Nati, C. and Magagnotti, N. 2005. Harvesting and transport of root biomass from fast-growing poplar plantations. *Silva Fennica* 39: 539-548.

Spinelli, R. and Hartsough, B. R. 2001. A survey of Italian chipping operations. *Biomass and Bioenergy* 21 : 433-444.

Suadicani, K. and Talbot, B. 2010. Extracting and chipping hardwood crowns for energy. *Scandinavian Journal of Forest Research* 25: 455-461.

Suadicani, K. 2004. Industrial round-wood or fuel-chips in medium-aged Norway spruce. *International Journal of Forest Engineering* 15: 78-84.

Tolosana, E., Laina, R., Martinez-Ferrari, R. and Ambrosio, Y. 2011. Work organization and logistics for residual forest biomass harvesting in Spanish hybrid poplar plantations. *Biomass and Bioenergy* (In press).

Väätäinen, K., Asikainen, A., Sikanen, L. and Ala-Fossi, A. 2006. The cost effect of forest machine relocations on logging costs in Finland. *Forestry Studies* 45: 135-141

Verani, S., Sperandio, G.,Picchio, R., Spinelli, R. and Picchi, G. 2008. Field Handbook – Poplar Harvesting. International Poplar Commission Working Paper IPC/8. Forest Management Division, FAO, Rome.

Ye, K. and Wang, J. 2003. Processing and utilization of poplar wood from plantations. *China Wood Industry* 17: 5-7 (In Chinese, Engl. Summary).

Received 05 January 2011
Accepted 05 April 2011

СТРАТЕГИИ ДЛЯ ОБРАБОТКИ ДЕРЕВА ВЕРШИНЫ ИЗ ГИБРИДНЫХ ТОПОЛЕЙ ПЛАНТАЦИИ

R. Spinelli и N. Magagnotti

Резюме

Промышленные плантации тополя представляют стратегический источник древесины для многих стран. Заготовленные после 10 до 30 лет, они дают около 200 т / га-1 древесины и 100 т / га-1 промышленной древесины. Последнее получается, вершины тополя конвертируя в щепу или сочетая древесную массу и щепу. Проведены исследования по сравнению четырех вариантов переработки вершин тополей. Альтернативы получены при пересечении двух стратегий продукции (древесной массы и чипсов, или только чипсов) с двумя методами обработки древесной массы (ручной или механизированной). В обоих случаях механизации и упрощения (при только одном продукте) удалось снизить себестоимость продукции, но предыдущее имело более сильный эффект. Испытания показали, что все параметры были экономически эффективными и могут вернуть некоторую прибыль. Однако эксклюзивное производство щепы дает более низкую прибыль по сравнению с явно выраженной стратегией продуктов, направленной на максимизирование возвращения прибыли. В случае итальянских плантаций тополя, разница в цене древесной массы и щепы, как правило, больше, чем сокращение расходов, полученных при интегральной обработке. Аналогичные выводы были сделаны и другими авторами работ по ели и буку в Центральной Европе. Конечно, это верно только для текущего уровня цен древесной массы и щепы: результаты изменятся, если эта цена будет изменена в соответствии с растущим спросом на биотопливо.

Ключевые слова: биомасса, тополь, плантация, механизация