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Comparing Terrain and Roadside Chipping in Mediterranean Pine Salvage Cuts

Enrico Marchi, Natascia Magagnotti, Lisa Berretti, Francesco Neri, Raffaele Spinelli

Abstract – Nacrtak

In central Italy, the increasing demand for fuel chips and the epidemic spread of maritime pine bast scale have favored the development of large-scale industrial logging operations. After years of extensive commercial trials, local operators have developed their own industrial harvesting systems, through a wise mix of Scandinavian and North American methods. The result is original and effective, and allows keeping harvesting cost below 20 € gt^{-1}. The study compared terrain chipping with roadside chipping, as applied to the coastal pine stands of Tuscany. Under the conditions of our study, roadside chipping was over four times more productive than terrain chipping, and it allowed reducing harvesting cost by one third (12.3 vs. 18.3 € gt^{-1}). Despite the intense use of diesel, total fossil energy inputs accounted for less than 3% of the potential energy in the wood chips. Terrain chipping and roadside chipping yielded 36 and 47 times the energy they used, respectively. The coexistence of the two systems was most interesting. The harvesting systems described in the study perform best in clear-cuts, but they can also work in partial cuts, including thinning operations. They are actually used in thinnings in the same Regional Park of San Rossore, although their productivity is lower than in clear-cuts.

Keywords: biomass, logistics, productivity, economics, salvage cuts, Mediterranean

1. Introduction – *Uvod*

Many studies forecast a significant increase in the use of energy biomass over the coming years (Berndes et al. 2003), and the forest industry is already exploring this new growing market. Biomass harvesting does add to the complexity of forestry, but it also offers a significant opportunity to increase efficiency, raise value recovery and reduce logging and management costs (Björheden 2000). The recovery of forest biomass generally requires some form of processing – chipping or bundling – aimed at increasing the density and the homogeneity of the feedstock (Spinelli and Magagnotti 2009). Under ideal access conditions, the biomass can be chipped in the stand, and chips rather than trees can be extracted to the roadside landing (Kalaja 1984): among other things, direct delivery of chip loads to the roadside reduces the landing space requirements, and makes this system most suited to the situations where the forest infrastructure is poor or fragmented (Kofman 1993). However, terrain chipping requires dedicated equipment, often smaller and less productive compared to truck or trailer mounted chippers, working at the roadside. Furthermore, chipping at the roadside allows dumping the chips directly into the trucks, which avoids the additional cost of loading onto transportation vehicles. These benefits of roadside chipping may offset the higher cost of extracting bulky uncomminuted residues. On the other hand, both systems are faced with interaction delays, which occur between the chipper and the chip extraction fleet in the case of terrain chipping, and between the chipper and the transportation fleet in the case of roadside chipping (Spinelli and Visser 2009).

When choosing between these two options, one is confronted with two conceptual problems: point of comminution and economy of scale (Björheden 2008). These problems are exacerbated in industrial operations, due to the massive material flow, the high operating costs and the reduced operational flexibility. Industrial logging operations are increasingly popular in Central Italy, favored by a large biomass demand and the urgent need for extensive salvage logging, consequent to the epidemic spread of maritime pine bast scale (*Matsucoccus feytaudi*). This is a specific pest of Maritime pine that is endemic in the Iberian Peninsula and southwestern France, and invasive in southeastern France, Italy and Corsica, where it is causing large scale forest damage (Kerdelhué and Decroocq 2006). Despite the rapid evolution of pest management techniques, clearcutting of infected forests is still the most common control measure applied to most cases, and especially in central Italy (Brockerhoff et al. 2006). Clear-cutting is also applied to overmature umbrella pine plantations, which are very common along the Tuscan coastline (Barbero et al. 1998). These stands were planted about a century ago and are now old, weak and increasingly vulnerable to sea winds (Cantiani e Scotti 1988). The mainstream silvicultural prescription is again clear-cutting, followed by replanting or by re-naturalization if the quality of the hardwood understory is good (Zerbe 2002)

In turn, large clear-cuts have favored the introduction of heavy industrial machinery, which performs best under such conditions. This has resulted in a steady reduction of supply costs, and a parallel search for operational optimization. Large and expensive operations are especially vulnerable to poor planning, and their managers are especially keen on finding the best deployment strategy. After all, harvesting and transportation cost can represent approximately 70% of the total biomass cost (Panichelli and Gnansounou 2008), and today this cost represents one of the most important barriers to the increased use of biomass (Rentizelas et al. 2009). In Tuscany, salvage harvesting operations have been optimized to a point that the Tuscan enterprises can afford ferrying their biomass across the Mediterranean sea to Sardinia, for co-firing in a large power station. This would not be possible unless harvesting incurred a very low cost. Until now, most operators adopted terrain chipping with heavy industrial units, and that seemed to be the key to their enduring success. However, one operator has recently introduced an even more powerful truck-mounted chipper for chipping at the roadside, turning upside down the mainstream operational philosophy of the region. That is a radical innovation, and the large size of the new machine has raised many questions. The international literature can offer little support, due to the very large size of these machines, and to their deployment in the middle of the Mediterranean basin, where few people are credited with much experience of large scale mechanized harvesting operations, except perhaps for the Tuscan entrepreneurs (Spinelli et al. 2009a).

The goal of this study is to provide a quantitative comparison of terrain and roadside chipping operations, conducted with very powerful chippers under the conditions of industrial clear-cutting in a Mediterranean environment. Such comparison spans over the whole operation – from standing tree to chips loaded on the trucks – and includes both technical and economical aspects, as represented by productivity, workplace time allocation and harvesting cost per unit product. Sensitivity analysis is used to refine the comparison, by gauging the effect of varying conditions on harvesting cost, for both systems.

2. Material and Methods – *Materijal i metode*

The trials were conducted near Pisa, Italy, inside the Regional Park of San Rossore, which encloses a surface of about 3,000 hectares (ha) and is in large part covered by pine plantations (Spinelli et al. 2009b).

The trial took place during commercial harvesting of two different woodlots, both in flat even ground. Terrain chipping was applied to a 120 years old umbrella pine (*Pinus pinea* L.) plantation, over-mature and declining. In contrast, roadside chipping was applied to an 80 years old maritime pine (*Pinus pinaster* L.) plantation, with severe pine bast damage. Both stands were clear-cut, using 27-ton JD 759J swing-to-tree tracked feller-bunchers. These machines worked well ahead of the chippers, felling, separating the basal logs and bunching tops, large branches and small trees in big piles. The feller-bunchers also broke large branches, in order to facilitate forwarding and chipping. Hence, field conditions for chipping were quite similar in both stands, despite the different age and species. The actual concentration

Fig. 1 Terrain chipping operation: forwarder-mounted chipper and chip shuttle

Slika 1. *Iveranje u sastojini: forvarder opremljen iveračem i vozilo za transport ivera* of energy biomass was not measured, but was estimated to 80% of the total harvest, or 250 green tons (gt) ha^{-1}, based on earlier studies of the same sites and operations (Spinelli et al. 2002). This estimate accounted for both operations, since the amount of residue left on site appeared very similar. Besides, the quoted earlier studies covered both stand types and found little difference between them, at least in terms of quantity and size of residue biomass.

The terrain chipping operation was very simple, with a forwarder-mounted chipper blowing chips directly into chip shuttles (Suadicani 2003). Compared to the classic Danish example, the Italian version used a bigger chipper and simpler shuttles (Fig. 1). The chipper was an Erjo 12/90 model, powered by a 430 kW independent engine and mounted on a John Deere JD1410 D forwarder. The chip shuttles consisted of two 128 kW Valtra T161 farm tractors, each pulling a large silage trailer, with a capacity of 22 and 30 m^3. The terrain chipper did not carry its own built-in container, and blew chips directly into the tractor trailers. Once full, the trailers were driven to a large paved landing about 2 km away, and their content was dumped on the ground for subsequent loading on trucks. The chipping operation was manned by two operators only, one on the chipper and the other taking turns on the tractors, alternatively parking the empty trailer under the chipper and driving the full one to the landing. If the chipper had to move to a new stack, the chipper driver would first drive the chipper to its new work station, then dismount, move the shuttle and finally climb back onto the chipper cab to resume chipping. Chips would be loaded into open-top chip vans with a 20-ton Liebherr 904 excavator, equipped with a clam bucket and a high-raise cab. This system was introduced to the region 10 years ago and is now the most common, with about 7 operations running the same way. Local operators know its potential and limits, and have refined its application over the years.

The roadside chipping operation was more complex, involving more units and a significantly higher investment. Three 14-ton JD 1410 forwarders were used to move uncomminuted energy biomass to a roadside landing, about 150 m from the centre of the woodlot. Here the biomass was chipped with an Erjo 15/120 drum chipper, powered by two 515 kW engines, for a 1030 kW total delivered power (Fig. 2). The chipper was mounted on a semitrailer and relocated using a truck tractor. It was fed by a modified 26-ton Liebherr 924 excavator, with a log grapple and a high-raise cab. The chips were blown directly into open top chip vans, so that separate re-loading was not necessary. A chip shuttle of the type described above was parked by the chipper and used as a surge bin, if trucks were delayed (Blair 1998). Once full, the chip shuttle would be driven to the landing used for the terrain chipping operation, whence the chips could be reloaded on trucks using the clam-bucket. This operation was manned by four operators, three on the forwarders and one on the excavator. The latter would also operate the chipper, using a remote control.

Fig. 2 Roadside chipping operation: the heavy chipper filling a chip van

Slika 2. *Iveranje na stovarištu: teški iverač puni kamion iverom*

Both operations were owned and managed by the same main contractor, so that company policy and manager skills would not change between treatments. Both systems worked hot-deck, with limited buffers between the chipping and the extraction units (Han et al. 2004). Both chippers were equipped with the standard bar screen, designed for producing industrial chips.

All operators included in the study were experienced professionals, who knew their job and equipment, and had at least 5 years of experience with the type of machine they were using. The only exception was the operator of the roadside chipper, whose machine had been commissioned one year earlier. However, he was a very experienced chipper operator, who had run industrial chippers for over 20 years.

In order to determine productivity and workplace time distribution, we carried out a typical time and motion study (Bergstrand 1991). The study focused on the chippers, considered as the pivotal element of the chipping operation. Chip shuttles, forwarders and the excavator-base loader were considered as auxiliary to the chippers, and their hourly cost was simply added to the hourly cost of the chippers they served. If machine unbalance affected the chipper, this would be reflected by the presence of chipping delays. If that affected the auxiliary units, the study would not detect it, but these units were already accounted for their full cost, regardless of whether they worked full time or not. We also conducted a separate study at the landing in order to determine the productivity and the cost of loading. In all cases, a full chip load (chip shuttle or chip van) was considered as a full work cycle.

Each cycle was stop watched individually, using a conventional 3-watch time-study board (Picchio et al. 2009). Productive time was separated from delay time (Björheden et al. 1995), but all delays were included in the study, and not just the delays below a certain duration threshold, because such practice may misrepresent the incidence of downtime (Spinelli and Visser 2008). However, delays generated by the study itself were separated and removed from the data sets. The incidence of delays was represented by the delay factor (DF), i.e. the ratio of delay time to net work time. Contrary to the incidence of delays over total time, a DF has no internal correlation and is easier to generalize.

The output was estimated by measuring the volume of all chip shuttles and chip vans, and by taking all chip vans to the certified weighbridge installed at the Park gate and used by the forest owner to quantify the sale. The bulk density figure obtained from the chip vans was then applied to the chip shuttles, converting all output into weight figures. Twenty 1-kg chip samples were randomly collected from each test and taken to the laboratory: half of the samples were used for determining moisture content according to the European standard CEN/TS 14774-2, and half for determining particle size distribution according to the European Standard CEN/TS 15149-1. Although

Table 1 Costing assumptions and machine cost, excluding labor
Tablica 1. *Pretpostavke troškova i trošak stroja, ne uključujući trošak radnika*

Machine *Radni stroj*	Type *Vrsta*	Terrain chipper *Iverač u sastojini*	Chip Shuttle *Vozilo za dopremu ivera*	Forwarder *Forvarder*	Roadside chipper *Iverač na stovarištu*	26-t loader *26-tonski utovarivač*	20-t loader *20-tonski utovarivač*
	Model *Model*	Erjo 12/90	Valtra 161	JD 1410D	Erjo 15/120	Liebherr 924	Liebherr 904
Purchase price *Nabavna cijena*	€	500000	120000	320000	1000000	140000	110000
Economic life *Radni vijek*	Years *Godine*	10	10	10	10	10	10
Resale value *Preprodajna vrijednost*	% new *% novog*	25	33	25	25	25	33
Interest rate *Kamatna stopa*	%	5	5	5	5	5	5
Fuel consumption *Potrošnja goriva*	l SMH^{-1}	35	10	20	110	15	15
Depreciation *Amortizacija*	€ year^{-1} € god^{-1}	37500	8040	24000	75000	10500	7370
Annual use *Godišnja iskorištenost*	SMH	1500	1500	1500	1500	1500	1500
Total fixed cost *Ukupni fiksni troškovi*	€ SMH^{-1}	38.3	8.7	24.5	76.5	10.7	12.0
Fuel & lubricant *Trošak goriva i maziva*	€ SMH^{-1}	50.1	14.3	28.6	157.3	21.5	21.5
Repair & maintenance *Troškovi popravaka i održavanja*	€ SMH^{-1}	12.5	1.9	5.6	17.5	2.5	2.6
Total variable cost *Ukupni varijabilni trošak*	€ SMH^{-1}	62.6	16.2	34.2	174.8	24.0	24.1
Overhead (20%) *Opći troškovi*	€ SMH^{-1}	20.2	5.0	11.7	50.3	6.9	7.2
Total cost *Ukupni troškovi*	€ SMH^{-1}	**121.1**	**29.9**	**70.4**	**301.6**	**41.6**	**43.3**

Note: costs in Euro (€), as on July 26th, 2011. 1 € = 1.44 US Dollars; SMH = Scheduled Machine Hours, including delays (e.g. workplace time)
Napomena: cijene su u eurima (€) za 26. srpnja 2011. 1 € = 1,44 američka dolara; SMH = planirani sati rada stroja, uključuju prekide rada (vrijeme na radnome mjestu)

Table 2 Total operation cost, including labor
Tablica 2. *Ukupni troškovi rada stroja s uključenim troškom radnika*

Operation *Radni zahvat*	Terrain Chipping *Iveranje u sastojini*		Roadside chipping *Iveranje na stovarištu*		Loading *Utovar*	
	n	€ SMH^{-1}	n	€ SMH^{-1}	n	€ SMH^{-1}
Terrain chipper *Iverač u sastojini*	1	121.1	0	0.0	0	0.0
Chip shuttle *Vozilo za dopremu ivera*	2	59.8	1	29.9	0	0.0
Forwarder *Forvarder*	0	0.0	3	211.2	0	0.0
Roadside chipper *Iverač na stovarištu*	0	0.0	1	301.6	0	0.0
26-t loader *26-tonski utovarivač*	0	0.0	1	41.6	0	0.0
20-t loader *20-tonski utovarivač*	0	0.0	0	0.0	1	43.3
Crew *Radna skupina*	2	40.0	4	80.0	1	20.0
Total ***Ukupno***		**220.9**		**664.3**		**63.3**

Note: SMH = Scheduled Machine Hours, including delays (e.g. workplace time)
Napomena: SMH = planirani sati rada stroja, uključuju prekide rada (vrijeme na radnome mjestu)

this analysis separated the classic six size classes (< 3, 3 – 16, 16 – 45, 45 – 63, 63 – 100 and > 100 mm), we grouped classes into three main functional categories to make interpretation easier. These were: oversize (> 63 mm), accepts (3 – 63 mm) and fine (< 3 mm) particles.

Machine costs were calculated with the method described by Miyata (1980), over costing assumptions provided by the contractor himself. Fuel consumption was determined by recording the quantities of diesel added to the tanks during the trials, as well as the tank levels at the beginning and at the end of the trials. The calculated operational cost was increased by 20% in order to include relocation and administration costs, the former already capable of representing up to 10% of the total machine cost (Väätäinen et al. 2006). Further detail on cost calculation is shown in Table 1. Table 2 reports the total cost of each operation, and includes labor cost, estimated to 20 € hour^{-1} inclusive of all taxes and benefits.

The actual harvesting cost was calculated as the sum of felling, extraction, chipping and loading. As to chipping and extraction, the unit cost was obtained by dividing the system costs reported in Table 2 by the respective system productivities. The loading cost was obtained by dividing loader cost by loader productivity. The resulting figure was added entirely to the cost of the terrain chipping system, where all chips had to be re-loaded on chip vans. With roadside chipping, we calculated the percent of chips blown in the surge bins, and used this figure to pro-rate the cost of loading for the roadside system. The cost of felling and bunching was obtained from the contractor, and resulted to be 2.2 € gt^{-1}. This figure excludes the separation of butt logs, as this cost is fully charged to the round wood product. Felling and bunching cost was added equally to both treatments, in order to calculate the total harvesting cost, from standing tree to chips on the chip van.

Both direct and indirect fossil energy consumption were estimated, with the exclusion of manual work. Direct energy inputs were estimated by multiplying the measured diesel consumption by its energy content of 37 MJ l^{-1} (Bailey et al. 2003), and then inflating this value by 1.2 in order to account for the additional fossil energy consumed in the production and transportation of diesel fuel (Pellizzi 1992). Indirect energy inputs incurred during machine manufacturing, repair and maintenance were estimated as 30% of direct energy consumption (Mikkola and Ahokas 2010). The heating value of conifer chips was assumed to be equal to 20 MJ dry kg^{-1} (Spinelli et al. 2011)

The Mann-Whitney non-parametric comparison test was used to check the statistical significance of differences between treatments (SAS 1999). Non-parametric statistics were adopted, since data distribution deviated from normality.

The study on terrain chipping lasted 29.3 workplace hours, during which the terrain chipper produced 57 loads, or 446 gt. The study on roadside chipping covered 22.5 workplace hours, during which the chipper produced 51 loads, or 1281 gt. Finally, the study on loading lasted 11.1 workplace hours, during which the loader filled 17 chip vans, for a total of 476 gt.

3. Results – *Rezultati*

Table 3 shows how the loading and felling costs were calculated. As an average, the loader took about 20 minutes to fill a chip van: 10 more minutes were needed to cover the load and tie the tarpaulin, so that the average terminal time of a chip van was 30 minutes, excluding delays. Chip van delays were not quantified with this study, but loader delays were, and they added about 38% to net time consumption. About three quarters of the loader delays consisted in waiting idle for a new chip van to show up. While all the chips produced by the terrain chipping operation were dumped on the ground and had to be loaded, only 10% of those produced by the roadside operations had to be dumped on the ground, because directed to the surge bin, which could not be dumped directly into a truck. The remaining 90% was blown directly into the chip vans and required no separate loading. Hence the additional loading cost for the roadside chipping operation was 10% of the full loading cost, i.e. 0.15 € gt^{-1}.

Table 4 shows the productivity of the two chipping operations, the total harvesting cost and its breakdown by process step. Under the conditions of our study, roadside chipping was over four times more productive than terrain chipping, and it allowed reducing harvesting cost by one third. Once up and running, the powerful roadside chipper could process over 100 green tons of chips per hour, filling a chip van in less than 20 minutes. Productivity remained exceptional even after including all accessory work time and delays, the latter adding over 30% to net time consumption (chipping + accessory work time). The graphs in Fig. 3 show the higher incidence of delays for the roadside chipping operation. A large proportion of the roadside chipper delays is related to the higher maintenance needs. In contrast, terrain chipping is less affected by delay time. Here, moving between stacks and repeated parking of the chip shuttles are the main elements limiting productivity. The incidence of waiting times is small with both systems. Given the recent introduction of the new roadside chipping system, further improvements may be expected as a consequence of technological learning (Junginger et al. 2005).

As expected, chipping and extraction were the most expensive process steps, accounting for 80% of the total harvesting cost. Felling and bunching represented between 12 and 17% of the total harvesting cost. Loading had a minor yet significant impact.

The detailed time study allowed checking the cost effect of placing a surge bin by the roadside chipper (Table 5). Without a surge bin, extraction, chipping and loading cost would have increased by 3.2%, i.e. 0.33 € gt^{-1}.

Both operations used large amounts of fuel, with the roadside chipper burning over 100 l of diesel per hour. Fuel cost represented 31% and 36% of the total harvesting cost for terrain chipping and roadside

Table 3 Calculating the additional cost of loading and felling
Tablica 3. *Obračun dodatnih troškova utovara i sječe*

Operation *Radni zahvat*		Terrain chipping *Iveranje u sastojini*	Roadside chipping *Iveranje na stovarištu*
Loading net productivity *Neto proizvodnost utovara*	gt PMH^{-1}	59.2	59.2
Loading gross productivity *Bruto proizvodnost utovara*	gt SMH^{-1}	43.0	43.0
Delay Factor for loading *Udio općih vremena pri utovaru*	%	37.7	37.7
Loading cost *Trošak utovara*	€ gt^{-1}	1.5	1.5
% mass loaded *Masa ivera ispuštena na tlo, pa utovarena, %*	%	100	10
Cost of loading *Dodatni trošak utovara*	€ gt^{-1}	1.5	0.1
Cost of felling *Trošak sječe*	€ gt^{-1}	2.2	2.2

Notes: PMH = Productive Machine Hours, excluding delays; SMH = Scheduled Machine Hours, including delays (e.g. workplace time)
Napomena: PMH = pogonski sati rada stroja bez prekida rada; SMH = planirani sati rada stroja s prekidima rada

Table 4 Chipper productivity and total harvesting cost
Tablica 4. *Proizvodnost iverača i ukupni troškovi pridobivanja ivera*

Operation *Radni zahvat*		Terrain chipping *Iveranje u sastojini*	Roadside chipping *Iveranje na stovarištu*	*p*
Observations *Broj opažanja*	N	57	51	
Load size *Veličina tovara*	gt t (svježega ivera)	7.8	25.1	< 0.0001
Moisture content *Udio vlage*	%	49.3	48.8	0.6831
Chipper productivity *Proizvodnost iverača*	gt chip only hour^{-1} bt *ivera* h^{-1}	23.3	111.1	< 0.0001
Net operation productivity *Neto proizvodnost radnoga zahvata*	gt PMH^{-1}	16.7	90.9	< 0.0001
Gross operation productivity *Bruto proizvodnost radnoga zahvata*	gt SMH^{-1}	15.2	66.7	< 0.0001
Delay factor for chipping *Udio općih vremena pri iveranju*	%	10.7	32.4	0.5333
Unit production cost *Jedinični trošak proizvodnje*	€ gt^{-1}	**18.3**	**12.3**	< 0.0001
Felling cost *Trošak sječe*	% of total cost *% udio u ukupnim troškovima*	12.0	17.8	
Chipping & Extraction cost *Troškovi iveranja i privlačenja drva*	% of total cost *% udio u ukupnim troškovima*	79.9	81.0	
Loading cost *Trošak utovara*	% of total cost *% udio u ukupnim troškovima*	8.1	1.2	

Notes: PMH = Productive Machine Hours, excluding delays; SMH = Scheduled Machine Hours, including delays (e.g. workplace time); *p* = significance of differences between the average values for terrain and roadside chipping as resulting from the Mann-Whitney non parametric test, conducted at the 5% level.

Napomena: PMH = pogonski sati rada bez prekida rada; SMH = PPS planirani sati rada stroja s prekidima rada; p (signifikantna razlika) = značajnost razlike između prosječnih vrijednosti iveranja u sastojini i na stovarištu određivana je Mann-Whitneyevim neparametarskim testom provedenim na razini od 5 %.

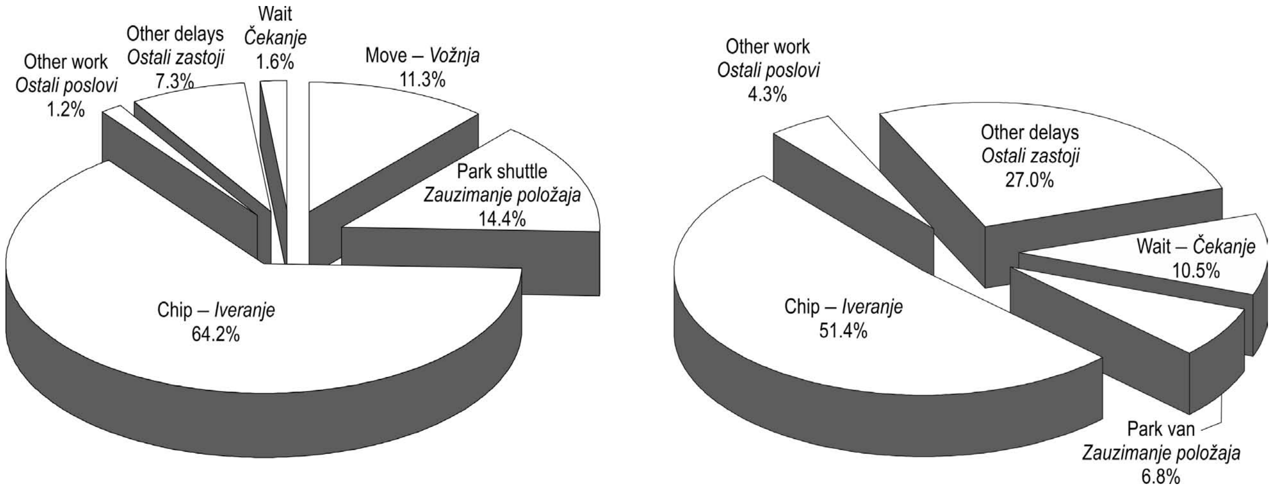


Fig. 3 Breakdown of chipper workplace time for terrain chipping (left) and roadside chipping (right)
Slika 3. *Podjela radnih zahvata iverača u sastojini (slika lijevo) i na pomoćnom stovarištu (slika desno)*

chipping, respectively. This justified the concern for the effect of diesel price on harvesting cost, given the ever increasing fuel prices. Fig. 4 shows the results of a sensitivity analysis, tying total harvesting cost to fuel price. If fuel price increased over 50% and passed from the base 1.3 € l^{-1} assumption to a maximum 2 € l^{-1}, harvesting cost would increase by 22 and 25% for terrain chipping and roadside chipping, respectively. Total harvesting cost would still be limited and below 23 € gt^{-1}, in the worst case.

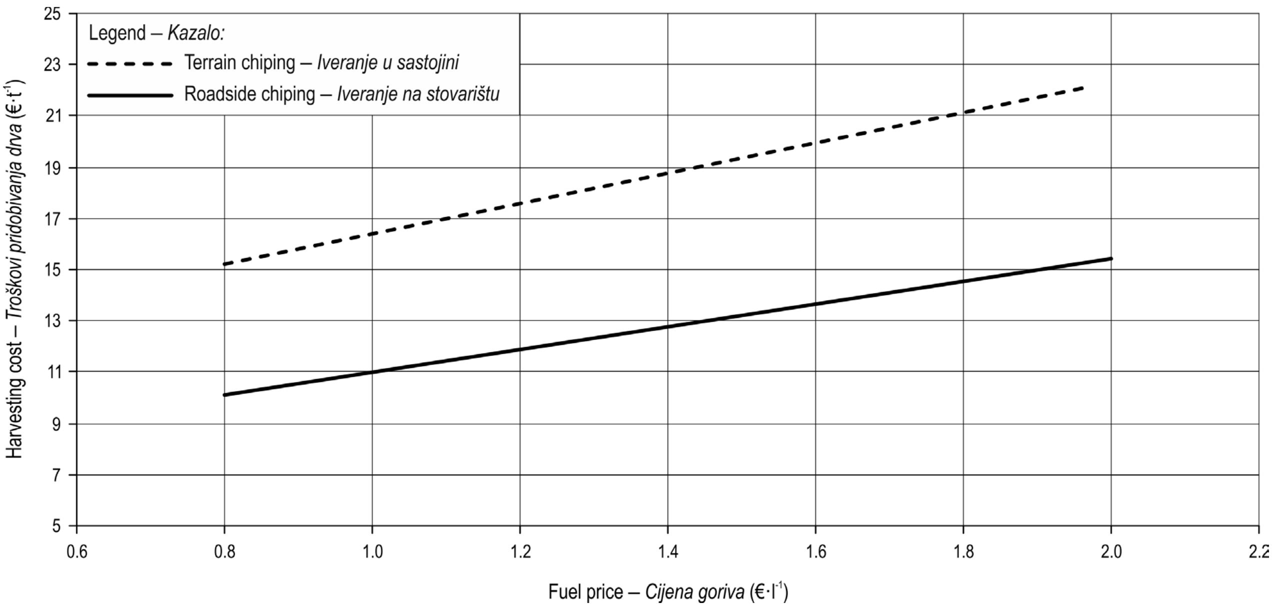
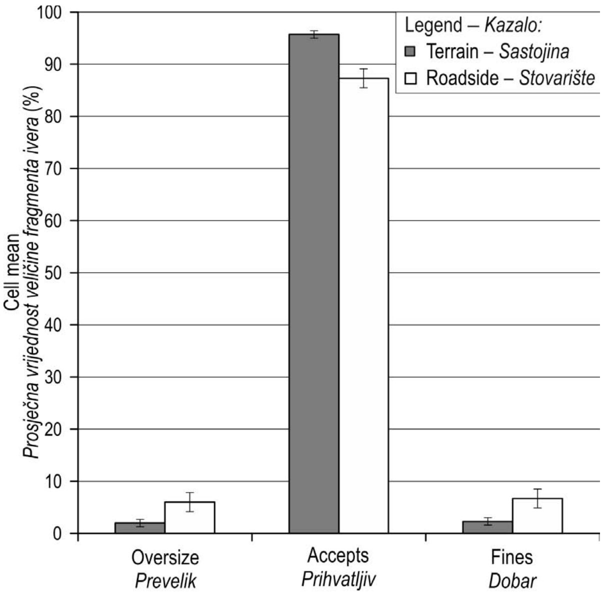


Fig. 4 Sensitivity of harvesting cost to diesel fuel price
Slika 4. *Osjetljivost troškova pridobivanja drva s obzirom na kretanje cijene dizelskoga goriva*

Table 5 Impact of a surge bin on roadside chipping cost
Tablica 5. *Utjecaj korištenja lomilice na troškove iveranja na pomoćnom stovarištu*

Surge bin ***Lomilica***		**Yes** ***Da***	**No** ***Ne***
Felling & extraction rate *Cijena sječe i privlačenja*	€ SMH^{-1}	664	634
Felling & extraction productivity *Proizvodnost sječe i privlačenja*	gt SMH^{-1}	66.7	60.8
Felling & extraction cost *Troškovi sječe i privlačenja*	€ gt^{-1}	9.96	10.43
Loading cost *Trošak utovara*	€ gt^{-1}	0.15	0
Total cost *Ukupni troškovi*	€ gt^{-1}	10.11	10.43
Cost increment *Uvećanje troškova*	€ gt^{-1}	-	0.33
Cost increment *Uvećanje troškova*	%	-	**+3.2**

The intense use of fossil fuel remains a concern with respect to energy efficiency, even if harvesting cost is kept within reasonable bounds. Hence the energy balance drawn in Table 6. Fossil energy inputs are 554 and 423 MJ odt^{-1} for terrain and roadside chipping, respectively. About half of the total fossil energy inputs derive from chipping, whereas felling, bunching extraction and loading represent the other half. In any case, total fossil energy inputs account for less than 3% of the potential energy in the wood chips. Terrain chipping and roadside chipping yield 36 and 47 times the energy they use, respectively.



Note: Oversize =>63 mm; Accepts 3-65 mm; Fines =<3 mm. Spacers on top of bars represent the 95% confidence interval bounds
Bilješka: Preveliki fragment =>63 mm; Prihvatljiva veličina fragmenta ivera od 3 do 65 mm; dobra veličina =<3 mm. Fiksatori na vrhu stupaca predstavljaju 95 %-nu pouzdanost granice intervala

Fig. 5 Particle size distribution (%) of chips obtained with the two systems (n = 20)
Slika 5*. Postotni udio veličine čestica ivera dobivenih na oba načina (n = 20)*

Fig. 5 shows the particle size distribution of chips produced with the two machines. The percent incidence of accepts and fines is significantly different between the two machines, according to the Mann-

Table 6 Energy balance for terrain and roadside chipping
Tablica 6. *Energijska potrošnja pri iveranju u sastojini i na pomoćnom stovarištu*

	Terrain chipping *Iveranje u sastojini*		Roadside chipping *Iveranje na stovarištu*	
	MJ h^{-1}	MJ odt^{-1}	MJ h^{-1}	MJ odt^{-1}
Inputs ***Ulazni podaci***				
Felling *Sječa*	959	54	959	54
Chipping & extraction *Iveranje i privlačenje*	3516	456	12468	365
Loading *Utovar*	959	44	959	4
Total *Ukupno*		554		423
Total output *Ukupni učinak*		20000		20000
Output/Input *Učinak/ulaz*		**36.1**		**47.3**
Input/Output % *Ulaz/učinak %*		**2.8**		**2.1**

Note: odt = oven-dry ton
Napomena: suha tvar u tonama

-Whitney non-parametric comparison test, conducted at the 5% level (accepts, $p = 0.0015$; fines, $p = 0.0008$). Differences in the proportion of oversize particles are also large, but not statistically significant ($p = 0.1208$). The smaller terrain chipper offers a superior product, with very little fines and oversize particles.

4. Discussion and Conclusions
Rasprava sa zaključcima

After years of extensive commercial trials, Tuscan operators have developed their own industrial harvesting systems, through a wise mix of Scandinavian and North American methods. The result is original, effective and much different from the Central European family of biomass harvesting techniques, popular in the Alpine regions (Stampfer and Kanzian 2006). In Tuscany, the extensive use of disc-saw feller-bunchers is borrowed from North American operations, and is justified by the large proportion of low quality biomass obtained from pine clearcuts. On the other hand, Nordic forwarders are given preference over conventional skidders, in an attempt to reduce product contamination. The technology mix can be steered more towards the Scandinavian or the North American prototypes, depending on operational conditions.

The terrain chipping operation analyzed in this study mirrors the typical Danish system, based on a terrain chipper and a chip shuttle (Talbot and Suadicani 2005). The main adaptations consist in the adoption of a larger chipper and in the replacement of the expensive forwarder-based chip shuttle with cheaper tractor-based equivalents. The lower investment cost of the latter solution allows using two chip shuttles instead of one, thus building more buffer capacity while avoiding the extra cost of a built-in chip container on the forwarder. In turn, renouncing the integral chip container is a pre-requisite to the adoption of a bigger chipper, as the forwarder could not support both a bigger chipper and a container. The reason for using a bigger chipper is based on the type of cut: the traditional Danish system was designed for thinnings (Brenøe and Kofman 1990), whereas the Italian version is sized on clear-cuts. Of course, terrain chipping is especially dependent on favorable terrain conditions, and in particular moderate slopes and good soil bearing capacity.

The roadside chipping operation reflects North American operational philosophy, which favors processing at the landing, in an effort to achieve better scale economy. For this reason, roadside chipping has become increasingly popular also in Europe, including the Nordic Countries (Tahvanainen and Anttila 2011). Both the investment and the productivity estimated for the Tuscan operation are in line with those reported in similar North American studies (Adebayo et al. 2007, Mitchell and Gallagher 2007).

The coexistence of these two systems is most interesting. On one hand it demonstrates a good availability of woodlots, as well as a significant investment capacity. On the other it hints at a very skilful management, which can discriminate with good accuracy between different work conditions and deploy the best system for each given case. Experience and good managerial skills are also demonstrated by the use of a surge bin, which generates but a marginal benefit. Hence, the operation manager showed the capacity of fine-tuning his operation, taking the right decision even when the difference was not self-evident. (Marchi et al. 2005).

Given the right conditions, roadside chipping allowed a further reduction of harvesting cost, compared to terrain chipping. In fact, the two systems were not compared under exactly the same conditions, especially for what concerned extraction distance. This was much longer for terrain chipping. However, a longer extraction distance might be considered as the inherent characteristic of terrain chipping, as applied in Tuscany. The use of cheaper silage trailers implies dumping on the ground and reloading onto the transportation vehicles. Hence the need for accumulating enough chips at a single landing to contain loader relocation frequency. At the same time, there is a keen interest in looking for old farm yards with a concrete floor pad, so as to reduce chip losses and chip contamination during reloading. Extending chip forwarding distance is an effective way to find an appropriate landing pad. The decision to dump on the ground is not irrational. Tuscan operators have a good knowledge of both roll-on containers and high-dumping chip bins, which could avoid the need for dumping on the ground. However, container trucks have a high tare weight and are not the ideal way to transport chips over medium to long distances (Talbot and Suadicani 2006). After the initial pioneering trials, today very few Italian loggers use roll-on containers to transport chips (Spinelli et al. 2007).

Filling the chip vans with a loader has been the favorite system until the introduction of the new roadside chipper. This is because a good loader can fill a chip van in 20 minutes, whereas even the largest chippers available until now would still take about 40 minutes to fill a chip van (Spinelli and Hartsough 2001). So far, separate loading has allowed a substantial reduction of truck idle time and a proportional increase of trucking capacity, for the same fleet. However, the new roadside chipper can also fill a chip van in 20 minutes, filling the gap with separate loading and making it redundant.

The harvesting systems described in this study perform best in clear-cuts, but they can also work in partial cuts, including thinning operations. They are actually used in thinnings in the same Regional Park of San Rossore, although their productivity is lower than in clear-cuts. Much depends on proper operation planning and on a tree selection pattern allowing for efficient machine traffic. This is one more reason to use forwarders rather than skidders, as the former have better maneuverability inside the stand, once loaded with tree sections.

The energy consumption for the studied operation is about 2 times higher than reported for mechanized round wood operations (i.e. 82 MJ gt^{-1}, Athanassiadis 2000). That depends on the high energy input required by chipping. Once the comparison is made with data from other chipping operations the match is quite good (cfr. 210 – 440 MJ gt^{-1}, Gingerich and Hendrickson 1993). The energy balance estimated in this study is also corroborated by previous studies, reporting an input-output ratio in the range of 2% (Timmons and Viteri-Mejia 2010).

Interpreting the differences in particle size distribution is made uncertain by the processing of different species. Although umbrella pine and maritime pine have similar general form and wood characteristics, they are not the same. What is sure, is that the two chippers used different knife layouts. The terrain chipper adopted a classic two-knife design, with knives running the whole length of the drum. In contrast, the roadside chipper used a four-knife design, with each knife covering half the drum length. The number of full cuts per revolution was the same, but the distribution of impacts was spread more evenly on the larger roadside machine.

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Sažetak

Usporedba iveranja u sastojini i na pomoćnom stovarištu pri sanitarnoj sječi primorskoga bora

*U središnjoj je Italiji sve veća potražnja za drvenim iverom, a zbog ubrzanoga širenja primorskoga bora (*Pinus pinaster*) uvelike se razvijaju radni zahvati u pridobivanju drva. Nakon godina opsežnih komercijalnih pokušaja lokalni su privatnici razvili vlastiti sustav pridobivanja drva kombinacijom skandinavskih i sjevernoameričkih metoda.*

Rezultat je učinkovit te omogućuje održavanje troškova pridobivanja drva ispod 20 € po bruto toni. U istraživanju je uspoređena metoda iveranja u sastojini i iveranje na pomoćnom stovarištu, a primijenjena je u sastojinama primorskoga bora u Toskani. U uvjetima ovoga istraživanja iveranje na pomoćnom stovarištu postiglo je veću proizvodnost za više od četiri puta od iveranja u sastojini. To je omogućilo smanjenje troškova pridobivanja drva za trećinu (12,3 €/bt u odnosu na 18,3 €/bt). Jednom kada je iverač postavljen na pomoćnom stovarištu, njime se može preraditi više od 100 tona svježe mase ivera po satu, puneći kamion iverom za manje od 20 minuta. Prizvodnost je ostala vrlo visoka i s uključenim općim vremenima rada, iako to čini više od 30 % utroška vremena (iveranje + opća vremena). Kao što se i očekivalo, iveranje i privlačenje bili su najskuplji radni zahvati, čineći 80 % od ukupne cijene pridobivanja drva. Na sječu i uhrpavanje otpalo je od 12 do 17 % ukupne cijene pridobivanja drva. Utovar je imao manji, ali ipak značajan utjecaj. Detaljna izrađena studija rada i vremena omogućila je provjeru učinka troškova u odnosu na postavljanje lomilice uz iverač na stovarištu. Bez lomilice troškovi privlačenja, iveranja i utovara povećali bi se za 3,2 %, odnosno 0,33 €/bt. U oba radna zahvata korištene su znatne količine goriva, pri čemu iverač na pomoćnom stovarištu troši i više od 100 l dizela po satu. Trošak goriva čini 31 % odnosno 36 % od ukupnih troškova pridobivanja drva za iveranje u sastojini odnosno na pomoćnom stovarištu. U slučaju povećanja cijene goriva preko 50 % te uz polaznu pretpostavku od 1,3 €/l do 2 €/l, troškovi će se pridobivanja drva povećati za 22 % za iveranje u sastojini te 25 % za iveranje na pomoćnom stovarištu. U najnepovoljnijem slučaju ukupni će troškovi pridobivanja drva biti i dalje ispod 23 €/bt. Unatoč korištenju dizelskoga goriva izračunato je kako ukupni unos fosilnih goriva (energije) iznosi manje od 3 % potencijalne energije ivera. Iveranje u sastojini daje 36 puta više energije, dok iveranje na pomoćnom stovarištu 47 puta više energije nego što se energije utroši na same radne zahvate. Navedene su metode pridobivanja drva ostvarile najbolje rezultate u čistoj sječi, ali se mogu primijeniti i u proredama (kao što se i primjenjuju u regionalnom parku San Rossore), ali će ipak proizvodnost sustava rada u proredama biti manja nego u čistoj sječi.

Ključne riječi: *biomasa, logistika, proizvodnost, ekonomija, sanitarne sječe, Sredozemlje*

Authors' addresses – *Adrese autorâ:*

Enrico Marchi
e-mail: enrico.marchi@unifi.it
Lisa Berretti
e-mail: lisa.berretti@libero.it
Francesco Neri
e-mail: francesco.neri@unifi.it
DEISTAF University of Florence
Via S. Bonaventura 13
I-50145 Firenze
ITALY

Natascia Magagnotti
e-mail: magagnotti@ivalsa.cnr.it
Raffaele Spinelli
e-mail: spinelli@ivalsa.cnr.it
CNR IVALSA
Via Madonna del Piano 10
I-50019 Sesto Fiorentino
ITALY

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