A Low-Investment Fully Mechanized Operation for Pure Selection Thinning of Pine Plantations

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Abstract – Nacrtak

Over the last decades many Mediterranean sites were planted with conifers, which offered fast growth, good fibre quality and the capacity to grow on poor soils. If not thinned, these stands cannot develop strong and healthy trees and they become vulnerable to stress agents. The authors designed a complete operation for the thinning of conifer plantations under favourable terrain conditions by a feller-buncher, a farm tractor equipped with a skidding grapple, mounted on the three-point hitch and a trailer-mounted drum chipper. The whole investment in mechanical equipment was very limited, in the order of € 338,000, including the truck and a tractor to move the chipper. Felling and extraction were quite balanced, with an average productivity around 40 trees hour^{-1}. A spreadsheet was developed in order to determine the effect of tract size on biomass delivered cost, a crucial issue in Non Industrial Private Forests (NIPF) where the problems inherent to the generally small tract size are compounded by the limited quantity and value of the harvest.

Keywords: feller-buncher, Non-Industrial Private Forestry, biomass, whole-tree harvesting, thinning

1. Introduction – *Uvod*

Starting from the Second World War, an intensive activity of reforestation has been conducted all across Europe, with a number of different goals, including soil protection, the promotion of employment in rural areas and the establishment of a strategic reserve of a precious raw material. Most sites were planted with conifers, which offered fast growth, good fiber quality and the capacity to grow on poor soils. Species differed according to the climatic conditions of the sites: while Norway spruce and Scots Pine were most popular in Central Europe, Austrian Pine (*P. nigra* Arnorld) and Mediterranean pines (*P. pinaster* Aiton, *P. pinea* L., *P. halepensis* Mill; etc.) were prevalent further south, due to their better adaptation to dry summer conditions. Most efforts were successful, and plantation continued well into the early 1980s. However, the sound development of these stands depended on a timely thinning schedule. If not thinned, these stands cannot develop strong and healthy trees and become vulnerable to stress agents, such as drought and parasites. Thinning represents a problematic issue, due to its very low economic sustainability: on one hand, the operation generally produces a harvest of little commercial value, often suitable for energy production only; on the other hand, the low harvest intensity and small tree size contribute to reduce operational efficiency, thus raising production costs (Kärhä et al. 2003). Recently, the growing demand for energy biomass is offering an opportunity to thinning operations, which may accrue the double benefit of improving stand stability and of mobilizing significant amounts of biomass. In turn, this may help preventing the growing competition between new forest energy users and the traditional consumers of wood fiber, which starts to be felt across Europe (Lundmark 2006). Thinning operations lend themselves to the application of whole-tree harvesting (WTH), with significant gains in terms of increased productivity and reduced harvesting cost. Whole-tree harvesting involves the extraction of whole trees and their eventual processing at the landing, offering the advantage of simplified in-forest handling. First documented in the US (Kammenga 1983), the application of

WTH to thinning operations is often associated to whole-tree chipping, and its basic set-up has proven so effective to remain virtually unchanged and appreciated until our days (Mitchell and Gallagher 2007). However, standard WTH operations resort to heavy and expensive machinery, and can only be deployed under the conditions of a heavy geometric thinning, and of a significant capital commitment. This may pose a problem to small enterprises that lack the investment capacity required for purchasing modern forest machinery. The alternative – practiced by many – is to conduct a motor-manual operation, where trees are felled by chainsaw and dragged to the roadside with small tractors and winches. Much work has been devoted to developing cost-effective motor-manual thinning operation, but the ever increasing labor cost makes it a very hard challenge. Besides, mechanization is certainly preferable in terms of operator comfort and work safety (Bell 2002), which play a major role in the current technology shift. On the other hand, there is no need for heavy machines when handling small trees harvested in a thinning operation, so that dedicated thinning machinery could be downsized and simplified. Ideally, one may use a widely available general purpose prime mover to further reduce investment cost. Today, the market offers some interesting felling implements for application to small skid-steer loaders in the 4-tonnes class (Windell and Bradshaw 2000), and adapted skid-steer loaders have shown some potential in the thinning of North-American forests (Becker et al. 2006).

The goal of the study was to develop and test a WTH system with the following specifications: 1) ability to carry out a pure selection thinning, without opening any strip roads; 2) complete mechanization of all work steps, with no personnel on the ground (for increased operator safety and comfort); 3) moderate capital cost, obtained by widespread use of lightweight general-purpose equipment.

2. Materials – *Materijal*

The authors designed a complete operation for the thinning of conifer plantations under favorable terrain conditions. A feller-buncher was obtained by applying a disc-saw with accumulating arms to the universal implement hitch of a 58 kW, 4-tonne tracked skid-steer loader. A 44 kW farm tractor was equipped with a skidding grapple, mounted on the three-point hitch. Both machines were not wider than 2 m, so that they could sneak into the standard 3 m inter row of most plantations. The third element in the operation was a trailer-mounted drum chipper, powered by a 162 kW independent engine and equipped with its own integral loader (Table 1). The operating principle was very simple: the feller-buncher reversed along every other inter row picking selected trees on both sides and laying 3–5 tree bunches in the middle of the inter row. The skidder collected the bunches and dragged them to the roadside landing, in front of the chipper. When enough trees were available, the chipper was started and whole-tree chips were blown directly into transportation vehicles parked alongside. The whole investment in mechanical equipment was very limited, in the order of € 338.000, including the truck and a tractor to move the chipper.

The trial was carried out in a pine plantation in the Province of Campobasso (Central Italy). The stand had been established with *Pinus halepensis* Mill. 25 years earlier and had never been thinned before. The terrain was relatively even, with a moderate slope gradient. The silvicultural prescription consisted in

Table 1 Machinery used for the thinning trial
Tablica 1. *Korišteni strojevi pri proredi*

Process – *Postupak*	Felling – *Sječa*	Extraction – *Privlačenje*	Chipping – *Iveranje*
Prime mover – *Osnovni stroj*	Skid-steer loader – *Mali utovarivač*	Farm tractor – *Poljoprivredni traktor*	Drum clipper – *Bubnjasti iverač*
Brand – *Proizvođač*	Bobcat	Valpadana	Pezzolato
Model – *Model*	T-250 Hi-Flow	6064	PTH 700
Engine power – *Snaga motora*, kW	60	44	162
Width – *Širina*, m	2.03	1.05	2.40
Weight – *Masa*, kg	4240	1280	6700
Implement – *Radno oruđe*	Disc saw – *Kružna pila*	Log grappe – *Hvatalo*	Loader – *Dizalica*
Brand – *Proizvođač*	Davco	Japa	Dalla Bona
Model – *Model*	QC 1400	SG	AS 510
Weight – *Masa*, kg	650	235	1200

Table 2 Site description
Tablica 2. *Opis sastojine*

Place name – *Mjesto*		Liscione
Municipality – *Lokalna samouprava*		Guardialfiera
Province – *Pokrajina*		CB
Surface area – *Površina*, ha		1.03
Altitude – *Nadmorska visina*, m		310
Species – *Vrsta*		*Pinus halepensis* Mill.
Age, years – *Dob*, godine		25
Treatment – *Uzgojni postupak*		Thinning – *Proreda*
Removal – *Sječa*	Trees – *Stabala*, n ha^{-1}	463
Removal – *Sječa*	Biomass – *Biomasa*, odt ha^{-1}	27.5
Removal – *Sječa*	DBH – *Prsni promjer*, cm	14.9
Removal – *Sječa*	Height – *Visina*, m	11.8
Removal – *Sječa*	Mass, odt tree^{-1} – *Masa*, odt/stablo	0.060
Residual, Trees – *Preostala stabla*, n ha^{-1}		1207
Slope gradient – *Nagib terena*, %		5
Terrain roughness, class *Površinske prepreke, razred*		1
Moisture content of whole-tree chips*, % *Mokrina iverja izrađenoga iz stabla**, %		47.4

odt – oven-dry tonne – *masa suhe tvari*, t

* determined according to the European Standard CEN/TS 14774-2

* *utvrđeno prema Europskoj normi* CEN/TS 14774-2

a selection thinning, with the purpose of removing 28% of the trees, chosen among weak, dead and malformed trees. Site characteristics are described in Table 2. The operation produced 27.5 oven-dry tonnes (odt) of whole-tree biomass per hectare.

3. Methods – *Metode*

All trees to be removed were marked and identified with a numerical code painted on their bark with fluorescent paint. The diameter at breast height (DBH) of all such trees was measured and noted together with the identification code, so that its value could be associated to processing time without interfering with the work process.

The authors carried out a time-motion study, designed to evaluate machine productivity (Bergstrand 1991). The study was conducted separately for all the main work steps: felling, extraction and chipping. Each processing cycle was stop watched individually, using Husky Hunter hand-held field computers running the dedicated Siwork3 time study software (Kofman 1995). A cycle was defined as the time to process a single tree, a single tractor trip and a single chip load, respectively, for felling-bunching, extraction and chipping. Extraction distances were measured with a cotton-thread hip chain, for each tractor trip. Productive time was separated from delay time (Bjorheden et al. 1995).

In order to translate DBH records into mass values, the Authors used the double-entry tariff tables developed by Castellani et al. (1982) for *P. halepensis*, after building a DBH-height curve with the heights of 30 sample trees. Volume figures were converted into dry weight by applying a base density value of 510 kg/m^3 (Giordano 1988). Moisture content was determined according to the European Standard CEN/TS 14774-2, on 10 chip samples.

Machine costs were calculated with the method described by Miyata (1980), on the assumptions shown in Table 3. The calculated operational cost per Scheduled Machine Hour (SMH) was increased by 20% in order to include administration costs.

Table 3 Machine costing: assumptions and final result
Tablica 3. *Izračun troškova strojnoga rada – ulazni parametri i rezultati*

Machine – *Stroj*	Investment, € *Nabavna vrijednost*, €	Service life, years *Uporabno razdoblje, god.*	Utilization, SMH year^{-1} *Iskorištenost, sati/god.*	Crew *Broj radnika*	Hourly cost, € SMH^{-1} Trošak, €/sat
Feller-buncher *Sječno vozilo*	58.000	8	800	1	54
Tractor with grappe *Traktor s hvatalom*	40.000	8	800	1	41
Mobile chipper* *Mobilni iverač**	140.000	8	800	1	92
Truck *Kamion*	100.000	5	1800	1	54

* includes a 65 kW farm tractor for towing the clipper – *uključuje poljoprivredni traktor snage 65 kW za premještanje iverača*

Regression analysis of time-study data allowed developing a set of equations capable of predicting cycle time (and therefore productivity) as a function of statistically significant independent variables.

4. Results of experiments – *Rezultati istraživanja*

The Whole-tree harvesting method allows recovering a significant amount of biomass even from the thinning in a young stand, and that is especially important with *P. halepensis*, generally characterized by poor form and therefore only capable of yielding a relatively small amount of conventional low quality roundwood products. The graph in Fig. 1 shows the incidence of branch material (diameter <3 cm) over the total tree mass, as a function of DBH.

The trial demonstrated that the skid-steer feller-buncher can maneuver in the 3 m wide inter rows, cutting removal trees and forming bunches of 4–6 trees, thus making extraction much easier. Occasional problems were caused by the very strong base sweep (pistol-butt) of some trees, which made it difficult to grab and cut the stem at the same time. In fact, the saw and the grab-arms are aligned on the same axis, and any significant deviation of the tree stem from the rectilinear form complicates the operation. In this case the best solution was to cut the stem above the base sweep and then finish the work with a second cut to cut the stump to the ground level. If the skid-steer is not fitted with appropriate forestry guarding around the cab and the hydraulic hoses, it is advisable to prune the trees along the working side of the row, in order to avoid damage. Extraction requires a tractor, able to drag a load of about 500–600 kg. Ideally, this machine should be heavy and powerful enough to tow a small trailer for relocating the feller-buncher. This way one would obtain a self-contained operation, capable of quick moving between sites and therefore specifically suited to harvesting the small-size tracts characterizing much of the non-industrial private forestry (NIPF) so abundant across Europe.

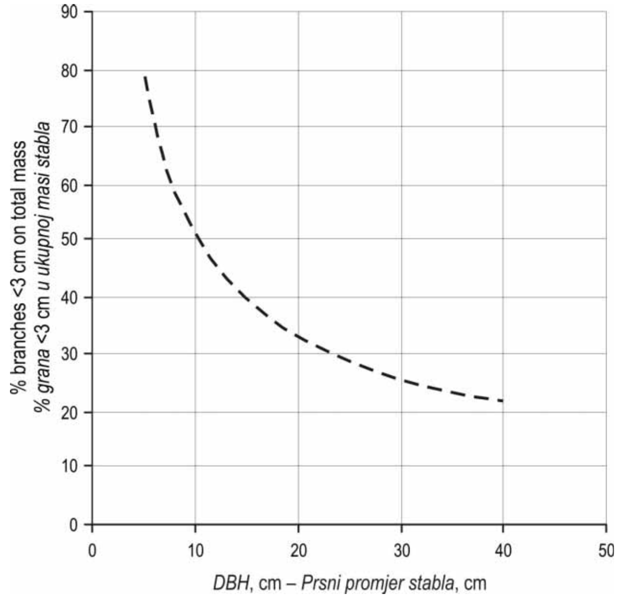

Fig. 1 Incidence of the branch portion (diameter <3 cm) on the total tree mass, weighted with portable scales

Slika 1. *Udjel granjevine (promjera < 3 cm) u ukupnoj masi stabla, mjereno prijenosnom vagom*

A special warning must be given about the fire-hazard represented by the operation of high-speed disc saws during summer. The contact of the fast rotating disc with stones can generate sparks, which

Table 4 Recorded productivity data

Tablica 4. *Ostvarena proizvodnost*

Process – *Postupak*	Felling – *Sječa*	Extraction – *Privlačenje*	Chipping – *Iveranje*
Prime mover – *Osnovni stroj*	Skid-steer loader *Mali utovarivač*	Farm tractor *Poljoprivredni traktor*	Drum clipper *Bubnjasti iverač*
Brand – *Proizvođač*	Bobcat	Valpadana	Pezzolato
Model – *Model*	T-250 Hi-Flow	6064	PTH 700
Tree DBH – *Prsni promjer stabla*, cm	14.9	14.9	14.9
Tree mass – *Masa stabla*, odt	0.060	0.060	0.060
Extraction distance – *Udaljenost privlačenja*, m	-	300	-
Delays – *Prekidi*, %	20	20	35
Productivity, trees SMH^{-1} – *Proizvodnost, stabala/sat*	45.7	36.4	66.8
Productivity, odt SMH^{-1} – *Proizvodnost, odt/sat*	2.7	2.2	4.0
Preparation, hours day^{-1} – *Priprema, sat/dan*	0.75	0.50	1.00

may start a fire under the appropriate soil, fuel and weather conditions. Since we are proposing this system for Mediterranean stands, it is important that readers realize the risks involved when the system is used during the dry summers so common in this region. For safeguard, disc saw operations should be avoided during the days when the fire risk is highest, and fire-extinguishers should always be available on the machine and at the landing. This is also needed when operating a chipper during the hot summer days, since chippers tend to develop a lot of flammable dust and engine heat, and are particularly prone to catch fire.

Trial results are reported in Table 4, which shows the gross productivity recorded for each process stage: these figures are calculated on the overall time consumption, including delays but excluding preparation and relocation time. It must be noted that felling and extraction are quite balanced, with an average productivity around 40 trees hour^{-1}. On the other hand, chipping proceeds at a much higher rate, almost twice as high. Therefore, one can choose three different operating modes: 1) stop and go, where the chipper sits idle at the landing and is turned on only when the other two machines have accumulated enough wood to fill a truck load; in the meantime the chipper operator can perform other jobs, such as removing big branches in the alternate inter rows trafficked by the feller-buncher. This operating mode is not the most effective, but is the simplest and most expedient; 2) dispatching two feller-bunchers and two tractors to serve one chipper, which however requires good organizational capacity and a reasonably large woodlot size; 3) organizing chipping as a separate operation, which is moved to a landing only after the trees have been felled, extracted and piled, possibly allowing for partial drying of the biomass before chipping. In this case it is necessary to equip the felling and extraction operation with a loader for stacking the extracted trees. This could also be done by fitting the farm tractor with a front-end loading fork and/or by carrying a quick-couple fork for the skid-steer, so that at regular intervals the machine can drop the disc saw, attach the fork and stack the trees being skidded.

5. Simulation with a spreadsheet model
Simulacija modela tabličnim kalkulatorom

The different options mentioned above have not been all tested directly, but they have been simulated after building a simple spreadsheet model with the productivity data recorded during the study. These data were statistically analyzed to estimate any relation existing between time consumption and working conditions (SAS 1999), and the resulting equations were organized in a spreadsheet model capable of returning a specific harvesting cost figure for the specific operational and economic assumptions made by each user. The model includes an estimate of relocation time and cost (Table 5), which is spread over the total amount of product obtained from each tract. The model can simulate options 1 (stop and go chipping) and 3 (chipping as a separate operation), on the assumption that option 2 is not compatible with both the firm organization and the tract size most common in NIPF.

Then a comparative simulation was run under the following assumptions: tract size of 4 ha, DBH of removal tree of 15 cm, extraction and transportation

Table 5 Relocation time and cost
Tablica 5. *Vrijeme premještanja i troškovi*

Tractor and grapple with feller-buncher *Traktor s hvatalom i sječno vozilo*	Travel speed – *Brzina kretanja*, km h^{-1}	35
	Relocation distance – *Udaljenost premještanja*, km	30
	Load and unload, hour – *Utovar i istovar, sati*	1.5
	Travel time, hour – *Vrijeme kretanja, sati*	0.9
	Working cost, € hour^{-1} – *Trošak rada*, €/sat	95
	Relocation cost – Trošak premještanja, €	**223**
Chipper towed by farm tractor *Iverač vučen poljoprivrednim traktorom*	Travel speed – *Brzina kretanja*, km h^{-1}	35
	Relocation distance – *Udaljenost premještanja*, km	30
	Load and unload, hour – *Utovar i istovar, sati*	1.5
	Travel time, hour – *Vrijeme kretanja, sati*	0.9
	Working cost, € hour^{-1} – *Trošak rada*, €/sat	133
	Relocation cost – Trošak premještanja, €	**312**

distance of 300 m and 24 km, respectively. Delivered price of the biomass was assumed to reach 85 € odt^{-1}. Simulation results are shown in Table 6, showing a thinning cost of approximately 400 € ha^{-1}. The different options appear similar to each other, with the »stop and go« method costing only 3% more than the other two. This explains why so many enterprises adopt this method, as already pointed out in other studies (Spinelli and Hartsough 2001). If the chipper operator can be employed in other activities, a discontinuous chipping pattern will only affect the depreciation cost of the equipment, with a limited impact on the whole production cost, provided that the initial investment paid for the machine is not too high, as in the case of the medium-size trailer-mounted chipper used in the study. A further advantage of this work pattern system can be the relative independence of chipping and transport. Of course, this simulation suffers from the typical limit of all deterministic models dealing with interactive work, and may not fully reflect the inefficiencies of a system where all links are interdependent. Nevertheless, it offers a first attempt to estimating system performance, and its findings seem to be corroborated by the observation of common practice. Although common practice is not necessarily the benchmark for the best possible use of resources, it still provides a reasonably good guarantee for an acceptably efficient work method.

Table 5 allows determining the effect of tract size on biomass delivered cost. This is a crucial issue in NIPF where the problems inherent to the generally small tract size are compounded by the limited quantity and value of the harvest (Kittredge et al. 1996). The operation designed by the authors is very agile, but even its minimal relocation cost has a considerable impact on total harvesting cost, due to the very low removal levels. The graph in Fig. 2 shows a strong effect of tract size on overall delivered cost up for lot surface areas below 4 ha: on larger tracts, harvesting cost is much less dependent on harvest surface, indicating a better amortization of relocation cost.

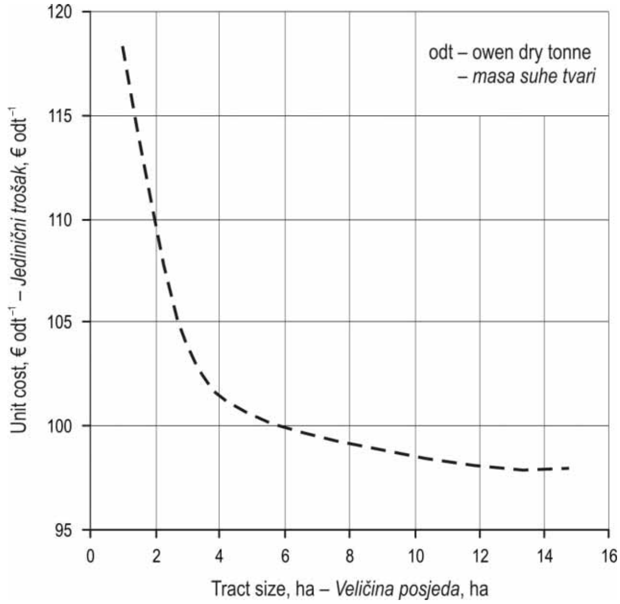

Fig. 2 Delivered cost as a function of woodlot size

Slika 2. *Troškovi proizvodnje ovisno o veličini šumoposjeda*

Table 6 Comparison of two different operating modes

Tablica 6. *Usporedba sustava rada*

Input – *Ulaz*		Results – *Rezultati*		Stand-by chipper *Iveranje u sustavu*	Independent chipping *Neovisno iveranje*
Relocation distance – *Udaljenost premještanja*, km	30				
Tract size – *Veličina posjeda*, ha	4	Felling *Sječa*	hours – *sati*	39	49
Removal, trees ha^{-1} – *Sječa*, stabala/ha	400		€	2122	2713
Avg. DBH Removal – *Pros. prsni promjer*, cm	15	Extraction *Privlačenje*	hours – *sati*	47	47
Avg. Mass Removal – *Pros. masa stabla*, odt	0.061		€	1957	1957
Extraction distance – *Udaljenost privlačenja*, m	300	Chipping *Iveranje*	hours – *sati*	28	28
Distance, forest road – *Udaljenost, šumska cesta*, km	0		€	3373	2527
Distance, mountain road – *Udaljenost, lokalna cesta*, km	0	Transport *Prijevoz*	hours – *sati*	38	38
Distance, state road – *Udaljenost, državna cesta*, km	24		€	2054	2054
Total harvest – *Ukupno posječeno*, odt	97	Relocation – *Premještanje*	€	536	536
Total harvest, trees – *Ukupno posječeno, stabala*	1600	Total cost – *Ukupni trošak*	€ odt^{-1}	**104**	**101**
Chip price, delivered, € odt^{-1}	85	Profit – *Dobit*	€ odt^{-1}	–19	–16
Cijena isporučenoga iverja, € odt^{-1}			€ ha^{-1}	–451	–387

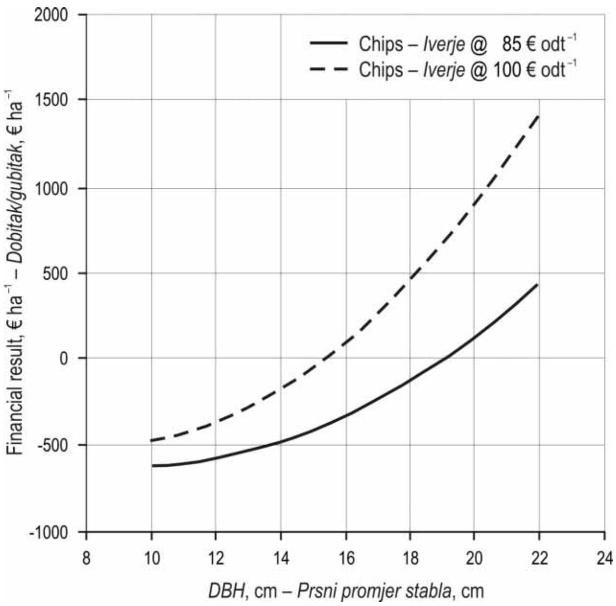

Fig. 3 Financial result as a function of removal tree DBH and the price of dry chips (85 or 100 per oven- dry ton)

Slika 3. *Poslovni učinak kao funkcija prsnoga promjera oborenih stabala prema cijeni drvnoga iverja od 85 €/odt i i 100 €/odt*

On a similar note, one can explore the effect of tree size on harvesting cost. A simulation was run under the same assumptions shown in Table 6, except for removal tree DBH, which ranged between 10 and 22 cm. Two different levels were set for chip price: the current 85 € odt^{-1} and the projected 100 € odt^{-1}. The graph in Fig. 3 shows that under current chip prices, the thinning operations start to accrue some profits only when DBH is bigger than 19 cm. However, the removal of such large trees may not be suited to a first thinning, but rather to a second thinning. If chip prices will actually reach the projected 100 € odt^{-1}, then thinning breaks even for a DBH of 15 cm, which is much more compatible with the needs of a first selection thinning.

Transport distance also affects the total harvesting and delivery cost, which increases by 20% when the distance increases from 20 to 60 km. Using greater trucks-and-trailer units with a larger payload, instead of simple trucks, is crucial to the reduction of transportation cost. Organizing a short-distance supply chain is always a good way to contain delivered cost, but the main cost component still remains harvesting and processing and therefore the primary focus should be on targeting those stands that offer favorable harvesting conditions (i.e. flat terrain, large tract and stem size), even if farther away.

6. Discussion and Conclusion – *Rasprava i zaključci*

The operation designed and tested by the authors offers a low investment option for the fully mechanized, pure selection thinning of conifer plantations in flat terrain. Such operation is also characterized by high mobility, which represents a strategic requirement imposed by the fragmentation of NIPFs.

Whole-tree harvesting allows increasing the amount of merchantable product obtained from the thinning, while decreasing production cost. It also results in the almost complete removal of slash, which is a cost-effective way to reduce fire risk (Hartsough et al. 2008), which is particularly high in conifer plantations and in the Mediterranean region (Lovreglio et al. 1999).

Since the industrial chipper is almost twice as productive as the other units, and the typically small tract size discourages doubling up the felling and extraction teams, chipping must either be separated from the other operations and occur at a later stage, or the chipper must work in a stand-by mode. Both options were simulated through a simple spreadsheet model, showing that operation in a stand-by mode is not much more expensive than the apparently more rational two-stage operation. In any case, thinning cost is relatively low, and the operation can break even if the projected 100 € odt^{-1} price target for forest chips is eventually reached. Such a result would be remarkable, considering the extremely challenging specifications of low investment cost, full mechanization of the operation and capacity to perform pure selection thinning.

It should be stressed at this stage that this harvesting method is only suitable to flat or gently sloping terrain, and it is recommended for conifer plantations – especially Mediterranean pines planted along the coast or on low hills.

The full mechanization achieved with this operation can be found attractive by local firms that operate in rural areas, since it can offer a relatively comfortable work place and a qualified employment to young loggers, while requiring reasonably low capital commitment.

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Sažetak

Snižavanje ulaganja za potpuno mehanizirano pridobivanje drvnoga iverja u selektivnim proredama borovih plantaža

Pridobivanje drva iz proreda s jedne strane ima vrlo nisku ekonomsku održivost zbog male komercijalne vrijednosti, najčešće energijskoga drva ili iverja, dok s druge strane niska sječna gustoća i prosječna veličina stabala pridonose smanjenju radne učinkovitosti i povećanju troškova proizvodnje. Zbog povećane potražnje za energijskim drvom u proredama se sve više koristi stablovna metoda sječe uz pomoć koje se smanjuju troškovi rada i povećava se proizvodnost. Zbog visokih troškova strojnoga rada kod stablovne se metode često pokušavalo uvesti i ručno-strojni način rada motornom pilom, no zbog njegove sve veće cijene ni takav način nije u potpunosti isplativ. Cilj je ovoga istraživanja razviti i ispitati primjenjivost stablovne metode sječe u pridobivanju energijskoga drva iz neindustrijskih privatnih šuma u Italiji pri čemu su trebali biti zadovoljeni ovi uvjeti:

⇒mogućnost izvođenja selektivnih proreda bez dodatnoga otvaranja šuma,

⇒potpuno mehanizirani rad bez radnika neposredno na tlu (povećanje sigurnosti i zaštite na radu),

⇒korištenje lakših specijaliziranih šumskih vozila radi smanjenja troškova.

Pri stablovnoj metodi pridobivanja energijskoga drva korištena su sljedeća specijalizirana šumska vozila na opisane načine: 1) sječna glava postavljena na mali utovarivač (Bobcat) za sječu te uhrpavanje oborenih stabala uzduž prorednih redova, 2) prilagođeni poljoprivredni traktor opremljen hvatalom za privlačenje drva do pomoćnoga stovarišta, 3) pokretni iverač opremljen hidrauličnom dizalicom. Svojstva su vozila prikazana u tablici 1. Istraživanje je provedeno u plantaži alepskoga bora Pinus halepensis Mill. u pokrajini Campobasso u središnjoj Italiji. Prije toga u plantaži nije bilo proreda te je metodom negativne selekcije odabrano i posječeno 28 % ukupne *drvne zalihe, što je 27,5 t suhe drvne tvari/ha (tablica 2). Pomoću studije rada i vremena određena je i produktivnost vozila po 3 faze rada: 1) rušenje stabala, 2) privlačenje drva, 3) iveranje drva. Obujam je stabala dobiven pomoću dvoulaznih tablica autora Castellani i dr. (1982) za alepski bor. Sadržaj vlage u drvu je određen na 10 uzoraka drvnoga iverja prema europskoj normi CEN/TS 14774-2, uz gustoću drva od 510 kg/m³. Troškovi strojnoga rada izračunati su Miyatinom metodom (1980) te su uvećani za dodatnih 20 % zbog troškova administracije (tablica 3). Pomoću stablovne metode u proredama mladih sastojina alepskoga bora moguće je pridobiti značajnu količinu biomase, što je i vidljivo na slici 1 koja prikazuje postotni udio mase grana debljine do 3 cm u ukupnoj masi stabala, ovisno o njihovu prsnom promjeru. U tablici 4 prikazana je proizvodnost strojeva po radnim sastavnicama. Sječom i privlačenjem drva postiže se približno jednaka proizvodnost rada (oko 40 stabala/h), dok se iveranjem drva postiže gotovo dvostruko veća proizvodnost. Određene su 3 inačice sustava rada:*

⇒1. Iverač je postavljen na pomoćnom stovarištu, ali se stavlja u pogon tek kada je srušeno i privučeno dovoljno stabala za puni tovar kamiona.

⇒2. Skupni rad dvaju malih utovarivača sa sječnim glavama i dvama adaptiranim poljoprivrednim traktorima s hvatalima te jednim iveračem za koji je potrebna visoka organiziranost.

⇒3. Iveranje je drva zasebna radna operacija te se iverač dovozi na pomoćno stovarište i stavlja u pogon tek nakon završenoga rušenja i privlačenja stabala te djelomičnoga prosušivanja drva.

Sve tri inačice rada nisu neposredno ispitane, već je uz pomoć algoritama i statističke analize podataka procijenjena povezanost utroška vremena rada i radnih uvjeta. U tablici 5 prikazani su troškovi po inačicama rada br. 1 i 3 uz procijenjeno vrijeme i trošak premještanja vozila, dok inačica br. 2 nije usklađena s organizacijom rada te prosječnom veličinom šumskih posjeda u neindustrijskim privatnim šumama u Italiji (NIPF – Non Industrial Private Forests). U tablici 6 prikazani su podaci ispitivanja radnih inačica uz ove ulazne podatke: veličina posjeda od 4 ha, prosječni prsni promjer stabla od 15 cm, prosječna udaljenost privlačenja od 300 m i prosječna udaljenost daljinskoga transporta od 24 km. Pokazalo se da 1. inačica rada ima troškove tek 3 % veće od ostalih dviju inačica te se dolazi do zaključka da ako se radnik na iveraču drva zaposli i na drugim poslovima na radilištu dok iverač nije u pogonu, ukupno će povećanje troškova ove inačice rada biti neznatno. Troškovi premještanja vozila imaju velik utjecaj na ukupne troškove pridobivanja energijskoga drva. Na slici 2 prikazana je ovisnost veličine posjeda na ukupne troškove po jedinici suhe drvne tvari energijskoga drva te je vidljivo da su troškovi pridobivanja niži na posjedima većim od 4 ha. Na slici 3 vidljivo je da će pri trenutačnoj cijeni drvnoga iverja od 85 €/t suhe drvne tvari dobit u poslovanju biti tek kod stabala s prsnim promjerom većim od 19 cm, dok se pri projiciranoj cijeni od 100 €/t suhe drvne tvari postiže dobit kod stabala s prsnim promjerom od 15 cm. Troškovi daljinskoga transporta uvelike utječu na ukupne troškove pridobivanja drvnoga iverja, i to povećanjem od 20 % pri povećanju udaljenosti transporta od 20 do 60 km. Istraživanje je pokazalo da su najmanji troškovi i najveća proizvodnost u pridobivanju energijskoga drva iz selektivnih proreda plantaža alepskoga bora pri korištenju stablovne metode, što ujedno i umanjuje rizik od požara jer se sva granjevina rabi za pridobivanje drvnoga iverja, pri odvajanju rada iverača od ostalih radnih operacija te pri veličini šumskih posjeda iznad 4 ha.

Ključne riječi: sječna glava, neindustrijske privatne šume, biomasa, stablovna metoda, prorede

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