Harvesting Short-Rotation Poplar Plantations for Biomass Production

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Abstract – Nacrtak

In Italy, short rotation forest has become very popular in recent years, with over 4,000 hectares already planted – almost exclusively with clone poplar. The study models the performance of modified forage harvesters on a range of short-rotation poplar plantations, identifies technical obstacles to the deployment of these machines and suggests solutions that may expand the capability of modified forage harvesters when treating short-rotation poplar. Data were collected from 16 operations, covering a total of 50 hectares and producing over 1000 green tonnes of wood chips. The average yield of the fields harvested during the trials was about 20 green tonnes/ha year, equivalent to 8 oven-dry tonnes/ha for a 60% average moisture content, measured in the laboratory. Gross machine productivity ranged from 9 to 44 green tonnes/scheduled machine hour (gt/SMH), with an average value of 25 gt/SMH. Of course, this result is affected by other factors than just forager performance, which is potentially much higher. A model was developed to predict harvesting performance and cost, showing that harvesting cost can be maintained below the 15 Euro/green tonne (2 Euro/GJ) ceiling only if field stocking exceeds 40 or 50 gt/ha when rows are long 300 and 100 m, respectively. The study also shows the need to optimize operations. Over a quarter of the total worksite time is occupied by unproductive delays, which may be reduced with improved planning and maintenance.

Keywords: short-rotation forest, biomass production, harvesting, forager, Italy

1. Introduction – *Uvod*

European farmers are increasingly attracted to energy crops, following the most recent changes in the Common Agricultural Policy and the rapid development of the bioenergy sector. Among potential sources of energy biomass, dedicated crops from surplus agricultural land have the highest potential contribution, and in the medium term they could account for three quarters of the total supply of energy biomass (Hoogwijk et al. 2003). Compared to other sources, dedicated crops offer the advantage of a highly intensive management that assures a strong impact relative to the land area involved (Alig et al. 2000). Of course, management intensity does not exclude multiple land-use, where the production of biomass is integrated with groundwater protection, ecological planning, etc. (Londo et al. 2004). This is especially the case with woody crops, including short rotation coppice (Heller et al. 2003). Among various cropping modules, short rotation coppice (SRC) seems to best reflect the expectations of farmers, who are used to short return times and generally show little enthusiasm for traditional wood plantations, harvested at 10–30 years intervals. However, SRC is an industrial crop, designed to produce large quantities of low-priced raw materials and to be successful all operations must be conducted with the utmost efficiency. Harvesting cost is estimated to be above 50% of the total cost of biomass produced from wood plantations (Moiseyev and Ince 2000), which underscores the special needs for optimizing these operations.

In Europe, Sweden has opened the way by launching an extensive plantation programme based on willow coppice: to date over 15,000 ha of short rotation willow coppices have been planted in this country (Larsson et al. 1998). Willow plantations are established at a very high density, and harvested every third or fourth year using modified forage harvesters, which have proved very effective (Danfors et al. 1998). More to the South – in Germany and in Italy, for example – poplar is considered better suited to the local environment than willow, and plantation programmes are largely based on this species. Modern poplar hybrids are highly suitable for ex-arable land. Short rotation coppice established with poplar resembles the Swedish model, but it also has some peculiar characteristics that may affect harvesting technology – among other things. As compared to willow, poplar wood is lighter and more brittle than willow wood, and poplar stools tend to generate fewer and larger sprouts when coppiced (Tharakan et al. 2003), which may have a considerable impact on harvesting performance.

In Italy, short rotation forest (SRF) is very popular in the North, along the Po Valley, where the Italian agricultural industry is concentrated. The Regional Government of Lombardy has been the first one to release grants for the establishment and the management of SRF crops: after that, several other regions have followed, but none is yet offering the same level of subsidies (Table 1). The result is evident: in less than four years, 3000 ha of SRF crops have been established in Lombardy, representing three quarters of the total SRF surface established in Italy. Plantations in Northern Italy are established almost exclusively with poplar: sites are fresh enough, farmers are already familiar with the species and specific clones are available for biomass production (Frison et al. 1990). In fact, several nurseries have got into developing new clones, and have obtained a remarkable success. Hence the interest in finding the most effective harvesting system, exploring first the capacity of modified foragers, which have already proved the best option in the Nordic Countries.

Table 1 Grants released for the establishment and maintenance of SRF in Italy

Tablica 1. *Odobrene potpore za osnivanje i gospodarenje šumama kratkih ophodnji u Italiji*

Region *Regija*	Establishment *Osnivanje*	Maintenance *Gospodarenje*	Compensation *Naknada*	Max. cycle *Najduži period*
	Euro/ha	Euro/ha year *Euro/ha god.*	Euro/ha year *Euro/ha god.*	years *godine*
Lombardy	3,150	620*	105–725	15
Friuli	4,000	–	–	15
Veneto	4,000	–	–	15
Piemonte	4,000	–	–	15
Emilia	3,840	–	–	15
Tuscany	2,000	–	–	15
Umbria	2,320	–	–	15
Lazio	2,000	–	–	15

* first 2 years – *prve 2 godine*

The goal of this study is: 1) to document the performance of modified forage harvesters on a range of short-rotation poplar plantations; 2) to identify technical obstacles to the deployment of these machines and 3) to suggest solutions that may expand the capability of modified forage harvesters when treating short-rotation poplar. In the process, a costing model will be developed and applied, for providing unambiguous reference figures.

2. Materials and methods – *Materijal i metode*

The study tested four different Claas foragers of the series Jaguar Mega, and namely the 840, 850, 860 and 880 models, with engines capable of delivering 254, 286, 306 and 340 kW, respectively. The Claas SRF harvesting system is based on a standard forage harvester, fitted with a special SRF header. Claas have produced two header versions, specifically designed for the Scandinavian market: the HS-1 and the HS-2 headers. In 2004 two Italian contractors purchased three of the newer HS-2 models and mounted them on already available Jaguar Mega foragers. Compared to the older HS-1, the HS-2 is a completely new design (Fig. 1). It is a purpose-built tool and not a modified sugar cane header. The circular saws placed at the bottom have a larger diameter, and the two vertical feed rollers placed above them on the old model have been replaced by crop-collectors with solid steel fingers: these move cut stems to a couple of horizontal in-feed rollers and eventually to the chopper of the forager – the same used for chopping maize, but with every other blade removed in order to produce larger wood chips. The new header looks more compact than the old one and offers better visibility to the driver. The machine was developed in Germany, but the Swedish users have added a few modifications, as suggested by practical experience. Besides the original Claas HS-2 header, the study also tested an Italian-made header – the GBE-1 model – very similar in design to the German unit but heavier and stronger, possibly better suited to handling of large stems. In both cases, the system is based on a forager and 2 to 4 tractor-trailer units which receive the chips from the forager and move them to a collection point: once there, the chips are loaded on transportation vehicles and moved to the plant (Fig. 2).

The machines were studied while carrying out their scheduled commercial activity, on 16 different sites representative of the two main cropping modules used for SRF poplar in Italy: the annual and the biannual system. Plantations managed on the annual system are harvested at 1-year intervals and

Fig. 1 HS-2 header on Class forager Jaguar Mega 840
Slika 1. *Žetvena glava HS-2 na Classovu silažnom kombajnu Jaguar Mega 840*

Fig. 2 Harvesting system based on a forager and tractor-trailer unit
Slika 2. *Sustav pridobivanja drvnoga iverja pomoću silažnoga kombajna i traktora s prikolicom*

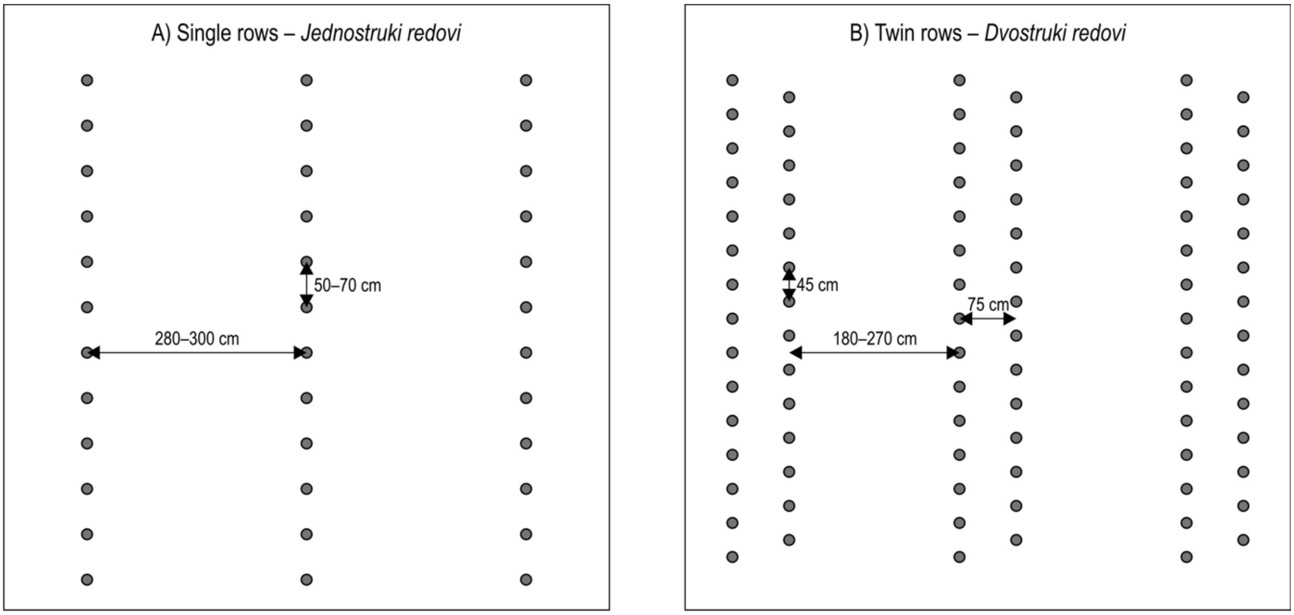

Fig. 3 Planting systems
Slika 3. *Raspored sadnje*

adopt a planting density of about 10,000 cuttings/ha. Cuttings are planted in twin-rows, with a spacing of 1.8–2.7 m between twin-rows, 75 cm between the rows forming a pair and 45 cm along the rows (Fig. 3). Stem size at harvest reaches 2–3 cm (cut level), with peaks of 6–8 cm. Seeking a better fibre-to-bark ratio, many farmers resort to the biannual system, where the plantation is harvested at 2–3-years intervals, and is accordingly less thick. Cuttings are planted in single rows, with a spacing of 2.8–3.0 m between the rows and 0.5–0.7 m along the rows, which results in a planting density of 6,000–7,000 cuttings/ha. Stem size at harvest reaches 10–12 cm at cut level. Overall, the tests spread over 50 hectares of experimental plots.

The study was designed to evaluate machine productivity and to identify the most significant variables affecting it. The data collection procedure consisted of a set of detailed time-motion studies conducted at the cycle level. In general, detailed time studies are more discriminating than shift-level studies and can detect smaller differences between treatments than shift-level studies can detect (Olsen et al. 1998).

Cycle times for each machine were defined and split into time elements considered to be typical of the functional process analyzed. This was done with the intent of isolating those parts of a routine that are dependent on one or more external factors in order to enhance the accuracy of the productivity models (Bergstrand 1991). The criteria considered for such subdivisions were: 1) isolating significant cycle elements, 2) reflecting as much as possible other similar existing protocols (Bjorheden et al. 1995) and, 3) avoiding unnecessary detail. All time elements and the related time-motion data were recorded with Husky Hunter® hand-held field computers running Siwork3® time-study software (Kofman 1995).

Output was estimated by measuring the volume of all chip containers produced during each test, and by taking all of the containers to a certified weight bridge. Moisture content determination was conducted on samples, collected in sealed bags and weighted fresh and after drying for 48 hours at a temperature of 103°C in a ventilated oven.

Row spacing was measured with a tape, and the length of row harvested for each load with a laser range-finder. This way, it was also possible to calculate the surface actually harvested at each site.

Tests were conducted from 2004 to 2006 on 4 different machines (all the units currently used in Italian commercial operations) that harvested a total of 1036 green tonnes on 49 hectares at 16 different sites. The valid time study sessions lasted 54 hours.

Data were statistically analyzed with both ANOVA and regression techniques to detect and formalize significant relationships (SAS 1999). Operating costs were calculated using the procedures described by Miyata (1980), on an estimated annual utilization of 1200 hours for the forager and 500 hours for the header. The corresponding investment costs are 250,000 and 140,000 Euro, respectively, and in both

Table 2 Description of 16 test sites
Tablica 2. *Opis 16 pokusnih ploha*

Place *Mjesto*	Forager *Silažni kombajn*	Header *Žetvena glava*	Age *Dob*	Rows *Redovi*	Rotation *Ophodnja*	Surface *Površina*	Diameter *Promjer*	Harvesting density *Sječna gustoća*	Productivity *Učinak*	Annual yield *Prinos*
	type *tip*	type *tip*	years *godine*			ha	cm	gt/ha	gt/SMH*	gt/ha year gt/ha *god.*
Sforzesca	Mega 840	HS-2	1	twin *dvostruki*	first *prva*	9.2	2.05	9.0	9.2	9.0
Bigli	Mega 840	HS-2	1	twin *dvostruki*	second *druga*	3.2	2.34	25.5	19.5	25.5
Frascarolo	Mega 840	HS-2	1	twin *dvostruki*	third *treća*	8.4	2.13	10.9	10.5	10.9
Alperolo	Mega 840	HS-2	1	twin *dvostruki*	second *druga*	0.6	1.89	40.8	44.2	<u>40.8</u>
Calignano	Mega 850	HS-2	2	twin *dvostruki*	first *prva*	0.6	4.31	43.1	13.2	21.6
Cura	Mega 850	HS-2	2	twin *dvostruki*	first *prva*	2.5	3.91	28.2	23.1	14.1
Albuzzano	Mega 840	HS-2	1	twin *dvostruki*	first *prva*	2.7	1.76	7.2	12.1	7.2
Linarolo	Mega 840	HS-2	1	twin *dvostruki*	third *treća*	1.2	1.58	27.6	28.7	27.6
Torbole	Mega 860	HS-2	1	twin *dvostruki*	first *prva*	2.0	2.23	13.5	20.2	13.5
Travagliato	Mega 860	HS-2	1	twin *dvostruki*	first *prva*	4.3	1.71	8.4	11.7	8.4
Pudiano	Mega 860	HS-2	1	twin *dvostruki*	second *druga*	3.1	2.29	37.9	38.0	<u>37.9</u>
Carpignano	Mega 850	HS-2	2	twin *dvostruki*	second *druga*	1.3	3.37	71.9	33.3	<u>36.0</u>
Eraclea	Mega 880	GBE-1	2	single *jednostruki*	second *druga*	1.0	4.64	24.8	35.0	12.4
Caorle	Mega 880	GBE-1	2	single *jednostruki*	second *druga*	4.5	4.43	31.4	41.7	15.7
Arre	Mega 880	GBE-1	2	single *jednostruki*	second *druga*	1.2	4.20	53.5	33.7	26.8
Conselve	Mega 880	GBE-1	2	single *jednostruki*	second *druga*	3.6	3.70	27.8	24.3	13.9
Mean – *Srednja vrijednost*						**3.1**	**2.9**	**28.8**	**24.9**	**20.1**
Minimum – *Najmanja vrijednost*						0.6	1.6	7.2	9.2	7.2
Maximum – *Najveća vrijednost*						9.2	4.6	71.9	44.2	40.8

* green tonne per scheduled machine hour – *tona svježe tvari po ukupnom radnom satu*

cases the depreciation period was assumed to be 8 years. Repair and maintenance was estimated to 70% of depreciation, while labour cost was set at 16 Euro/hour. Fuel cost was assumed to be 0.90 Euro/L (subsidized fuel for agricultural use). The total costs are inclusive of 20% profit and overheads. Similar assumptions were used for the trailer and the tractor-trailer units. The resulting operating costs are 234 Euro/h and 71 Euro/h, respectively for the forager and the tractor-trailer unit. Conversion into energy figures was obtained on the assumption that the energy content of dry hardwood equals 18.5 GJ/t (Hartmann et al. 2000).

3. Research results – *Rezultati istraživanja*

Table 2 contains a description of test sites and some preliminary results. The fields present sample variations, with individual sizes ranging from 0.6 to 9 hectares and stocking from 7 to 70 green tonnes/ha. They have all been established using the new Alasia clones »Pegaso« and »AF2«: measured under operational conditions, yields varied between 7 and 40 green tonnes/ha year depending on site fertility and tending care. Hence the halved values refer to 2 year rotations (annual yield is half the actual yield at harvest age), while full values refer to 1 year rotations. Underscored values denote top performance obtained with good planting material on good soils, and may be indicative of future crops, once sufficient experience is gathered.

Gross machine productivity ranges from 9 to 44 green tonnes/scheduled machine hour (gt/SMH), with an average value of 25 gt/SMH. Of course, this result is affected by other factors than just forager performance, which is potentially much higher. Harvesting progress is slowed down by a number of delays, caused by mechanical breakdowns, operator fatigue and machine interference within the support fleet. In fact, actual harvesting represents about 70% of the total worksite time, whereas machine maintenance and waiting for the transport units account respectively for 13% and 12% of the total time (Fig. 4).

Defined as the percent ratio between maintenance-free worksite time and total worksite time, machine availability can give a measure of how the harvester copes with the strain of handling wood, rather than softer forage or maize. The data in Table 3 may suggest that machine maintenance becomes more intense when harvesting 2-year-old plantations, whose bigger stems may cause higher mechanical stress on the harvester. This observation may be corroborated by the higher occurrence of minor blockages during the harvesting of older plantations.

Table 3 Machine availability and utilization rates
Tablica 3. *Odnosi iskorištenosti i ispravnosti stroja*

Place *Mjesto*	Age, years *Dob, godine*	Rows *Redovi*	Rotation *Ophodnja*	Diameter, cm *Promjer, cm*	Utilization, % *Iskorištenost, %*	Availability, % *Ispravnost, %*	Blockage, % on harvesting time *Kvarovi, % od vremena sječe*
Sforzesca	1	twin *dvostruki*	first *prva*	2.05	78.2	92.8	0.0
Bigli	1	twin *dvostruki*	second *druga*	2.34	55.6	76.9	0.0
Frascarolo	1	twin *dvostruki*	third *treća*	2.13	82.0	93.7	3.5
Alperolo	1	twin *dvostruki*	second *druga*	1.89	97.7	100.0	6.8
Calignano	***2***	twin *dvostruki*	first *prva*	4.31	54.3	70.7	9.6
Cura	2	twin *dvostruki*	first *prva*	3.91	90.9	94.7	3.4
Albuzzano	1	twin *dvostruki*	first *prva*	1.76	97.7	100.0	5.6
Linarolo	1	twin *dvostruki*	third *treća*	1.58	95.7	100.0	3.8
Carpignano	1	twin *dvostruki*	second *druga*	2.23	54.5	77.0	5.6
Torbole	1	twin *dvostruki*	first *prva*	1.71	93.5	100.0	0.0
Travagliato	1	twin *dvostruki*	first *prva*	2.29	76.6	79.8	0.0
Pudiano	2	single *jednostruki*	second *druga*	3.37	89.9	99.3	1.7
Caorle	2	single *jednostruki*	first *prva*	4.64	78.8	100.0	2.6
Eraclea	***2***	single *jednostruki*	first *prva*	4.43	48.8	100.0	7.0
Arre	2	single *jednostruki*	second *druga*	4.20	52.0	79.9	5.4
Conselve	***2***	single *jednostruki*	second *druga*	3.70	40.7	65.2	3.2
Mean – *Srednja vrijednost*					**74.2**	**89.4**	**3.6**
Minimum – *Najmanja vrijednost*					40.7	65.2	0.0
Maximum – *Najveća vrijednost*					97.7	100.0	9.6

However, ANOVA testing did not confirm the inference, because the 10% difference in machine availability between the treatments (1-year-old and 2-year-old) did not prove statistically significant at the 0.05 level (Table 4). Yet, the near significance of the test at the 0.10 level raises some questions and demands for further investigations in future.

Table 4 Results of t-test for machine availability vs. rotation age
Tablica 4. *Rezultati t-testa odnosa ispravnosti stroja i godina ophodnje*

Rotation age, years *Ophodnja, godine*	Machine availability – *Ispravnost stroja*				
	Count *Broj opažanja*	Mean *Sredina*	Variance *Varijanca*	Std. dev. *Standardna devijacija*	Std. error *Standardna pogreška*
1	9	93.611	83.534	9.140	3.047
2	7	83.933	203.847	14.265	5.392
t-test	Degree of freedom *Stupanj slobode*	Mean difference *Srednja razlika*	*t* value *t vrijednost*	*p*-value *p vrijednost*	
1, 2	14	9.678	1.653	0.1205	

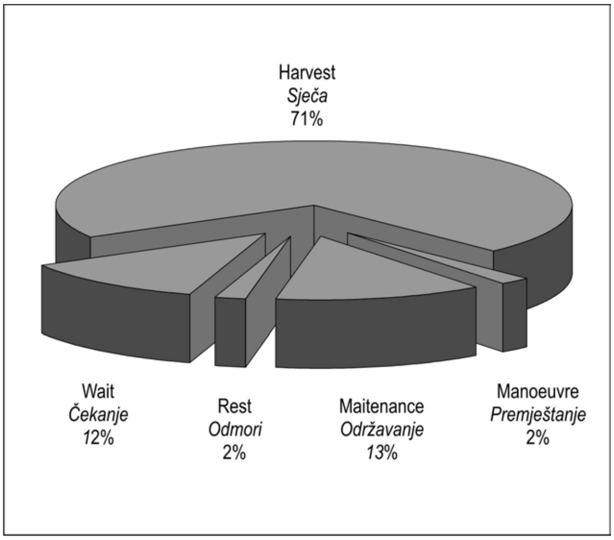

Fig. 4 Breakdown of worksite time (excl. preparation and relocation)
Slika 4. *Raščlamba radnoga vremena (bez vremena pripreme i premještanja)*

Table 5 Regression of harvesting time vs. crop density and forager model
Tablica 5. *Regresijska analiza vremena sječe u ovisnosti o gustoći stabala i tipu silažnoga kombajna*

Variables *Varijable*	Coefficient *Koeficijent*	Std. error *Stand. pogreška*	Std. Coeff. *Stand. devijacija*	*t*-value *t vrijednost*	*p*-value *p vrijednost*
Intercept *Slobodni član*	–0.450	0.154	–0.450	–2.931	0.0041
Crop density *Gustoća stabala*	10.736	0.656	0.776	16.374	<0.0001
Forager model *Tip silažnoga kombajna*	–0.430	0.090	–0.226	–4.757	<0.0001

R^2 = 0.783, n = 115

Like with most agricultural machinery, net harvesting time (machine progression through the crop) is related to crop density, and this relation can be calculated by statistical analysis. The equation in Table 5 is the best fit to the experimental data points obtained from 115 observations, each equal to one loaded trailer. It shows that productivity increases with crop density, and also with the use of the most powerful forager. Before calculating the regression, ANOVA post-hoc testing allowed detecting that the net productivity of the 880 forager model is significantly different from that of the other models, which show no significant differences among themselves. Hence the decision of including this effect as an indicator variable in the regression. End-row turn times can also be modelled, simply by adopting the median value of 0.57 minutes per occurrence.

The average operation consists of one forager and two transport units, for an hourly cost of 376 Euro. For the productivities recorded in the study, the harvesting cost of chips delivered to the farm centre varies between 8 and 40 Euro/green tonne, with an average value of 15 Euro/green tonne (2 Euro/GJ).

4. Discussion and conclusions – *Rasprava sa zaključcima*

The average yield of the fields harvested during the trials is about 20 green tonnes/ha year, equivalent to 8 oven-dry tonnes/ha for a 60% average moisture content, measured in the laboratory. This value increases to 9.2 odt/ha if the figures from the three evidently failed plantations are removed. It is interesting to notice that the average yield of the Italian short-rotation stands approaches the top yield measured further north for the best poplar (Karacic et al. 2003, Pellis et al. 2004) and willow (Nordh and Verwijst 2004) clones. Moreover, the best fields encountered in the study reached annual yields in the range of 15 odt/ha, proving good quality of the Ital-

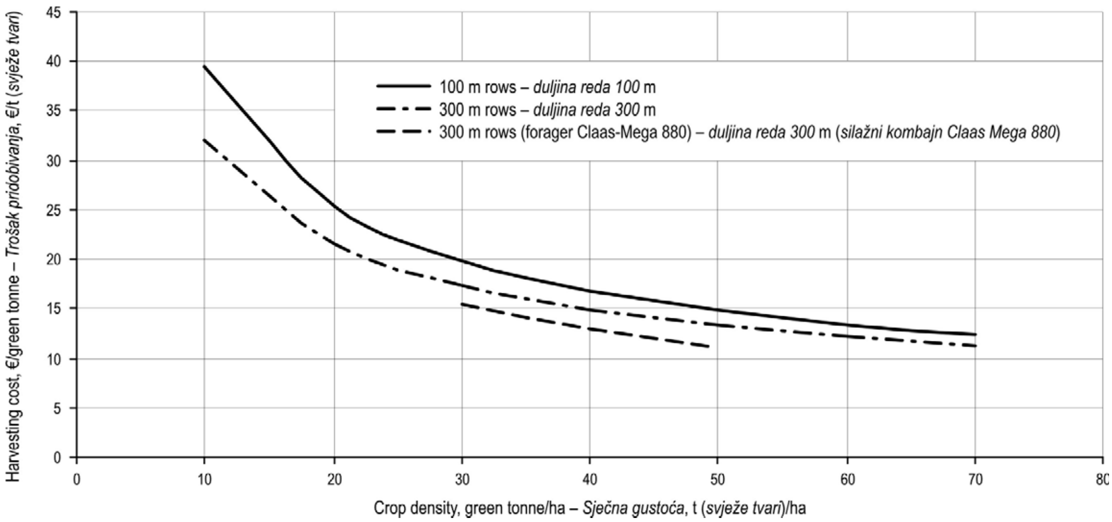

Fig. 5 Harvesting cost as a function of crop density, row spacing and machine type
Slika 5. *Troškovi pridobivanja u odnosu na gustoću stabala, razmak redova i tip stroja*

ian clones and climate. These values are net of the harvesting losses, which averaged 0.6 odt/ha.

The study also shows the need to optimize operations. Over a quarter of the total worksite time is occupied by unproductive delays, which may be reduced with improved planning and maintenance. In particular, waiting time can be curtailed by a better balance of the operation, which should be designed so that the capacity of the support fleet matches that of the forager. This entails predicting both productivities, which vary according to several factors, and namely: payload capacity and forwarding distance for the shuttles, crop density and forager model. The data contained in this study allow predicting the productivity of the forager, whereas that of the tractor is simpler to estimate.

Maintenance is also an important source of delays, and seems to take more time when harvesting 2-year-old plantations, due to higher mechanical stress on the harvester. Although this observation lacks statistical confirmation, it must be remembered that the observation of a distinct pattern in breakdowns would require longer term studies, and that the somewhat blurred picture (p = 0.12) transpiring from this study might just be the outline of a real phenomenon.

Modified foragers can reach a very high productivity, with peak values up to 80 green tonnes per hour, excluding turns and delays. However, top performance is only obtained when several factors concur, and namely: good terrain conditions, adequate machine choice, high crop density and appropriate row spacing. The forager is a heavy machine that cannot traffic wet or sloping soils, and should only be applied to flat and solid terrain. The most powerful version in the tested range seems to have a remarkable edge on the other units, especially when harvesting single-row two-year-old plantations: fitted with the heavier GBE-1 head, the Mega 880 can reach twice the productivity of the other models combined (84 gt/h vs. 41 gt/h) and the difference is statistically significant to p <0.0001. Of course, such a high productivity might also be the result of a different crop structure, as the 880 model operated on fields established according to the new single-row plantation module. The new plantations are designed to produce fewer and bigger stems, with a higher fibre content: this might be paid with a lower annual yield, due to the less intense exploitation of available space, as Table 2 seems to indicate.

Modified foragers cannot harvest stems that are too big and too close: cut stems have to be placed horizontally to enter the chopper, and if they are too long and too near to each other, they often get entangled with the uncut stems ahead, jamming into the header. This problem does not occur with small stems, which are shorter and more flexible, so that their tops bend and the butts can be fed horizontally to the chopper. Therefore, effective harvesting of large-size stems requires an accordingly large spacing, so that the tops of cut stems can sneak between the standing crop ahead and the stems can be laid horizontally. Similarly, row distance must follow strict rules, because the forager-based harvesting system is quite rigid with respect to crop spacing. Both the Claas and the GBE SRF headers have been built for harvesting twin rows placed 75–80 cm apart: any significant variation in row spacing makes harvesting difficult or even impossible. The distance between twin rows must also be adequate to allow machine traffic, and generally between 2.4 and 2.8 m. These same headers can also harvest single-row plantations, by working slightly offset to the row alignment, but in this case row spacing must be 3 m: typically these plantations are managed on two-year-rotations and produce larger stems.

Harvesting cost vary with the same factors listed above. The relationships calculated from this study allowed building a simple deterministic model to predict harvesting productivity and cost as a function of: crop density, row length, machine type and expected level of delays. The model also calculates transport fleet balance and operation relocating time, using the measured forager road speed of 22 km/h. Figure 5 shows the result of a simple simulation, calculated for a forwarding distance of 2 km, a 20% incidence of delays, a relocation distance of 10 km and an average lot size of 5 ha. Depending on crop density, row spacing and machine type, the total harvesting cost including forwarding to a collection site, preparation and relocation ranges from 10 to 40 Euro/green tonne (1.3 to 5.4 Euro/GJ). Harvesting cost is restrained below the 15 Euro/green tonne (2 Euro/GJ) ceiling only if field stocking exceeds 40 or 50 gt/ha when rows are long 300 and 100 m, respectively. The most powerful forager is fast enough to compensate for slightly lower stocking levels, and can harvest fields with only 30 gt/ha within the 15 Euro/gt limit.

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This model is available for free, and can be requested to the authors at: spinelli@ivalsa.cnr.it

Sažetak

Pridobivanje biomase sječom šumskih plantaža topola u kratkim ophodnjama

Šume kratkih ophodnji na poljoprivrednim zemljištima smatraju se industrijskim usjevima. One su podignute radi proizvodnje velikih količina drvnoga materijala niske cijene te su velik potencijalni izvor biomase za pridobivanje energije.

Na sjeveru Italije poljoprivrednici sve veću pažnju usmjeravaju prema energetskim usjevima i šumama kratkih ophodnji. Slijedeći iskustva poljoprivrednika skandinavskih zemalja, osnivaju se šumske plantaže velikoga broja stabala po površini koje se sijeku prilagođenim silažnim kombajnima svakih nekoliko godina. Pri tom se za podizanje šumskih plantaža koriste ponajprije klonovi topola, za razliku od šumskih vrbovih plantaža u Skandinaviji.

Regionalna vlada Lombardije među prvima je odobrila novčane potpore za osnivanje i gospodarenje šumama kratkih ophodnji. Slijedile su je ostale regionalne vlade, ali s manjom razinom financiranja (tablica 1). Rezultat svega je osnivanje 3000 ha šuma kratkih ophodnji u manje od četiri godine u Lombardiji, što predstavlja ¾ ukupne površine šuma kratkih ophodnji u Italiji.

Cilj je rada istražiti učinkovitost prilagođenih silažnih kombajna pri sječi šuma kratkih ophodnji, ustanoviti tehničke poteškoće pri njihovu radu, predložiti rješenja za veću učinkovitost silažnih kombajna pri sječi stabala iz šuma kratkih ophodnji te odrediti utjecajne čimbenike na troškove rada.

Istraživanje je provedeno na 4 različita tipa silažnih kombajna Claas opremljena specijaliziranim žetvenim glavama za sječu drvenastih vrsta (slika 1). Claas je razvio dva tipa takvih žetvenih glava za skandinavsko tržište (HS-1 i HS-2). One su opremljene kružnim pilama većih promjera na podnožju, dok su dva vertikalna uvlačna valjka zamijenjena čvrstim čeličnim hvatačima koja dovode posječeni drvni materijal do usitnjivača. U Italiji je razvijen novi tip teže i jače žetvene glave (GBE-1) koja je pogodnija pri sječi većih stabalaca. Sustav pridobivanja drvne biomase iz šumskih plantaža uključuje uz silažni kombajn i najmanje dva traktora s prikolicama za prihvat drvnoga iverja i prijevoz do stovarišta ili mjesta utovara na transportna vozila (slika 2).

Istraživanje je provedeno u 16 topolovih šumskih plantaža kojima se gospodari u jednogodišnjoj ili dvogodišnjoj ophodnji. Mnogi poljoprivrednici danas prelaze na dvogodišnju ophodnju šumskih plantaža jer se njihovom sječom dobiva veći udio drvnih vlakana u pridobivenom drvnom iverju.

Šumske plantaže kojima se gospodari u jednogodišnjoj ophodnji osnovane su s gustoćom sadnje od 10 000 stabala po hektaru, u dvostrukim redovima, s razmakom od 1,8 do 2,7 m između dvostrukih redova, 75 cm između dva reda te 45 cm unutar jednoga reda (slika 3). Srednji sječni promjer iznosi 2 – 3 cm, odnosno najviše 6 – 8 cm.

Šumske se plantaže dvogodišnje ophodnje osnivaju s gustoćom sadnje od 6000 do 7000 stabala po hektaru, u jednostrukim redovima, s razmakom sadnje 2,8 – 3,0 m između redova i 0,5 – 0,7 m unutar reda. Srednji sječni promjer iznosi 10 – 12 cm.

Razmak i duljina redova izmjereni su laserskim daljinomjerom. Proveden je studij rada i vremena pri sječi topolovih šumskih plantaža na svim ispitnim plohama. Utrošak je vremena radnih sastavnica mjeren terenskim računalom Husky Hunter pomoću računalnoga programa Siwork 3. Podaci su statistički obrađeni u računalnom programu ANOVA.

Mjerenjem dimenzija kontejnera na prikolici i mase svakoga punoga tovara prikolice na mosnoj vagi ustanovljeni su obujam i masa pridobivenoga drvnoga iverja. Sadržaj je vlage određen sušenjem uzoraka drvnoga iverja tijekom 48 sati na temperaturi od 103°C.

Tablica 2 daje opis 16 ispitnih ploha te ostvareni učinak radnih strojeva. Učinci se kreću u rasponu od 9 tona svježe tvari na sat do 44 tone svježe tvari na sat. Velik je raspon rezultata uzrokovan različitim prekidima rada zbog mehaničkih kvarova, umora radnika i čekanja traktora s prikolicom za rad silažnoga kombajna. U raščlambi radnoga vremena (slika 4) efektivno vrijeme čini oko 70 % ukupnoga utroška vremena.

Ispravnost je stroja određena kao odnos utrošenoga radnoga vremena (bez vremena održavanja stroja) i ukupnoga utrošenoga vremena rada te se govori o mogućnosti stroja za rad s drvenastim biljkama u odnosu na krmna bilja i kukuruz. Rezultati u tablici 3 ukazuju na veći udio vremena održavanja stroja i češće prekide pri radu u šumskim plantažama dvogodišnjih ophodnji. Zaključak je da veći promjeri stabala uzrokuju veći mehanički stres stroja.

Provedena regresijska analiza na 115 tovara prikolice pokazuje da se vrijeme utrošeno na pridobivanje punoga tovara prikolice drvnim iverjem smanjuje s gustoćom sadnje stabala i uporabom silažnoga kombajna veće snage *motora (tablica 5). Testom uz pomoć programa ANOVA utvrđeno je značajno veća učinkovitost silažnoga kombajna Claas Mega 880 od ostalih tipova.*

Troškovi su pridobivanja drvnoga iverja određeni na osnovi procijenjenih 1200 pogonskih sati silažnoga kombajna i 500 pogonskih sati žetvene glave. Investicijski troškovi iznose 250 000 EUR, odnosno 140 000 EUR s vremenom amortizacije od 8 godina. Troškovi popravka i održavanja procijenjeni su na iznos od 70 % od nabavne cijene. Trošak radnika iznosi 16 EUR/h, a trošak goriva 0,90 EUR/L (subvencionirana cijena za poljoprivrednike). Na osnovi navedene kalkulacije ukupni troškovi iznose 234 EUR/h za silažni kombajn, odnosno 71 EUR/h za traktor s prikolicom. Kako rad pridobivanja drvnoga iverja iz šumskih plantaža podrazumijeva uporabu silažnoga kombajna i najmanje 2 traktora s prikolicom, ukupni trošak iznosi 376 EUR/h.

Za ostvarene učinke troškovi pridobivanja drvnoga iverja iznose od 8 EUR/t svježe tvari do 40 EUR/t svježe tvari, odnosno prosječno 15 EUR/t svježe tvari. Na osnovi energetske vrijednosti drvnoga iverja od 18,5 GJ/t (Hartmann i dr. 2000) najveći trošak pridobivanja drvnoga iverja može iznositi približno 2 EUR/GJ.

Istraživanje ukazuje na potrebu optimizacije sustava pridobivanja drvnoga iverja silažnim kombajnima iz šuma kratkih ophodnji. Više od četvrtine ukupnoga radnoga vremena otpada na neproizvodne prekide, što se mora umanjiti poboljšanim planiranjem rada. Zastoje zbog čekanja traktora s prikolicom treba izbjeći boljom organizacijom rada koja će se temeljiti na utjecajnim čimbenicima, kao što su veličina tovara prikolice, udaljenost prijevoza, gustoća sadnje i tip silažnoga kombajna.

Prilagođeni silažni kombajni mogu postići vrlo veliku učinkovitost pri povoljnim terenskim uvjetima, velikoj sječnoj gustoći i prikladnim razmacima redova. Silažni su kombajni teški strojevi koji ne mogu raditi na vlažnim tlima i nagnutim terenima, već se preporučuje njihov rad na ravnim terenima dobre nosivosti tla.

Također se javljaju poteškoće pri radu silažnoga kombajna ako su stabla većih promjera i/ili su na malom međusobnom razmaku. Pri malom razmaku stabala često dolazi do nagnječenja i nakupljanja neposječenih stabala u žetvenoj glavi, što uzrokuje prekid rada. Stoga učinkovita sječa stabala većih promjera iz šuma kratkih ophodnji zahtijeva određeni razmak između i unutar redova. Pri dvostrukim redovima sadnje specijalizirane žetvene glave mogu ispravno raditi pri razmaku 75 – 80 cm unutar dvostrukih redova i 2,4 – 2,8 m između dvostrukih redova. Potreban razmak jednostrukih redova iznosi 3 m za pravilan rad žetvene glave. Jednostruki se redovi primjenjuju pri gospodarenju šumama kratkih ophodnji u dvogodišnjim ophodnjama, što pretpostavlja i veće promjere stabala te se stoga zahtijeva i veći razmak između redova.

Silažni kombajn najveće snage motora Class Mega 880 pri pridobivanju drvnoga iverja iz dvogodišnjih šuma kratke ophodnje zasađenih u jednostrukim redovima mogu postići dvostruko veći učinak u odnosu na ostale tipove.

Rezultati se istraživanja mogu koristiti za određivanje učinkovitosti sustava pridobivanja drvnoga iverja iz šuma kratkih ophodnji na osnovi sječne gustoće, duljine redova, tipa silažnoga kombajna i očekivanih prekida rada. Slika 5 prikazuje troškove pridobivanja drvnoga iverja u odnosu na gustoću stabala, razmak redova i tip silažnoga kombajna. Pri tome su pretpostavljeni ovi ulazni podaci: udaljenost prijevoza traktora s prikolicom od 2 km, udaljenost premještanja od 10 km, površina šumske plantaže od 5 ha i udio prekida od 20 % u ukupnom vremenu rada. Ukupni se trošak pridobivanja drvnoga iverja kreće od 10 do 40 EUR/t svježe tvari (1,3 do 5,4 EUR/GJ). Trošak manji od 15 EUR/t svježe tvari (2 EUR/GJ) moguće je postići jedino pri sječnoj gustoći od 40 gt/ha pri duljini redova od 300 m, odnosno 50 gt/ha pri duljini redova od 100 m. Jedino silažni kombajn veće snage motora može ostvariti troškove manje od 15 EUR/t svježe tvari pri sječnoj gustoći od samo 30 t (svježe tvari)/ha.

Ključne riječi: šuma kratke ophodnje, pridobivanje biomase, sječa, silažni kombajn, Italija

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