Application of a Sugarcane Harvester for Harvesting of Willow Trees Aimed at Short Rotation Forestry: an Experimental Case Study in Japan

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Abstract – Nacrtak

An experiment on the growing and harvesting of willow trees aimed at short rotation forestry was conducted in northern Japan. Willows were harvested using a sugarcane harvester from southern Japan during its agricultural off-season. The growing experiment showed the high potential of willow plantations to produce woody biomass of more than 10 dry-t/ha/y. The harvesting experiment showed that space for turning around, one line in one row as a planting method, a growing cycle of three years, and an extractor fan in the harvester are necessary for mechanical harvesting. Mechanical harvesting was considered to have little influence on willow regeneration provided that the machine cut reasonably well-grown trees. The system performance of harvesting and collecting willow billets in a hypothetical model field was calculated as 22.4 m^3/h, suggesting the feasibility of supplying low-cost wood chips.

Keywords: harvesting, Japan, short rotation forestry, sugarcane harvester, willow

1. Introduction – *Uvod*

Short rotation forestry (SRF), where fast-growing tree species such as eucalypt, poplar, and willow are reforested by planting rooted cuttings and repeatedly harvesting the sprouting stumps in short-term cycles of several years, has mainly been applied for producing pulp chips (Culshaw and Stokes 1995, Hartsough et al. 2000, Stokes and Watson 1991). In recent years, however, SRF has attracted attention worldwide as a new source of woody biofuel. Commercial willow plantations have been cultivated for bioenergy purposes in Sweden since the 1980s, and around 16,000 ha of short rotation willow plantations were established domestically from 1986 to 2000 (Mola-Yudego 2011). Other European countries and North America have been testing harvesting operations using agricultural and forestry machines aimed at SRF (Spinelli and Hartsough 2001, 2006, Spinelli et al. 2007, 2008, 2009, Volk and Luzadis 2009). Similarly in Japan, woody biomass from SRF is defined as an »energy crop« and is considered as a resource in the Biomass-Nippon Strategy alongside »unused biomass« such as logging residues (Anonymous 2005).

This paper outlines an experimental project for growing, harvesting, and utilizing willow trees in Japan. The project is currently underway in the boreal forests of Hokkaido prefecture, northern Japan, and has the following four objectives: (1) bioethanol production from willow tree chips; (2) effective utilization of abandoned agricultural land; (3) soil remediation; and (4) job creation. The growing period of *Salix schwerinii* and *S. sachalinensis*, which are indigenous willow species of Hokkaido, is estimated to be three years, and a high annual yield of 10 dry-t/ha/y is expected even with intensive cultivation. A sugarcane harvester from Okinawa prefecture in southern Japan was used for harvesting the willow trees; the machine was shipped a distance of more than 2,000 km to the test site during the agricultural off-season in Okinawa.

The usual operation of the sugarcane harvester is as follows: (1) the basecutter cuts the sugarcane at ground level and helps to feed the cane stalks to the butt lift roller; (2) the butt lift roller lifts the cut sugarcane stalks and guides them into the machine feed rollers; (3) the feed rollers transport and horizontally feed the cane stalks to the chopper drums; (4) the chopper drums cut the sugarcane and send the billets to the extractor chamber; (5) the primary extractor cleans the billets by removing vegetable and mineral impurities; and (6) the removable net container receives the sugarcane billets from the chopper. Regarding the use of a sugarcane harvester for other crops in Japan, Kobayashi et al. (2003) made machine modifications for harvesting kenaf (*Hibiscus cannabinus*) and examined its performance, and Iwasaki et al. (2007) conducted tests for harvesting wood species.

The main purpose of this study was to examine the feasibility of applying a sugarcane harvester to harvest willow trees aimed at SRF. In the growing experiments, growth increments of willows under boreal conditions and cultivation methods to increase the increment were investigated, while methods of land reclamation, planting, and cultivation appropriate for mechanical harvesting were discussed through the harvesting experiments. Operational efficiency and fuel consumption of the harvester were measured, and the influence of mechanical harvesting on willow regeneration by sprouting was evaluated.

2. Material and Methods – *Materijal i metode*

2.1 Experimental site – *Mjesto istraživanja*

The growing experiments were carried out at two sites in northern Hokkaido (NH) and eastern Hokkaido (EH). Three other sites were established for harvesting experiments; two in NH and one in northeastern Hokkaido (NEH), where indigenous willows grow naturally and a site was prepared by leaving rows of willow trees and cutting other ones (see the NEH site in Fig. 3).

2.2 Growing experiment – *Uzgojni pokus*

In order to compare the yields per unit area by performing or not performing cut-back and the difference in planting density (0.5 × 0.5 m and 1.0 × 0.5 m), growing compartments for *S. schwerinii* and *S. sachalinensis* were made in the NH and EH sites, i.e., there were 16 compartments in total, and 30 rooted cuttings of five clones were planted in each compartment. Cut-back, which means cutting shoots near the ground after defoliation in the year of plantation, is expected to encourage more shoots to sprout in the following spring and thus increase the productivity of the site.

Three years after planting, which was the growing period in the project, the average annual increment for two years was calculated in the compartment where cut-back was performed, while the average annual increment for three years was calculated in the compartment where cut-back was not performed, and the two increments were compared. As 0.5 × 0.5 m and 1.0 × 0.5 m indicate the spacing between rooted cuttings, the planting density was 40,000 and 20,000 stumps per hectare, respectively.

2.3 Harvesting experiment – *Pridobivanje energijskoga drva*

The experiment was carried out using a crawler-type sugarcane harvester (Fig. 1, UT-100K, Uotani-tekkou, Inc., Japan). Its engine output was 78 kW/ 2,200 rpm and the cubic capacity of its removable net container (Fig. 2) was 2.5 m^3. The basecutter of the harvester consisted of two rotary discs with four chopper blades attached to each disc. The machine was used to harvest willow trees in the manner described above, and then was moved to a landing for unloading when the container was filled with willow billets. A time study was conducted during the experiment with the following work elements: moving with no load, cutting, turning around, moving fully-loaded, unloading, hooking up a container, and others. The cutting length of the willow billet was set to 25 cm, and so the harvested willows required secondary chipping in order to be used as fuel for direct combustion equipment such as a boiler.

Fig. 1 Sugarcane harvester
Slika 1. *Kombajn za šećernu trsku*

Table 1 Outline of the three test sites
Tablica 1. *Opis triju istraživanih radilišta*

	NEH	NH				
		Ichi A	Ichi B	Ichi C	Sanru A	Sanru B
Age, years *Dob, godine*	3–5	2	2	2	3	3
Number of row *Broj redova*	12	13	8	8	10	10
Length of row, m *Dužina reda,* m	100	65	65	65	80	80
Space for turning around *Prostor za okretanje*	5 m	No *Ne postoji*	No *Ne postoji*	No *Ne postoji*	No *Ne postoji*	No *Ne postoji*
Planting method (in one row) *Metoda sadnje (u jednom redu)*	Wild-grown *Prirodan*	Two lines* *Dva reda**	Two lines** *Dva reda***	Two lines*** *Dva reda****	One line *Jedan red*	One line *Jedan red*
Planting density, stumps per 100 m^2 *Gustoća sadnje, biljaka po 100* m^2	102 ± 25.9	136	72	68	100	100
Extractor fan of the harvester *Separator na kombajnu*	Running *Uključen*	Running *Uključen*	Running *Uključen*	Running *Uključen*	Running *Uključen*	Non-running *Isključen*

*dense – *gusto*, **sparse – *rijetko*, ***staggered – *naizmjeničan*

Fuel consumption was measured during the experiment, and the weight of each filled container was measured by truck scale and then converted to dry weight by estimating the water content of the billets.

In the experiment, the following elements were examined: operational efficiency and fuel consumption according to the presence or absence of space for turning around, planting method (one line or two lines in one row), planting density, and running or non-running of an extractor fan. The outline and design of the three test sites are shown in Table 1 and Fig. 3, respectively. There were two sites in NH: Ichi-no-hashi (NH-Ichi) and Sanru (NH-Sanru); three compartments were made at the NH-Ichi site and two at the NH-Sanru site. Due to the wild willows growing in the NEH site, the age of the trees varied (3 to 5 years old, see Table 1) so there were some trees with a diameter at ground level exceeding 10 cm. In addition, since the density of stumps per unit area differed for each row in the NEH site, the influence of planting density on the machine cutting speed was also examined throughout the experiment.

Fig. 2 Removable net container
Slika 2. *Odvojivi spremnik*

2.4 Investigation on regeneration by sprouting
Istraživanje vegetativne obnove

Willow stumps can be damaged when a sugarcane harvester cuts the trees, leading to concerns about adverse effects on growth in the following year. Tearing of stumps by cutting and regeneration by sprouting were investigated by setting four plots in the NEH site; the length and width of the rows in each plot were 5 m and 2 m, respectively.

3. Results – *Rezultati*

3.1 Growing experiment – *Uzgojni pokus*

Table 2 lists the results: regardless of planting density, willow species, or test site, the average annual increment of the compartment where cut-back

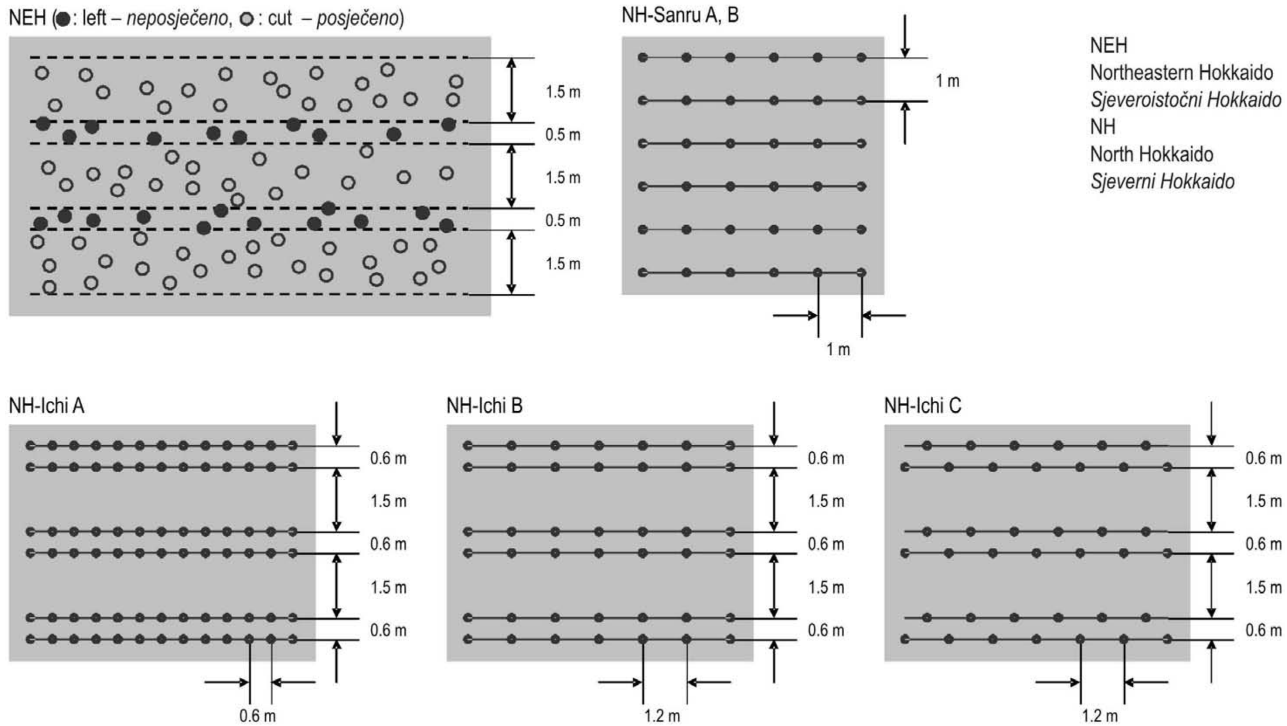

Fig. 3 Design of the three test sites
Slika 3. *Nacrt triju istraživanih radilišta*

Table 2 Results of the growing experiment, dry-t/ha/y
Tablica 2. *Rezultati uzgojnoga pokusa, tona suhe tvari po hektaru godišnje*

Planting density *Gustoća sadnje*	Cut back *Čepovanje*	*Salix schwerinii*		*Salix sachalinensis*	
		NH site	EH site	NH site	EH site
0.5 × 0.5 m	No	0.60	8.84	4.70	10.28
	Yes	0.93	11.80	5.06	16.03
1.0 × 0.5 m	No	1.67	9.32	2.89	7.56
	Yes	3.23	12.11	4.18	9.00

was performed was higher than that where it was not performed. In order to introduce this cut-back practice, however, a method for cutting 20,000 or 40,000 shoots per hectare should be designed. Moreover, since the first harvesting operation itself functions as cut-back, there is no need for cut-back during and after the second growing cycle. Taking cost-effectiveness into consideration, a decision must be made on whether or not to perform cut-back.

In terms of planting density, the average annual increment of the sparsely-planted compartment of *S. schwerinii* was higher than that of the densely-planted one, and vice versa in the case of *S. sachalinensis*, i.e., the densely-planted compartment produced a higher yield than the sparsely-planted one. *Salix sachalinensis* and EH showed better results in terms of willow species and test site, respectively, but some of the data on *S. schwerinii* in the NH site was significantly low. Since the NH site was located in a water channel area where gravelly soil was predominant, soil fertility might have been very poor in places. However, the overall average annual increment was more than 6 dry-t/ha/y, and more than 10 dry-t/ha/y in the EH site, showing the high potential of willow plantations as woody biomass even in northern Japan.

3.2 Harvesting experiment – *Pridobivanje energijskoga drva*

The results of the time study are shown in Fig. 4, and the relationship between planting density and cutting speed in Fig. 5. The stock of removable net containers prepared for the experiment ran out in

Table 3 Average operating time of work elements
Tablica 3. *Prosječni utrošci vremena po radnim sastavnicama*

Work element *Radna sastavnica*	Number *Veličina uzorka*	Avg., sec/cycle *Ar. sredina, s/tura*	SD, sec/cycle *Stan. devijacija, s/tura*
Turning around (smoothly) *Okretanje (bez poteškoća)*	23	26.5	8.45
Turning around (with difficulty) *Okretanje (s poteškoćama)*	22	60.5	17.0
Unloading *Istovar*	16	49.7	18.2
Hooking up a container *Prikapčanje spremnika*	15	93.7	23.9

the NH-Sanru B compartment, so the operation was continued without containers. As a result, the operating times for unloading and hooking up a net container in NH-Sanru B in Fig. 4 are short.

The percentage of the operating time for turning around to the total observed time was low in the NEH site, while that in the NH-Ichi and NH-Sanru sites was higher; this difference was due to the presence or absence of space for turning around (see Table 1). The average operating time of the work elements in Table 3 shows that turning around with difficulty took twice as long as turning around smoothly, suggesting the importance of space for turning around when considering introducing mechanical harvesting.

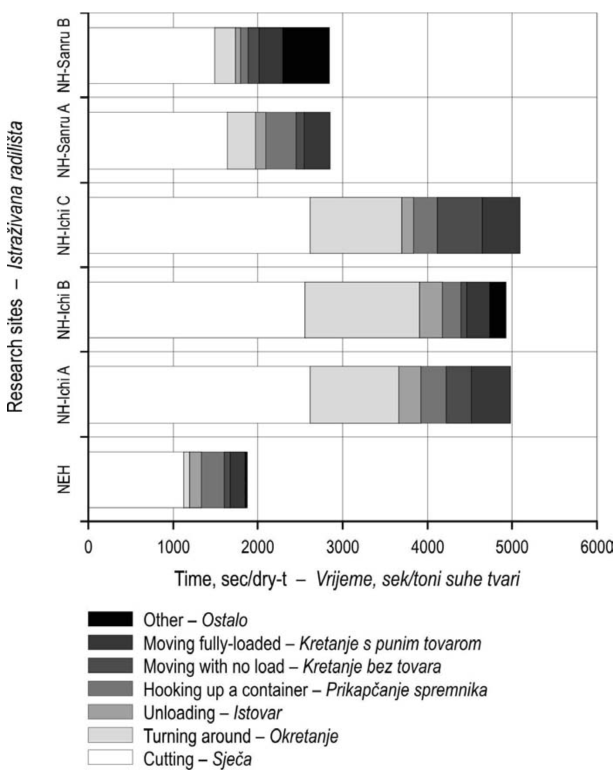

Fig. 4 Results of the time study
Slika 4. *Rezultati studija rada i vremena*

The correlation coefficient between planting density and cutting speed in Fig. 5 is calculated as –0.246, so there is no clear correlation at the 0.05 significance level. In terms of cutting speed in each test site, NEH (3- to 5-year-old trees) was 28.3 m/min (standard deviation (SD) = 5.25 m/min), NH-Ichi (2-year-old trees) was 41.2 m/min (SD = 11.0 m/min), and NH-Sanru (3-year-old trees) was 36.8 m/min (SD = 6.55 m/min), showing a trend in which the cutting speed decreases roughly in proportion to the tree age (or diameter at ground level). During the experiment, the operator controlled the cutting speed of the harvester since

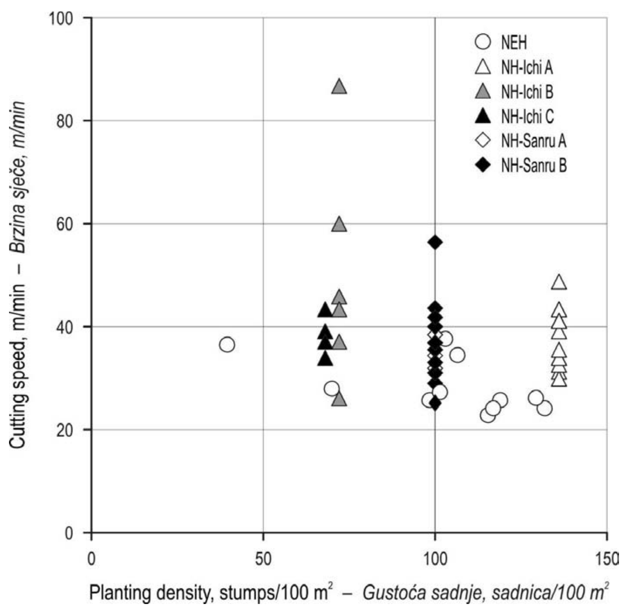

Fig. 5 Relationship between planting density and cutting speed
Slika 5. *Odnos između gustoće sadnje i brzine sječe*

the machine often could not pick up and »swallow« cut willows when the speed was raised. Concerning this cutting loss problem, the machine was found to have difficulty in swallowing willow branches that jutted to the side. Especially in the NH-Ichi site where rooted cuttings were planted with two lines in one row (the width between the two lines was 0.6 m, see Fig. 3), the rows of the willow plantation were wider than the horizontal clearance of the »mouth« of the harvester. Therefore, for mechanical harvesting, one line in one row appears to be a desirable planting method.

The operating times for »others« in Fig. 4 were as follows. The operation stopped in the NEH site because four willows, two of which were 9 cm in diameter at cutting height and the other two were >10 cm, were too thick for the machine to cut down. After the experiment, the operator reported that the maximum diameter of willow that the machine could cut down was considered to be 7 cm, suggesting that a growing cycle of three years is appropriate for mechanical harvesting. On the other hand, one of the basecutter blades had to be repaired because the machine »bit« stones in the gravelly soil in the NH-Sanru B compartment. Since the cutting height can be adjusted from the operator's seat, the height was raised during the experiment in order to avoid breaking the blades. In NH-Sanru B, however, the cutting height of the crawler-type harvester varied due to the rough ground and the machine dug up stones in the soil. Consequently, for harvesting willow trees mechanically, land for cultivation should be reclaimed. Furthermore, a sugarcane harvester is designed to cut sugarcane at 5 cm below ground level, so the basecutter must be improved for application to willow harvesting.

Table 4 Fuel consumption and weight of harvested willows per hour and weight per container

Tablica 4. *Potrošnja goriva i masa posječene vrbe po satu rada te po spremniku*

Site *Radilište*	Fuel consumption, L/h *Potrošnja goriva, L/h*	Weight of harvested willows per hour, dry-t/h *Masa posječene vrbe, tona suhe tvari po satu*	Weight per container, dry-t/container *Masa posječene vrbe, tona suhe tvari po spremniku*
NEH	10.05	1.92	0.369
NH-Ichi A	11.12	0.72	0.260
NH-Ichi B	14.54	0.76	0.280
NH-Ichi C	13.51	0.71	0.207
NH-Sanru A	12.00	1.26	0.324
NH-Sanru B	12.73	-	0.260

Table 4 lists the fuel consumption and weight of harvested willows per hour and the weight per container (the weight per hour in NH-Sanru B is not calculated due to the shortage of containers, as mentioned above). In the NH-Sanru site, where the running (NH-Sanru A) or non-running (NH-Sanru B) of the extractor fan was examined, there was no difference between the NH-Sanru A and B compartments in terms of fuel consumption. However, the weight of harvested willows per container in NH-Sanru B was less than that in NH-Sanru A; many tops and branches dropped into the net container in NH-Sanru B because the extractor fan stopped during the operation. In view of the importance of gathering wood fiber as well as returning minerals to the soil, the fan should be operated.

3.3 Investigation on regeneration by sprouting *Istraživanje vegetativne obnove*

Fig. 6 shows the number of torn and intact stumps and the rate of regeneration by sprouting according to the diameter at cutting height. Although tearing of stumps was observed in every diameter class thicker than 15 mm, all of the torn stumps at the plots sprouted. The rate of regeneration was proportional to the diameter, and all of the stumps with diameters thicker than 30 mm also sprouted. Therefore, provid-

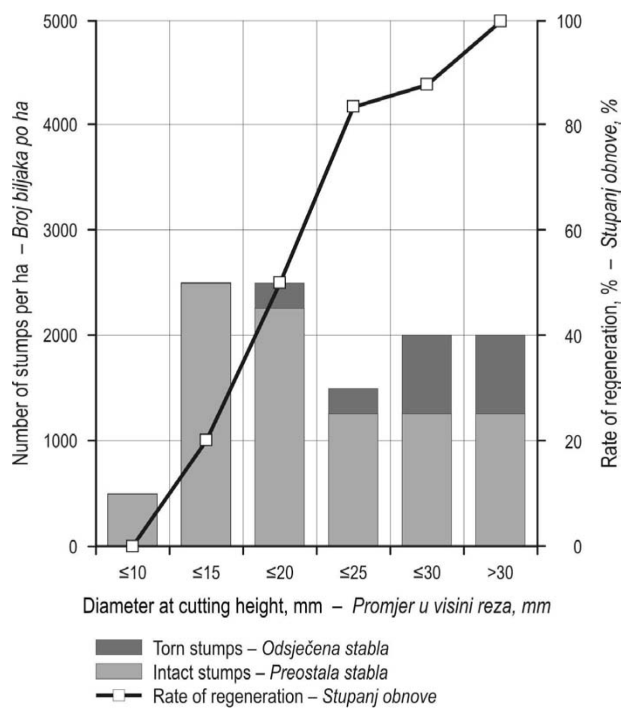

Fig. 6 The number of torn and intact stumps and the rate of regeneration by sprouting

Slika 6. *Broj odsječenih i preostalih stabala te stupanj vegetativne obnove* ed that reasonably well-grown trees are cut, mechanical harvesting is considered to have little influence on willow regeneration.

4. Discussion – *Rasprava*

Regarding the operational efficiency of the sugarcane harvester, the weight of harvested willows per hour listed in Table 4 is low and unsatisfactory, so machine productivity in a hypothetical model field is discussed. A model field of 270 m in length and 180 m in width is considered here (Fig. 7) and is a typical agricultural compartment in Hokkaido. It is assumed that a sugarcane harvester harvests willows and a forwarder collects removable net containers filled with willow billets. The following assumptions are also made:

⇒ Four strip roads for the forwarder are set up in the field, and the width of each road is 5 m. Data on the cutting speed in NH-Sanru (36.8 m/min) and the weight of harvested willows per container in NH-Sanru A (0.324 dry-t/container, see Table 4) are used here, while the operating times for turning around smoothly (26.5 sec/cycle), unloading (49.7 sec/cycle), and hooking up a container (93.7 sec/cycle) in Table 3 are also used;

⇒ The growing stock of willows per hectare at the time of harvesting is 30 dry-t/ha when the growing cycle and the annual increment are three years and 10 dry-t/ha/y, respectively, and the planting area is 4.50 ha (= 180 × 250 m) in consideration of the right-of-way of the four 5-m-wide strip roads. Therefore, the growing stock in the field is calculated as 135 dry-t;

⇒ The rows of willow trees are spaced at 1.8-m intervals for mechanical harvesting and perpendicular to the strip roads, so there are 100 rows (= 180/1.8) in the field; the growing stock in one row is thus calculated as 1.35 dry-t/row (= 135/100);

⇒ One cycle of the sugarcane harvester consists of cutting, unloading on a strip road, and hooking up a container. The harvester turns around once every four cycles;

⇒ Although the weight of harvested willows per container of 0.324 dry-t/container is slightly less than that of the growing stock to be harvested in one cycle (= 1.35/4), the cutting loss during operation is considered;

⇒ The forwarder collects four containers in one cycle and unloads them alongside a public road on the right side of the model field. The average running distance per cycle is 180 m; the running speed is estimated as 90 m/min, and the operating time for loading and unloading is each estimated as 1 min/container, i.e., 4 min/cycle.

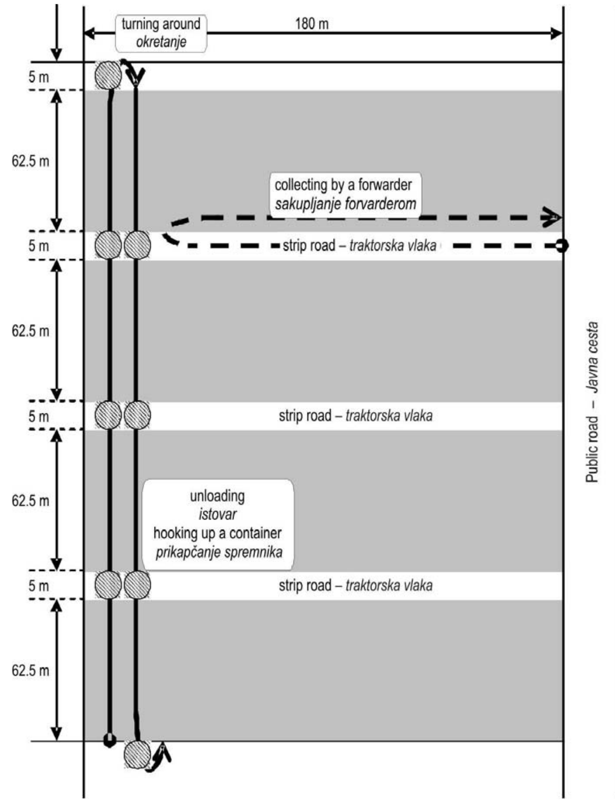

Fig. 7 Hypothetical model field
Slika 7. *Teorijski model radnoga polja*

As a result, the operational efficiency of the sugarcane harvester and the system performance in the model field are calculated as follows:

⇒ In terms of harvesting, the operations of cutting (36.8 m/min, i.e., 101.9 sec/cycle), unloading (49.7 sec/cycle), and hooking up a container (93.7 sec/cycle) are carried out 400 times (98,120 seconds in total), while the operation of turning around (26.5 sec/cycle) is carried out 100 times (2,650 seconds in total). The total operation time is 100,770 seconds, so the operational efficiency of the harvester is calculated as: 0.324 × 400 × (3,600 / 100,770) = 4.63 dry-t/h

⇒ Considering the running speed of 90 m/min, i.e., avg. 2 min/cycle and the operating times for loading and unloading of 4 min/cycle in each, the one cycle of a forwarder takes 10 minutes, so the operational efficiency of the forwarder is calculated as: 0.324 × 4 × (60 / 10) = 7.78 dry-t/h When the forwarder operates in parallel with the harvester, the system performance is calculated as: 4.63 × 7.78 / (4.63 + 7.78) = 2.90 dry-t/h

The system discussed here has the following four advantages: (1) capacity for handling narrow inter-rows; (2) tracked configuration allowing traversing of soft or steep terrain; (3) unitization of the product in bags, which allows independent harvesting and extraction, with all related benefits; and (4) better storage quality of billets compared to chips.

The average productivity of a sugarcane harvester with the same engine output as the studied one is 6.4 wet-t/h when harvesting sugarcane (from personal communications with an engineer from the machine manufacturer and a researcher from the Okinawa Prefectural Agricultural Research Center). Therefore, considering the water content of willow billets (about 120% on average on a dry-weight basis), it is expected that the performance of the sugarcane harvester in harvesting willows can be as much as that in harvesting sugarcane.

The system performance of 2.90 dry-t/h corresponds to 22.4 m^3/h of willow billets in volume. In order to discuss willow plantations as SRF, in principle, the cultivation process, e.g., reclamation of land, preparation of rooted cuttings, and application of fertilizer, should be considered in addition to the forwarding and collecting processes. However, a supply of low-cost willow chips could be achieved by introducing large, efficient transporting and chipping machines such as trailers and tub grinders.

5. Conclusions – *Zaključci*

In this study, an experiment on growing and harvesting of willow trees aimed at short rotation forestry was conducted in northern Japan. Willows were harvested using a sugarcane harvester from southern Japan during its agricultural off-season. The following conclusions are drawn:

⇒ The growing experiment showed the high potential of willow plantations to produce woody biomass of more than 10 dry-t/ha/y;

⇒ The harvesting experiment showed that space for turning around, one line in one row as a planting method, a growing cycle of three years, and an extractor fan in the harvester are necessary for mechanical harvesting;

⇒ Mechanical harvesting was considered to have little influence on willow regeneration provided that the machine cut reasonably well-grown trees;

⇒ The system performance of harvesting and collecting willow billets in a hypothetical model field was calculated as 22.4 m^3/h, suggesting the feasibility of supplying low-cost wood chips.

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Sažetak

Primjena kombajna za šećernu trsku pri pridobivanju energijskoga vrbova drva iz kultura kratke ophodnje: pokus u Japanu

U radu su prikazani uzgojni postupci, pridobivanje i upotreba energijskoga vrbova drva iz sastojina kratkih ophodnji u sjevernom Japanu. Istraživane su dvije vrste vrba, Salix schwerinii *E. Wolf. i* Salix sachalinensis *F. Schmidt, koje su autohtone vrste na Hokkaidu. Za sječu vrbovih stabala korišten je kombajn za šećernu trsku kako bi se povećala njegova iskoristivost izvan sezone žetve šećerne trske. Uzgojni postupci koji su provedeni u istraživanju pokazali su da plantaže vrbâ imaju velik potencijal u proizvodnji suhe tvari, i to do 10 tona suhe tvari po hektaru godišnje, čak i uz intenzivnu primjenu uzgojno-tehničkih mjera.*

Cilj je ovoga istraživanja bio ispitati primjenjivost kombajna za šećernu trsku pri pridobivanju energijskoga vrbova drva iz sastojina kratkih ophodnji. Pri provođenju uzgojnih postupaka istraživan je prirast biljaka pod utjecajem borealne klime, zatim uzgojne metode za povećanje prirasta, dok su metode za melioraciju tla, sadnju i uzgojni postupci pogodni za upotrebu mehaniziranoga pridobivanja drva raspravljeni u pokusima pridobivanja drva. Uz to su istraživani učinkovitost i potrošnja goriva, dok je utjecaj mehaniziranoga pridobivanja energijskoga drva na vegetativnu obnovu sastojina samo procijenjen.

Postavljene su dvije pokusne plohe za uzgojne radove na sjevernom dijelu Hokkaida (NH) te dvije na istočnom dijelu (EH). Plohe su podijeljene u 16 odjeljaka na koje su posađene oživljenice 30 različitih vrsta klonova. Istraživani su gustoća sadnje (0,5 × 0,5 ili 1,0 × 0,5) i utjecaj čepovanja na proizvodnju drvne tvari. Čepovanje je provedeno nakon prve godine. Nakon završetka istraživanoga razdoblja od tri godine na odjeljcima gdje je provedeno čepovanje računat je prosječni godišnji prirast za dvije godine, dok je na odjeljcima gdje nije provedeno čepovanje računat prosječni godišnji prirast za tri godine.

Pokusi pridobivanja energijskoga drva provedeni su na dvije pokusne plohe postavljene na sjevernom Hokkaidu (NH), prva je ploha naknadno podijeljena u odjeljke Ich (A, B, C), dok je druga podijeljena na odjeljke Sanru (A, B); uz to je postavljena jedna pokusna ploha na sjeveroistočnom Hokkaidu (NEH) gdje istraživane vrbe rastu prirodno (tablica 1, slika 3). Za pridobivanje energijskoga vrbova drva korišten je gusjenični kombajn za šećernu trsku (slika 3) snage motora 78 kW pri 2200 okretaja. Princip je rada kombajna sljedeći: 1) sječivo siječe trsku/drvo pri tlu; 2) pomoću sustava valjaka dovodi trsku/drvo do bubnja za sječenje, koji je prilagođen tako da siječe komade drva dužine do 25 cm; 3) nakon bubnja za sječenje isječena trska/drvo dolazi u separator gdje se odvajaju biljne i mineralne nečistoće (blato, sitne grančice koje se izbacuju nazad na proizvodnu površinu); 4) nakon separatora komadi trske/drva ulaze u spremnik. Nakon što se spremnik napuni, kombajn izlazi na pomoćno stovarište te se zamjenjuje spremnik. Spremnici su vagani pomoću kamionskih vaga te se na osnovi toga izračunala suha tvar na osnovi procjene udjela vode u komadima vrbovine.

Tijekom istraživanja proveden je i studij rada i vremena s radnim elementima: kretanje s praznim spremnikom, sječa, okretanje, kretanje s punim spremnikom, istovar, prikapčanje praznoga spremnika i ostalo.

S obzirom na to da je kombajn sjekao komade drva dužine do 25 cm, potreban je dodatni stroj (iverač) kako bi se dobio proizvod primjeren za upotrebu.

U tablici 2 prikazani su rezultati uzgojnih postupaka. Neovisno o gustoći sadnje, vrsti vrbe ili istraživanoj plohi, odjeljci gdje je provedeno čepovanje imali su veći prosječni godišnji prirast nego plohe gdje nije provedeno čepovanje. Ovisno o gustoći sadnje, plohe na kojima je Salix schwerinii *E. Wolf sađena rjeđim rasporedom sadnice imale su veći prirast nego plohe na kojima je sađena gušće, dok je u slučaju sadnje* Salix sachalinensis *F. Schmidt situacija bila obrnuta. Prosječni je godišnji prirast na svim plohama veći od 6 tona suhe tvari po hektaru, a na plohi na istočnom dijelu Hokkaida prirast je veći od 10 tona suhe tvari po hektaru godišnje.*

Na slici 4 prikazani su rezlutati studija rada i vremena, dok su na slici 5 prikazani rezultati ovisnosti gustoće sadnje o brzini sječe. S obzirom na to da je na plohi NH Sanru B postojao nedostatak spremnika, vrijeme za istovar i prikapčanje novoga spremnika je kraće. Prosječni utrošci vremena radnih sastavnica prikazani su u tablici 3, iz čega se može iščitati potreba za prostorom za okretanje kombajna. Odnos gustoće sadnje i brzine sječe prikazan je na slici 5, za koji je izračunat koeficijent korelacije – 0,246, što znači da nema povezanosti za razinu značajnosti od 0,05. U slučaju brzine sječe primijećeno je kako brzina ovisi o dobi biljaka, odnosno promjeru na panju.

U tablici 4 prikazana je potrošnja goriva, masa suhe tvari po satu te masa suhe tvari po spremniku. Na plohama NH Sanru praćena je upotreba separatora, u odjeljku A je separator bio uključen, dok je u odjeljku B bio isključen.

Nije zamijećeno povećanje potrošnje goriva, ali je uočeno da su spremnici u odjeljku B imali manju masu zbog neodvajanja sitnih grančica pomoću separatora. U obliku prikupljanja drva, ali i vraćanja dijela hraniva u tlo separator bi trebao biti uključen.

Na slici 6 prikazan je stupanj vegetativne obnove istraživanih ploha nakon provedene mehanizirane sječe, koji pokazuje da mehanizirana sječa nema nikakav negativni utjecaj na vegetativnu obnovu vrbovih sastojina kratkih ophodnji.

Kako su podaci iz tablice 4 o učinku kombajna niski i nezadovoljavajući, rasprava se temelji na teorijskom radnom polju prikazanom na slici 7, a koje predstavlja tipično radno polje na Hokkaidu. Za izračun modela korišteni su podaci o brzini sječe i masi punoga spremnika iz tablice 4, dok su vremena radnih sastavnica preuzeta iz tablice 3. Očekivana je zaliha na polju nakon ophodnje od 3 godine 135 tona suhe tvari po hektaru ili 1,35 tona u jednom redu, koji su posađeni na razmaku od 1,8 m. Forvarder u jednom ciklusu skuplja 4 spremnika i istovara ih uz rub javne prometnice, a vrijeme ciklusa je 10 min. Na temelju teorijskoga modela dobivena je proizvodnost kombajna od 4,63 tona suhe tvari po satu, dok je proizvodnost forvardera 7,78 tona suhe tvari po satu. Sustav opisan ovdje posjeduje četiri prednosti: 1) mogućnost rada u malom međurednom razmaku; 2) gusjenični kombajn omogućuje rad na nagnutom terenu; 3) mogućnost pohrane proizvoda u vreće, što omogućuje razdvajanje procesa sječe i izvoženja i 4) bolja kakvoća uskladištenih komada vrbe u usporedbi s iverjem.

Učinkovitost ovakva načina proizvodnje energijskoga drva od 22,4 m^3/h upućuje na mogućnost pridobivanja velikih količina jeftinoga iverja.

Ključne riječi: kulture kratkih ophodnji, vrba, kombajn za šećernu trsku, pridobivanje drva, Japan

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Received (*Primljeno*): December 9, 2011
Accepted (*Prihvaćeno*): January 9, 2012