Experiment on harvesting willow trees aimed at short rotation forestry

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Abstract: Harvesting willow trees aimed at short rotation forestry was experimented in northern Japan. For harvesting willows, a sugarcane harvester which was used in southern Japan was applied during its agricultural off-season. From the results of the experiment, the space for turning around, one line in one row in a planting method, a growing cycle of three years, and the running of an extractor fan of the harvester seemed to be necessary for mechanical harvesting. The system performance of harvesting and collecting willow billets in a hypothetical model field was calculated 22.4 m^3/h, suggesting the feasibility of the low-cost supply of wood chips.
Keywords: harvesting, Japan, short rotation forestry, sugarcane harvester, willow

要旨：短伐期林業を想定したヤナギの収穫実験を北海道で行った。実験には，沖縄県でサトウキビの収穫に使用されているケーンハーベスタの農閑期を活用した。その結果，機械による収穫のためには，圃場の整備方法として機械の旋回スペースの確保，ヤナギの植栽方法として一条植，3 年の収穫サイクル，枝葉や梢端部除去のための風選ファンの稼動が，それぞれ必要であると考えられた。北海道の殖民区画を参考にしたモデル圃場における収穫・収集システムの生産性が 22.4 m^3／時と試算されたことから，ヤナギチップを低コストで供給できる可能性が示唆された。
キーワード：収穫，北海道，短伐期林業，ケーンハーベスタ，ヤナギ

I Introduction

Short rotation forestry (SRF), where the fast growing tree species such as eucalypt, poplar, and willow are reforested by rooted cuttings and the sprouting stumps are harvested repeatedly in short-term cycles of several years, has been carried out mainly for the purpose of producing pulp chips. In recent years, the SRF as a new source of woody biofuel is drawing a great deal of attention worldwide. 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 during 1986-2000 (*4*). In other European countries and North America, the harvesting operations by agricultural and forestry machines aimed at the SRF have been experimented (*5-9*). Similarly in Japan, woody biomass from the SRF is defined as 'energy crops' and considered next to 'unused biomass' such as logging residues in terms of resource availability in the 'Biomass-Nippon Strategy' (*1*).

In this study, an experimental project for growing, harvesting, and utilizing willow trees in Japan is introduced. The project is now being carried out in the Hokkaido prefecture, which is located in the northern part of Japan and is in the boreal forests, 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 *Salix sachalinensis*, which are the indigenous willow species of Hokkaido, is assumed to be three years, and a high annual yield of 10 dry-t/ha/y is expected in spite of extensive cultivation. A sugarcane harvester which is used in the Okinawa prefecture of southern Japan was applied to the experiment on harvesting willow trees. The machine was shipped to the test site for more than 2,000 km during its agricultural off-season.

The machine usually harvests sugarcane in the following manners: (1) basecutter cuts the sugarcane at ground level and helps to feed the cane stalks to the butt lift roller; (2) butt lift roller lifts the sugarcane stalks cut by the basecutter and guides them into the machine feed rollers; (3) feed rollers transport and horizontally feed the cane stalks to the chopper drums; (4) chopper drums cut the sugarcane and send the billets to the extractor chamber; (5) primary extractor cleans the billets by removing the vegetable and mineral impurities; and (6) removable net container receives the sugarcane billets from the chopper. With respect to the application of a sugarcane harvester to harvesting other crops in Japan, KOBAYASHI *et al.* improved the machine for kenaf (*Hibiscus cannabinus*) and examined the performance (*3*), and IWASAKI *et al.* experimented for harvesting wood species (*2*).

II Materials and methods

Three sites were established for harvesting experiments. Two of the three were in the northern Hokkaido (NH), and the other was in the northeastern Hokkaido (NEH), where the indigenous willows grew naturally and the site was prepared for the experiment by leaving the rows of willow trees and cutting the other ones.

The experiment was carried out with a crawler-type sugarcane harvester (Fig. 1, UT-100K, Uotani-tekkou, Inc., Japan). Its engine had an output of 78 kW/2,200 rpm and the cubic capacity of its removable net container (Fig. 2) was 2.5 m^3. The machine operated for the harvest of willow trees with the

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Fig. 1 Sugarcane harvester

Fig. 2 Removable net container

Fig. 3 Willow billet

same manners mentioned above, and then moved to a landing for unloading when the container was filled with willow billets. A time study was conducted during the experiment, so the work elements of the time study were moving with no load, cutting, turning around, moving fully-loaded, unloading, hooking up a container, and others. Cutting length of the willow billet was set to 25 cm (Fig. 3), meaning the necessity of secondary chipping of the harvested willows for using them as fuel of a direct combustion equipment such as a boiler. Fuel consumption during the experiment was measured, and the weights of the filled containers were also measured with a truck scale and then converted to the dry weights by estimating the water content of the billets.

In the experiment, the operational efficiency and the fuel consumption according to the presence or absence of space for turning around, the planting method (one line or two lines in one row), the planting density, and the running or non-running of an extractor fan were examined. Outline of the three test sites is shown in Table 1. There were two sites in the NH, *i.e.*, 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, age of the trees was uneven (3- to 5-year-old, see Table 1) so that there were some trees whose diameters at ground level were more than 10 cm. In addition, the densities of stumps per unit area were different for each row in the NEH site, so, throughout the experiment, the influence of planting density on the machine's cutting speed was also examined.

III Results

The result of the time study is shown in Fig. 4, and the relationship between the planting density and the cutting speed in Fig. 5. The stock of removable net containers prepared for the experiment had run out during operation in the NH-Sanru B compartment; afterwards, the operation continued without a container. So, the operating times of unloading and hooking up a net container of the NH-Sanru B in Fig. 4 are short.

The percentage of the operating time of turning around to the total observed time is low in the NEH site, while those in the NH-Ichi and NH-Sanru sites are relatively higher; this difference is because of the presence or absence of space for turning around (see Table 1). The average operating time of work elements in Table 2 shows that turning around with difficulty took over twice longer time than turning around smoothly, suggesting the importance of space for turning around when considering the introduction of mechanical harvesting.

The correlation coefficient between the planting density and the cutting speed in Fig. 5 is calculated -0.246, so it is recognized that there is no definite correlation at a 0.05 significant level. In terms of the cutting speed in each test site, that in the NEH (3- to 5-year-old) is 28.3 m/min (the standard deviation (SD) = 5.25 m/min), that in the NH-Ichi (2-year-old) is 41.2 m/min (SD = 11.0 m/min), and that in the NH-Sanru (3-year-old) is 36.8 m/min (SD = 6.55 m/min), showing a trend that the cutting speed decreases roughly in proportion to the age (or diameter at ground level) of willow. During the experiment, the operator controlled the cutting speed of the harvester since it was often the case that the machine could not pick up and "swallow" cut willows when accelerating the speed. Concerning this cutting loss problem, it was observed that the machine had difficulty in swallowing willow branches jutting 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), the row of willow

Table 1 Outline of the three test sites

Item	NEH	NH-Ichi A	NH-Ichi B	NH-Ichi C	NH-Sanru A	NH-Sanru B
Age [y]	3-5	2	2	2	3	3
Number of row	12	13	8	8	10	10
Length of row [m]	100	65	65	65	80	80
Space for turning around	5 m	No	No	No	No	No
Planting method (in one row)	Wild-grown	Two lines (dense)	Two lines (sparse)	Two lines (houndstooth)	One line	One line
Planting density [stumps per 100 m^2]	Avg. 102 (SD = 25.9)	136	72	68	100	100
Extractor fan of the harvester	Running	Running	Running	Running	Running	Non-running

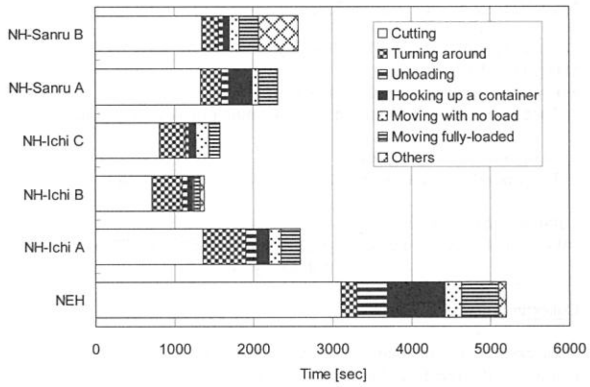

Fig. 4 Result of the time study

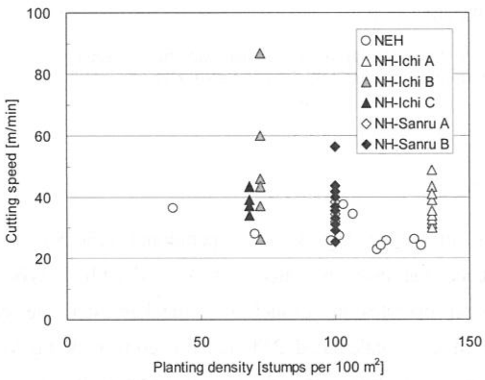

Fig. 5 Relationship between planting density and cutting speed

Table 2 Average operating time of work elements

Work element	Number	Avg. [sec/cycle]	SD [sec/cycle]
Turning around (smoothly)	23	26.5	8.45
Turning around (with difficulty)	22	60.5	17.0
Unloading	16	49.7	18.2
Hooking up a container	15	93.7	23.9

plantation was wider than the horizontal clearance of the "mouth" of the harvester. Therefore, for mechanical harvesting, one line in one row seems to be a desirable planting method.

Here describes the details of the operating time of others in Fig. 4. The operation had 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 gave feedback that the maximum diameter of willow which the machine could cut down was considered to be 7 cm, suggesting that a growing cycle of three years is appropriate from the point of view of mechanical harvesting. On the other hand, one of the basecutter knives was repaired because the machine "bit" stones in the gravelly soil in the NH-Sanru B compartment. Cutting height can be adjusted from an operator's seat so that the height was heightened during the experiment in order to avoid the breakage of knives. In the NH-Sanru B, however, the cutting height of the crawler-type harvester changed due to the ground roughness so that the machine dug up stones in the soil. Consequently, with consideration of harvesting willow trees mechanically, a land for cultivation should be reclaimed. Furthermore, a sugarcane harvester is originally designed to cut sugarcane at 5 cm under ground level, so the improvement of a basecutter seems to be necessary for applying the machine to willow harvesting.

Table 3 lists the fuel consumption and weight of harvested willows per hour and the weight per container (the weight per hour in the NH-Sanru B is not calculated due to the runout of the stock of containers, as mentioned above). In the NH-Sanru site, where the running (NH-Sanru A) or non-running (NH-Sanru B) of an extractor fan of the harvester was examined, there is no difference between the NH-Sanru A and B compartments in terms of the fuel consumption. However, the weight of harvested willows per container in the NH-Sanru B is lighter than that in the NH-Sanru A; a lot of tops and branches dropped into a net container in the NH-Sanru B because the extractor fan stopped during operation. For prioritizing the acquirement of wood fiber as well as returning minerals to the soil, the fan should be activated.

IV Discussion

From the aspect of the operational efficiency of the sugarcane harvester, the weights of harvested willows per hour listed in Table 3 are low and unsatisfactory, so the machine productivity in a hypothetical model field is discussed. The model field, of which length and width are 270 m and 180 m, respectively, is considered here (Fig. 6) and is a typical agricultural compartment in the Hokkaido prefecture. It is supposed that a sugarcane harvester harvest willows and a forwarder collect removable net containers filled with willow billets, and the following assumptions are made:

- Four strip roads for the forwarder are set up in the field, and the width of each road is 5 m. Data of the cutting speed in

Table 3 The fuel consumption and weight of harvested willows per hour and the weight per container

Site	Fuel consumption per hour [L/h]	Weight of harvested willows per hour [dry-t/h]	Weight per container [dry-t/container]
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

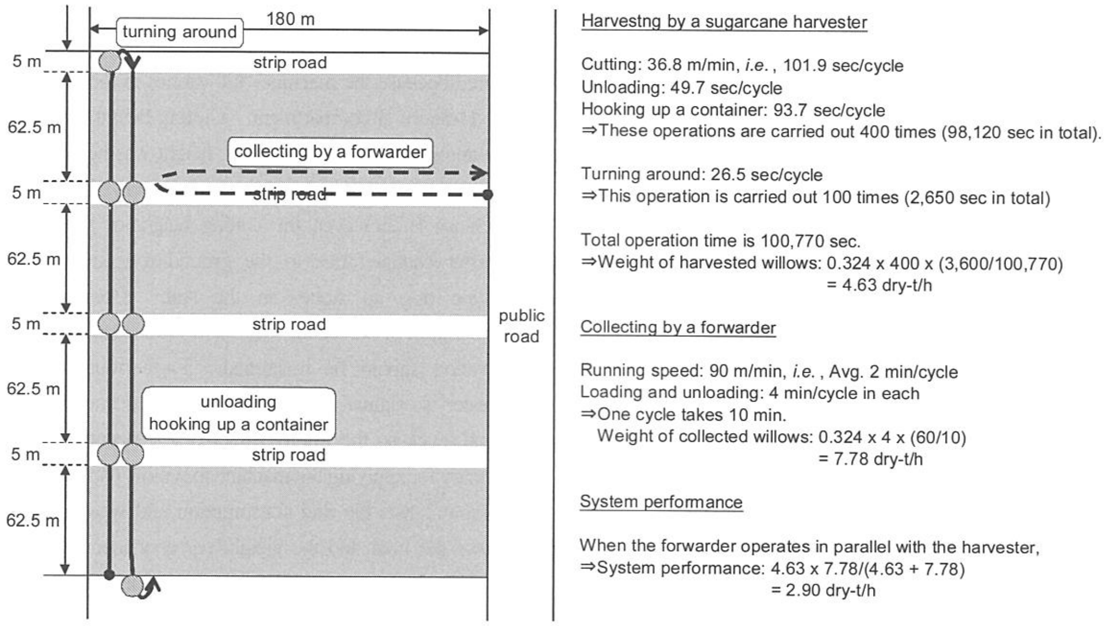

Fig. 6 Hypothetical model field

the NH-Sanru (36.8 m/min) and the weight of harvested willows per container in the NH-Sanru A (0.324 dry-t/container, see Table 3) are used here, while the operating times of turning around smoothly (26.5 sec/cycle), unloading (49.7 sec/cycle), and hooking up a container (93.7 sec/cycle) in Table 2 are also used;

- The growing stock of willows per hectare at the time of harvest 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 m x 250 m) with consideration of the right-of-way of the four strip roads of which widths are 5 m. Therefore, the growing stock in the field is calculated 135 dry-t;
- Rows of willow trees are 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 then calculated 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 in 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 occurrence of the cutting loss during operation is considered;
- The forwarder collects four containers in one cycle and unloads them alongside a public road located along the right side of the model field. The average running distance per cycle is 180 m; running speed is estimated 90 m/min, while each operating time of loading and unloading is also estimated 1 min/container, *i.e.*, 4 min/cycle.

As shown in Fig. 6, the operational efficiency of the sugarcane harvester is calculated 4.63 dry-t/h. When the forwarder operates in parallel with the harvester, the system performance is calculated 2.90 dry-t/h, corresponding to 22.4 m^3/h of willow billets in volume. In order to discuss willow plantation as SRF, essentially, the cultivation process, *e.g.*, reclamation of land, preparation of rooted cuttings, application of fertilizer, should be considered in addition to the forwarding and collecting processes. However, the low-cost supply of willow chips can be expected by introducing large efficient transporting and chipping machines such as a trailer and a tub grinder.

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