

Development and Utilization of a New Mechanized Cabbage Harvesting System for Large Fields

Mitsuru HACHIYA^{1*}, Tetsuro AMANO², Makoto YAMAGATA³ and Makoto KOJIMA³

^{1,3} Department of Integrated Research, National Agricultural Research Center for Hokkaido Region (Kasai, Hokkaido 082–0071, Japan)

² Department of Integrated Research, National Agricultural Research Center for Hokkaido Region (Sapporo, Hokkaido 065–8555, Japan)

Abstract

In establishing a technology system for labor saving in cabbage production, the most important issues are streamlining harvesting, reducing the work load, and reducing the amount of time required. We developed a mechanized trailer-supported harvesting system for cabbage growers in upland field areas. The system will benefit family-managed farms. The system, which requires only three people to operate, consists of a harvester, remote-controlled tractor, and a trailer, where the cabbage can be processed, boxed and palletized. We investigated the suitability of this system from the point of work efficiency, ergonomics, and farm management through trials on a commercial farm. This article presents the results of the field tests of the system.

Discipline: Agricultural machinery

Additional keywords: harvester, trailer system, labor saving, ergonomics, upland agriculture

Introduction

In large-scale upland rotation-crop areas in Tokachi-Hokkaido, the average farm household has primarily been cultivating wheat, sugar beets, potatoes, and beans on upland fields of about 30 ha of land. The prices of these crops have stagnated. To maintain farm household incomes, and to increase the variety of rotation crops, farmers have had to introduce vegetable production. Although the profitability of vegetable production per 10 a exceeds that of wheat or soybeans, the amount of time required per unit area is much higher than that for other crops. As shown in Fig. 1, compared to wheat (2 h-person/10 a), and soybeans (11 h-person/10 a), vegetables such as Chinese yam, edible burdock (sorted individually), and cabbage require many more hours of work: 51 h-person/10 a, 63 h-person/10 a, and 48 h-person/10 a, respectively³. Under such conditions even if agricultural expenditures rise and agricultural income per 10 a generated in vegetable production somewhat decreases, if the area of vegetable production can be greatly expanded by

mechanization, total agricultural income generated by the farm can be expanded. Development of labor saving technology in such a direction is necessary in the Tokachi region. Cabbage had shown constant increases in planted area, but after peaking at 2,820 ha in 1995 planted area started to decrease. It decreased to 2,080 ha, or 70% of its peak, in 2001. The decline in prices, caused by vegetable imports, has contributed to this trend, but other factors for the decrease have been a shortage of labor for harvesting and the heavy workload involved in manual harvesting^{1,6}.

Outline of the mechanized trailer-supported cabbage harvesting system

The testing of the new mechanized trailer-supported cabbage harvesting system was conducted with the goal of quickly introducing it to regular cabbage production. The system is considered to be the first step in a semi-automated system that addresses the needs of large-scale cultivation.

Examination of the new system of mechanized cab-

Present address:

¹ Crop Production Machinery and System Department, Institute of Agricultural Machinery (Saitama, Saitama 331–8537, Japan)

*Corresponding author: fax +81–48–654–7129; e-mail mhachiya@affrc.go.jp

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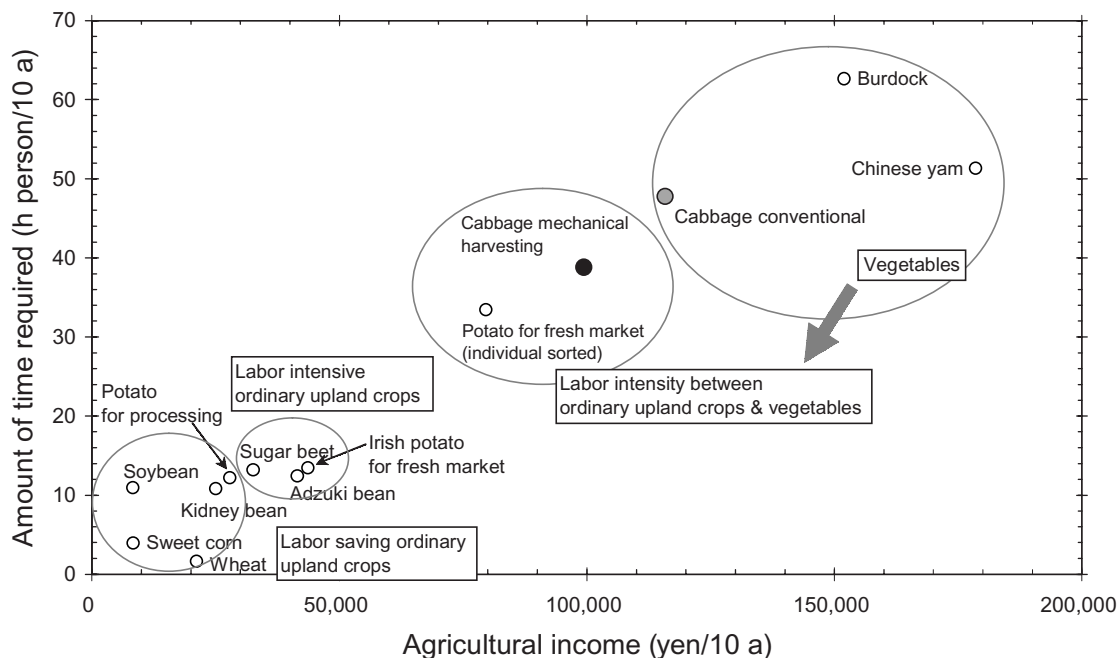


Fig. 1. Agricultural income vs. amount of time required by crop⁵

The calculations are based on the results of a survey conducted in Memuro-Tokachi. Vegetable prices are based on the *Annual Report on Wholesale Market of Vegetables and Fruits*, Sapporo Market. The agricultural income is after agricultural cash expenses and depreciation expenses were subtracted from the agricultural gross income. The family labor expenses are not included in the agricultural expenses.

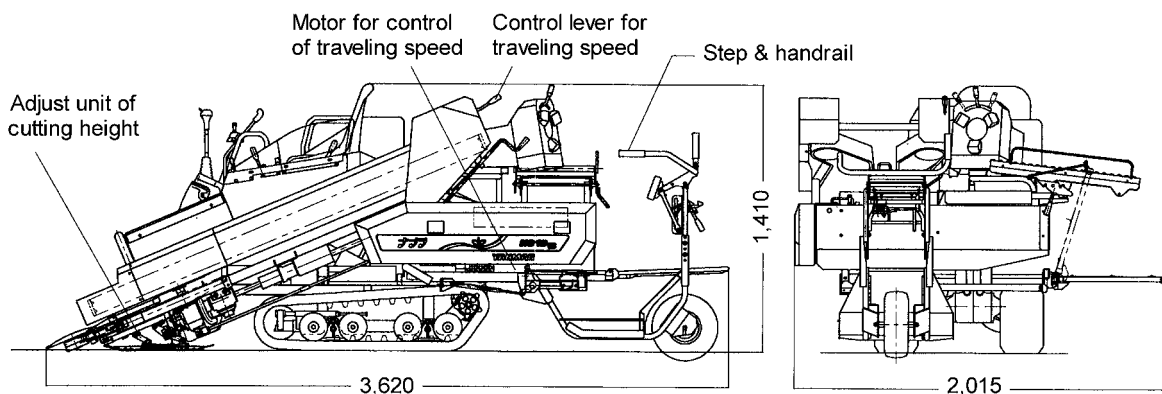


Fig. 2. Cabbage harvester improved for one-man operation

bage harvesting was conducted with consideration for its early introduction in the field. The system is considered to be the first step in improving a man-machine system that addresses the need for large-lot cultivation. Mechanization and rationalization of product handling and a decrease in costs have been realized through use of a tractor and a trailer, both of which are already owned by ordinary cabbage growers. A tractor and a trailer were the platform of the system, to which were attached simple equipment such as a belt-conveyer and a roller-conveyer. Outlines of each part of the system are as follows:

(1) The harvester was developed jointly by the BRAIN-Institute of Agricultural Machinery and a private company through the “Urgent Development of Agricultural Machinery and It’s Commercial Enterprises Project”, and was commercialized in late 2001. The harvester guides and pulls out cabbage plants using 2 counter-rotating disks. Another rotating disc blade cuts off the stem and outer leaves while cabbages are carried up toward the rear of the machine, where processing equipment cuts off any remaining unnecessary parts. The design concept of the manufacture of this harvester origi-

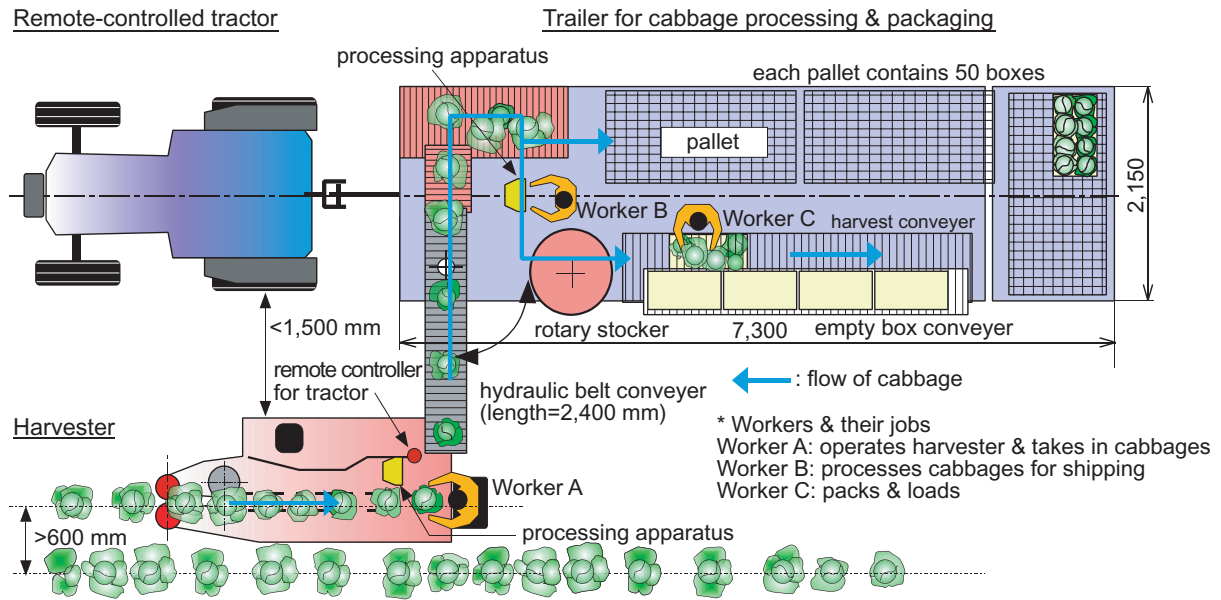


Fig. 3. Schematic diagram of trailer-supported mechanized harvesting system based on harvester improved for one-man operation

nally called for operation by 2 workers. We improved this machine to be operable by one person stationed at the rear of the machine, who is able to steer and to adjust the cutting height and traveling speed (Fig. 2).

(2) The tractor portion of the system is controlled by Worker A, the harvester operator, who is able to control the engine speed, steer, and shut down engine devices in case of an emergency. The tractor pulls a trailer, the third part of the system, which has a hydraulic conveyor protruding horizontally and carries the cabbage to the trailer from the harvester (Fig. 3). It is easy to adjust manually. This improvement made it possible for Worker A to safely and easily load the cabbage onto the conveyor.

The conveyor gradient is also easily adjustable. Worker B, riding on the trailer, picks the cabbage off the belt conveyor and processes cabbage by removing 2 or 3 outer leaves then placing it on the rotary stocker. On the left side of the trailer, 2 roller conveyers are installed for packaging and loading. The first sloped conveyor carries stacks of empty corrugated boxes (5 boxes per stack) to Worker C, and the second conveyor is used as a work table for Worker C, who puts 7 or 8 heads into each box, depending on the shipping standards. The second conveyor also carries the packed boxes to the rear of the trailer to be stacked on pallets by Worker C. Each pallet contains 50 boxes (according to the current shipping method). The trailer has space for 3 pallets, which can hold cabbage from 3.2 a (One returning operation can cover an area of 1.2 m (0.6 m × 2 rows), and a row length of approx. 270 m. Therefore, the harvested area is $270 \times 1.2 = 320 \text{ m}^2$ or approx. 3.2 a).

Working performance of the harvesting system

Prior to field testing the trailer-supported cabbage harvesting system on a commercial farm in Tokachi, a test was conducted to estimate the quality of work of the harvester. 3 varieties of cabbage were used—ball type, sour type and *kandama* type. From 1.5 to 3.0% of the harvested heads were discarded because they were cut too deeply by the machine, and are considered a “cutting loss”. No soil was seen on the harvested cabbage and there was no difference between the varieties in the num-



Fig. 4. Harvesting, processing, boxing and loading unified in one harvesting system

ber of the outer leaves removed. These test results show that cutting accuracy was sufficient for practical use. The producers on the experimental farm and on the neighboring cabbage farms gave generally satisfactory evaluations of the harvester cutting precision. Therefore the key to the rapid dissemination of the harvester is the systematization of harvest work using this harvester as its core, and the systematization must be appropriate for the farm scale and the crop rotation system of each production area.

The field test for the trailer-supported harvesting system was conducted in Tokachi. The farm used as the test site was 25 ha in size (including 2.3 ha planted in cabbage) with a work force of 3, all family members. Fig. 4 shows the harvest system in operation. As shown in Table 1, the yield averaged from 386 to 501 boxes/10 a. About 1% of the harvested heads were discarded because of being cut too deeply by the machine or other damage.

The rate of shippable heads was not stable, being from 70 to 80%. More than 20% of the harvested cabbage heads were discarded because they were below the standard size. From these experiments we confirmed the importance of establishing technology to unify the size of cabbage for enabling mechanized non-selective harvesting^{4,10}. Traveling speed was about 10 cm/s. This was considered a suitable speed so as not to overload the

worker. Worker A standing on the step attached to the rear of the harvester could slightly adjust the cutter so that it did not stick into the soil, and thus was able to continue to run the harvester without stopping. A forklift unloaded the boxed cabbage on the pallet after every round trip. Field efficiency of the trailer-supported harvesting system exceeded 80% because there was no need to stop the harvester for unloading. Amount of time required was about 18 h·person/10 a, i.e. more than 50% less time than conventional manual harvesting, which requires 37.8 h·person/10 a⁶. In general, the conventional manual harvesting work is the following. The worker carries out the repetition of cutting each cabbage with a kitchen knife and filling each box in order along the furrow. The workers pile the boxes of cabbage on a truck cargo stand after harvesting.

Effectiveness of introducing new system in terms of ergonomics

We measured and analyzed work strain and working posture during different steps in the process of conventional manual harvest and mechanized harvest. In order to measure work strain, a heart rate monitor (VINE Co.) with electrodes that attach to the chest was used with a 0.1 Hz sampling frequency. To measure posture, electro-

Table 1. Test results of the trailer-supported harvesting system for cabbage

Test no.		1*	2**	3***
Tested field area	[a]	8.6	5.7	5.9
No. of workers	[persons]	3	3	3
Yield	[t/10 a]	6.1	4.7	5.2
		(501 boxes/10 a)	(423 boxes/10 a)	(386 boxes/10 a)
Average head weight	[g]	1,516 ± 150	1,387 ± 160	1,633 ± 86
Head shape index (= height/dia.)	[-]	0.79	0.73	—
Traveling speed	[cm/s]	8.81	9.89	9.50
Percentage of sub-standard heads	[%]	20.3	29.4	37.3
(1) sub-standard	[%]	13.3	23.5	14.1
(2) split	[%]	0.8	0.6	13.2
(3) diseased or pest-damaged	[%]	4.3	3.6	3.2
(4) injured by machine	[%]	0.4	0.2	0.7
(5) deep cut	[%]	0.6	0.4	2.3
(6) other	[%]	0.9	1.1	3.7
Rate of work	[h/100 boxes]	1.24	1.37	1.66
Amount of time required	[h·person/10 a]	18.8	17.4	19.2
Field efficiency	[%]	84.2	80.4	76.2

* Test no.1: Direct sowing on June 17 & harvesting on Sept. 11, 2002.

** Test no.2: Direct sowing on June 24 & harvesting on Sept. 13, 2002.

*** Test no.3: Direct sowing on May 15 & harvesting on Aug. 13, 2003.

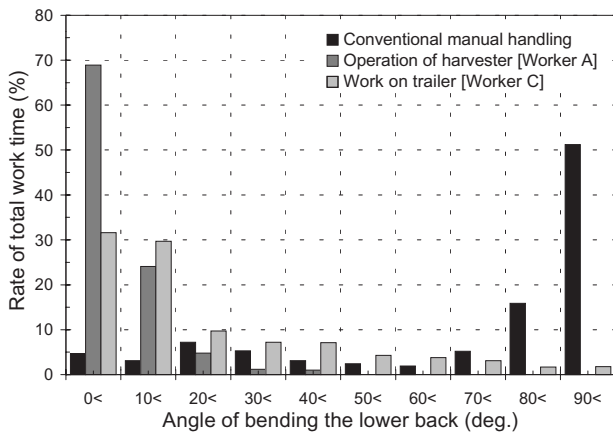


Fig. 5. Classification of working postures based on the harvest work system

static-capacity-type inclination sensors (VINE Co.), with a 2 Hz sampling frequency, were used. They were attached at 7 points of the body, including upper arm, femur, and trunk. As shown in Fig. 5, the angle at which workers have to bend at the waist was small in mechanized harvest. The operator of the harvester bent forward within a range of 10° and Worker C on the trailer about 10 to 15°. The conventional system requires a worker to bend to an angle of 111° as the mode value. There was no significant bending problem with the positions of the lower limbs of the workers. Compared with conventional manual harvesting, the test revealed that work postures were greatly improved and workload was reduced.

During harvesting work using the mechanized system we developed, two subjects' heart rate ranged from 96 to 99 beats/min, an increase of 31 to 33%, compared to at rest (Fig. 6). Taking into account personal age differences among subjects, their work intensity under mechanized work was confirmed to be equivalent to a "relative heart rate"⁹ of 53 to 58% HRmax against

70.3 ± 2.9% HRmax during conventional manual harvesting. The results show that the mechanized trailer-supported harvesting system improves the working conditions of the laborer. The work intensity level equaled moderate physiological loads based on the increase in the worker's heart rate. Regarding the relative heart rate as the index, the optimal continuous work period estimated from workload^{2,5,7} can be calculated as follows:

$$t = \text{antilog}_{10}(\log 5700 - 0.019 \times \text{HRmax} + 0.567) \quad (1)$$

where:

$$\text{HRmax} [\%]^* = \text{Ave. of HR} [\text{beats/min}] / \text{Estimated max. of HR} [\text{beats/min}]$$

$$\text{Estimated max. of HR}^{**} = 220 - \text{age}$$

*: relative heart rate

** : estimated using the American Heart Association equation

The total rest time necessary⁸ to recover from fatigue is estimated using the following equation:

$$Tr = Tw \cdot (e - b) / e - 1.5 \quad (2)$$

where:

Tr = rest time [min]

Tw = work time in a day [min]

e = physical working strength [Vo₂max]

b = permitted limit for physical working strength [Vo₂max]

The optimal continuous work period based on the heart rate of the test subjects is estimated to be approximately 2 to 2.5 h. Furthermore, to work continuously, a total of 1.5 h of rest time is necessary or desirable during an 8-hour workday, i.e. 6.5 h of actual work time in a day. One series of operations in the 2002–2003 field experiment took approximately 2 h, which is an appropriate length of time for a work period in terms of work intensity. As a result, it was determined, using proportional allotment

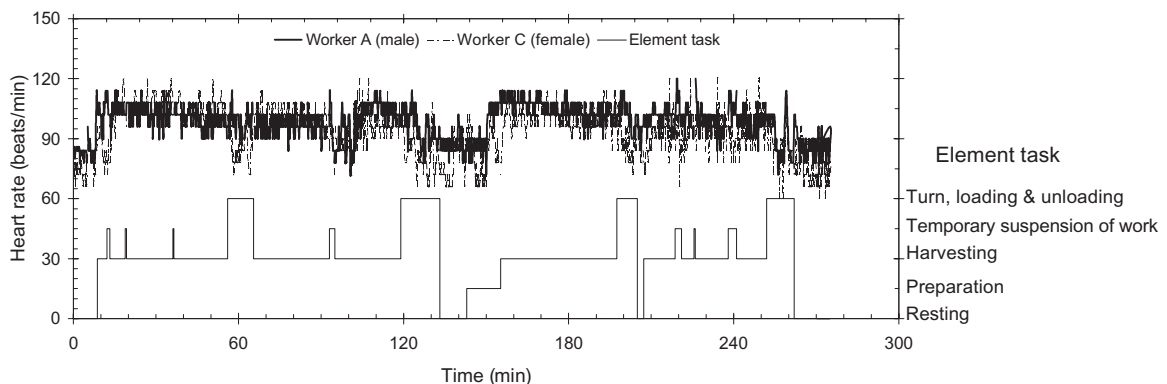


Fig. 6. Changes in heart rate during continuous mechanized harvesting work

based on the data in Table 1 (rate of work-1 & -2), that 3 workers can harvest, without overstraining themselves, 11 to 12 a in one day (assuming an interrow distance of 60 cm).

Suitability of system from a farm management viewpoint

The mechanical harvesting system consists of the cabbage harvester for one-man-operation improved by us. A remote-control tractor and trailer for cabbage processing and packaging has the potential for wide-spread use by cabbage farmers as long as work load can be reduced and work efficiency of the machine can be increased. Capital expenditures with the introduction of this trailer-supported harvesting system are necessary. The machine purchase price including remodeling cost with the remote control of the tractor is 4.16 million yen (harvester; 2.85 million yen). Based on the results of field tests of the trailer-supported harvesting system, we implemented management evaluations of 20, 25 and 30 ha farms, which are the typical sizes of upland/vegetable farms in the district where the field tests were conducted. Linear Programming Program XLP, (Oishi et al.) was used to calculate the increase in cabbage cultivation with the introduction of the system.

Fig. 7 shows the case when cabbage is the only vegetable produced in an upland farm. Cabbage acreage is estimated to increase by 0.8–0.9 ha using the mechanized trailer-supported harvesting system compared to conventional manual harvesting. When Chinese yam is also produced, cabbage acreage is estimated to increase by 1.0–1.7 ha using the new harvesting system. Also, we have calculated the upper limit of the possible investment for

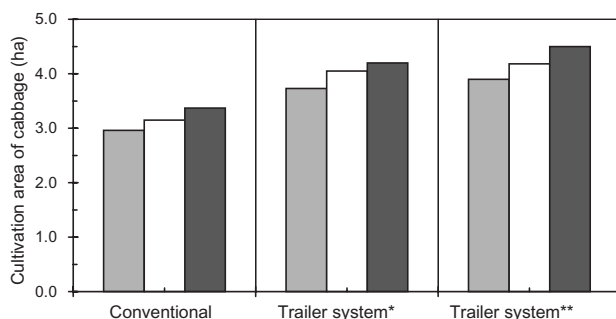


Fig. 7. Changes in the cultivation area of cabbage with introduction of trailer-supported harvesting system

■ : 20 ha, □ : 25 ha, ■ : 30 ha.
 * traveling speed = 10 cm/s.
 ** traveling speed > 11 cm/s (expectation).

introducing this harvesting system. For the calculation, we set the expected useful life of the machine at 5 years, and the rate of earnings on investment at 2.5%, which is approximately the same as the basic interest rate of the Agriculture Modernization Fund. The investment limit is calculated as 2–2.5 million yen, meanwhile the capital outlay is 2.37 million yen assuming subsidies for agricultural machines are available. Investing in the trailer-supported harvesting system is evaluated as a rational decision, considering the workload reduction.

Conclusion and outlook

This research was performed to establish a systematic cabbage harvesting method for large-scale upland fields using a new harvester. The basis of this farm mechanization system is a remote-controlled tractor traveling with the harvester. The tractor draws a trailer that is equipped with conveyers to transfer cabbage from the harvester to the trailer where workers can process and pack the cabbage into corrugated boxes. This method only requires 3 workers to harvest, process and package cabbage. We investigated the suitability of this system from the point of work efficiency and ergonomics through trials on a commercial farm. We obtained the results as follows:

- (1) The amount of time required for harvesting was 18 h-person/10 a (1.7 a/h), i.e. more than 50% less time than conventional manual harvesting, which requires 37.8 h-person/10 a. Effective labor exceeded 80%, because it was unnecessary to interrupt the operation of the harvester to unload the boxed cabbage.
- (2) The operator of the harvester had to bend at the waist about 10° and the processing and loading workers had to bend 15°. The conventional method required a worker to bend to an angle of over 110°. Taking into consideration the maximum heart rate, in the case of the tested subjects in these trials, one continuous work period should be limited to 2–2.5 h and the optimum total rest period should be 1.5 h in an 8 h work shift.
- (3) Evaluating this system from a farm management viewpoint, the capital outlay can be compensated for the most part when introduction of the system is subject to governmental subsidies.

We can say that the mechanization of cabbage harvesting in Tokachi represents a step in the right direction¹. We will strive to further improve the efficiency of the system.

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