JARQ 30, 35-41 (1996)

Development of Chinese Cabbage Harvester

Mikio KANAMITSU and Kenji YAMAMOTO

Planning Department, Institute of Agricultural Machinery, Bio-oriented Technology Research Advancement Institution (BRAIN) (Nissin, Omiya, Saitama, 331 Japan)

Abstract

Chinese cabbage harvester was developed and tasted to save time and labor for harvesting. The machine is a once-over harvester for one row. To meet the functional requirements of the machine and design specific machine components, the physical properties of the plant were analyzed. After obtaining the information of the physical properties of Chinese cabbage, the pulling mechanism and cutting mechanism were developed. The puling mechanism consists of a set of biaxial screw augers and a set of feed belts. Chinese cabbages were pulled off from the ground and transported by the pulling mechanism. When the heads are transported by the pulling mechanism, the wrapper leaves are removed by the cutting mechanism that consists of a rotating disk-cutter. A one-row walking prototype of harvester with the pulling and cutting mechanisms was constructed and tested in the field The machine worked continuously for pulling Chinese cabbages, cutting the wrapper leaves and leaving the heads in the field. After evaluation of the performance of the walking-type harvester, a treactor-mounted-type harvester was constructed and improved by the addition of an elevator, a bulk bin and a height controller system. This machine was operated at a harvest rate of 2 a/h. Two men are required for the harvesting operation. Heads were not lost and were shipped to the market by hand retrimming. Total harvesting work rate including retrimming by hand was about 30 man-h/10 a.

Discipline: Agricultural machinery/Horticulture
Additional key words: mechanical harvester, once-over harvest, automatic position control

Introduction

Possible decrease in vegetable supply is a matter of concern in Japan because of the increase of farmers' average age and the shortage of labor. The cultivated area of Chinese cabbage is about 40,000 ha and Chinese cabbage ranks 4th among all the vegetables produced in Japan[4].

Although the yield per unit area of Chinese cabbage has been increasing in recent years, the planting area is decreasing gradually[4]. Presently, Chinese cabbage is harvested entirely by hand which requires much labor, the working rate being 36-42 man-h/10 a. Therefore, in view of the importance of Chinese cabbage in Japan, attempts have been made to promote mechanization by developing on efficient harvester. Assuming that Chinese cabbages are planted in a row on each ridge, a once-over harvester was designed and developed for reducing the labor required for cutting heads and carrying them out of the field.

Physical properties of Chinese cabbage[1]

To obtain basic data for the development of the harvesting mechanism, the physical properties and the pulling force of 8 varieties of Chinese cabbage

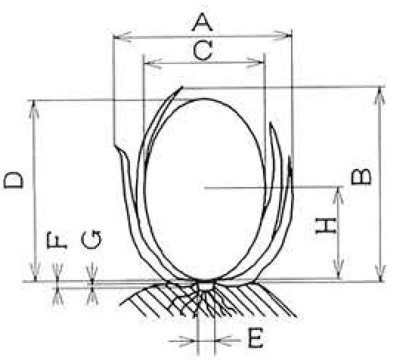

Fig. 1. Physical properties of Chinese cabbage plant
A: Plant diameter, B: Plant height,
C: Head diameter, D: Head height,
E: Stem diameter, F: Length of leaf stem,
G: Length of stem, H: Height of center of gravity.

Table 1. Physical properties of Chinese cabbage plants

Variety	Number	P.H.[a) (mm)]	P.D. (mm)	H.H. (mm)	H.D. (mm)	H.C.G. (mm)	L.S. (mm)	L.L.S. (mm)	Mass (kg) Whole	Mass (kg) Head	S.D. (mm)	N.W.L.
Hiratsuka 1 gou	11	336[b)]	412	260	136	169	11	21	1.87	1.38	26	12.5
		30[c)]	51	32	13	13	3	5	0.24	0.19	2	3.9
Kinsyu	26	391	471	284	169	147	21	31	3.66	2.75	23	12.5
		28	93	9	11	18	4	7	0.59	0.38	2	2.8
Shinriso	30	340	259	289	200	106	27	33	4.19	2.94	32	14.6
		59	25	19	17	9	5	8	0.44	0.27	7	1.8
Ousyo	11	310	223	294	194	118	21	33	3.99	2.95	29	20.0
		8	14	7	11	5	3	7	0.48	0.51	3	3.3
Taibyo 60 nichi	51	312	444	247	145	96	11	12	2.45	1.87	26	14.8
		24	59	16	16	13	4	4	0.57	0.38	5	2.7
Muso	10	343	461	279	166	108	20	25	3.17	2.51	23	10.0
		13	57	10	5	6	3	4	0.21	0.20	1	1.7
Bando	10	304	252	281	189	109	17	32	3.51	2.68	32	15.5
		9	9	8	11	18	2	3	0.18	0.52	2	1.0
Ryutoku	10	437	294	278	205	108	9	17	3.83	2.50	41	9.2
		13	25	14	16	9	2	3	0.62	0.50	1	1.8

a): P.H.; Plant height, P.D.; Plant diameter, H.H.; Head height, H.D.; Head diameter, H.C.G.; Height of center of gravity, L.S.; Length of stem, L.L.S.; Length of leaf stem, S.D.; Stem diameter, N.W.L.; Number of wrapper leaves.

b): Upper colum; Mean value.

c): Lower colum; Standard deviation.

were determined (Fig. 1). Table 1 summarizes the data on the properties analyzed. The concave depth of the bottom of head varies depending on the harvesting time and the variety, in the range from 9 to 27 mm, the standard deviation of a variety ranging from 2 to 5 mm. We assumed that, by cutting wrapper leaves and leaf stem it may be possible to cut at a constant position by setting the base at the bottom of the head. Since the bottom of Chinese cabbage is close to the ground, Chinese cabbage could be lifted first, the wrapper leaves could be held laterally, and then the wrapper leaves and the leaf stem could be cut during the transport.

The pulling force was small in a field consisting of Kuroboku soil (volcanogenous soil) with an average value of 110 N, but it was large in a field consisting of Gray Lowland soil, the average value being 250 N. It will thus be necessary to soften the soil to pick up Chinese cabbage satisfactorily by machine.

Lifting and cutting mechanisms

Through the examination of the lifting and cutting mechanisms, it was found that the transport of Chinese cabbage could be performed without damage by using a set of feed belts. Chinese cabbage could be lifted by the combination of a set of biaxial screw augers under a set of feed belts. The sets of feed belts are softened by tension sprockets. Feed belt consists of a roller chain with attachment plates. Attachment plate is made of rigid polyvinyl chloride resin. The surface of the attachment plate is covered with neoprene sponge rubber. These plates are fixed to the roller chain by bolts and nuts. The screw auger consists of a rigid plastic rod. The diameter of the screw auger is 55 mm and the depth of groove is 10 mm. A set of screw augers with an inclination of 15° rotates inward. When the machine moves forward, a leaf stem of Chinese cabbage is inserted between screw augers. Then Chinese cabbage is lifted by the screw augers.

A rotating disk-cutter with a peripheral speed of 6 m/s enabled to cut the wrapper leaves and the leaf stem. A rotating disk-cutter was fixed between the biaxial screw augers and the feed belts. The top of the biaxial screw augers was used as the reference plane. It was possible to cut and remove wrapper leaves and leaf stem at a constant position.

Walking-type harvester

On the basis of the above results, a walking-type harvester was developed and tested in the field (Fig. 2, Plate 1). The harvester lifts, moves the Chinese cabbages by the set of biaxial screw augers and set of feed belts, cuts and removes wrapper leaves and leaf

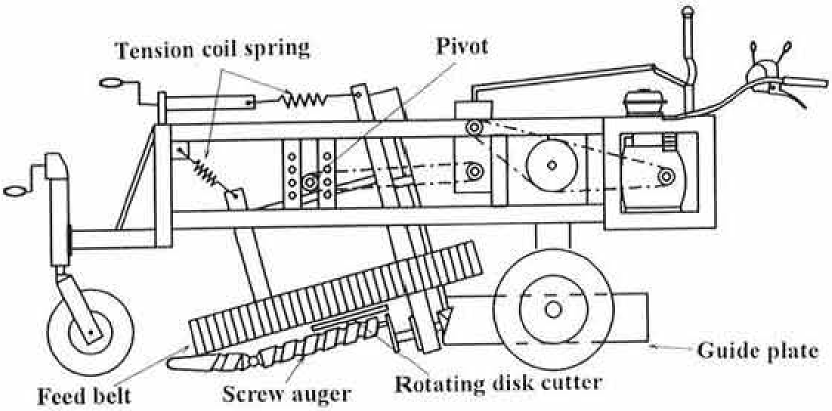

Fig. 2. Schematic representation of walking-type harvester
Length: 2,735 mm, Height: 1,220 mm, Width: 855 mm, Mass: 285 kg.

Plate 1. Lateral view of walking-type harvester

stem with a rotating disk-cutter, and leaves head parts in a row on the field with wrapper leaves and leaf stem. The lifting and cutting device pivots at the center of gravity in bearings beneath the framework. Two springs support the front ànd rear ends of this device to make it float when it comes into contact with the ground. As the machine is equipped with stepped wheels, it is possible to adjust the position of the harvesting apparatus to the ground surface. Feed belts and screw augers moved at or near ground speed. This experimental machine could harvest continuously at the working speed of 0.17–0.28 m/s. Because the cutting position of the disk-cutter was not suitable and the head was occasionally cut, damage of heads occurred during the lifting and transport operations.

Tractor-mounted-type harvester[2)]

A tractor-mounted-type harvester was developed to improve the cutting efficiency (Fig. 3, Plate 2). It consists of a set of biaxial screw augers, a set of feed belts (Plate 3), a rotating disk-cutter, an elevator, and a carrier to improve the carrying performance of the heads out of the field. The elevator, made of a 920 mm long roller chain conveyor, receives the head from the lifting and cutting device. The elevator, inclined at 30°, takes over the head to the carrier through a chain-flight arrangement. The harvester is mounted on a 15 kW tractor and is driven by a hydraulic system. The harvester was able to continuously carry out the operations including lifting the Chinese cabbages at the working speed of 0.2 m/s and cutting wrapper leaves and leaf stem while transporting the heads to the carrier. The carrier could load about 100 heads and carry them out of the field. During the work, an assistant operator rode on the carrier and transferred heads from the elevator to the carrier. It took more than 2 s for an assistant operator to transfer a head from the elevator to the carrier. The occurrence of diagonal cut of the head decreased when the transfer velocity ratio of the screw augers to the feed belts was set of 1.13.

The effect of the screw auger pitch on the cutting accuracy was tested using three different varieties of Chinese cabbage with different masses. Table 2 summarizes the data on the test of cutting accuracy. The results indicate that a 120 mm pitch screw auger causes less damage than a 80 mm pitch screw auger. The rate of head leaf loss for Kinshu, which had a small pulling force and medium mass, was equal to or less than 10%, the lowest loss among the three varieties.

The power required for harvest work, when the hydraulic flow rate was controlled by a bleed-off circuit and meter-in circuit (Fig. 4), was in the range of 0.4–1.5 kW, 1.5–1.8 kW, respectively. The changes in the flow rate and pressure in hydraulic circuit during the operation were negligible in the meter-in circuit, and the accuracy of harvest work slightly improved (Fig. 5).

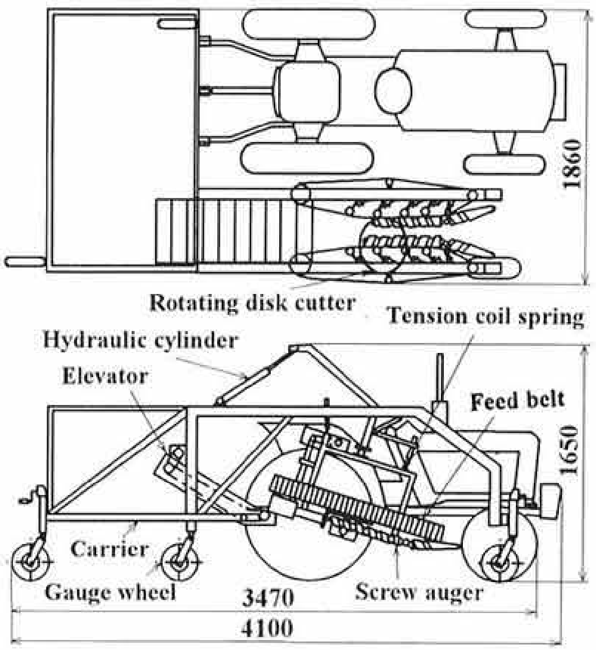

Fig. 3. Schematic representation of tractor-mounted-type harvester

Plate 2. Lateral view of tractor-mounted-type harvester

Plate 3. Front view of screw augers and feed belts

Table 2. Test of performance of machine — Effect of screw auger pitch on cutting quality

Variety (Head mass: kg) (Pulling force: N)	Test no.	C.[a] (mm)	Speed (m/s)	Screw auger pitch (mm)	Cutting quality[b] (%)				
					M.	P.I.	I.I.	P.E.	I.E.
Osyo	1	15	0.20	80	7	69	8	7	8
(1.62 ± 0.53)	2	17	0.20	100	7	30	9	9	46
(261 ± 69)	3	18	0.20	120	8	65	7	7	13
Muso	4	15	0.20	80	8	26	1	39	25
(2.26 ± 0.29)	5	17	0.18	100	35	17	11	23	14
(194 ± 33)	6	15	0.21	120	0	22	24	30	24
Kinsyu	7	15	0.20	80	10	33	1	20	36
(2.05 ± 0.50)	8	15	0.20	80	5	77	7	9	2
(169 ± 30)	9	15	0.19	120	15	68	1	8	8
	10	15	0.20	120	16	70	4	4	5

Test location: BRAIN-attached farm (Gray Lowland soil).
The values of the ratio of screw auger speed to feed belt were 1.13, 1.17 and 1.20 when screw auger pitches were 80, 100 and 120 mm, respectively.
Hydraulic circuit of tests no. 8 and 10 consists of meter-in circuit and the other consists of bleed-off circuit.
a): C.; Clearance of screw auger and cutter.
b): M.; Moderate cutting, P.I.; Parallel and insufficient cutting, I.I.; Inclined and insufficient cutting, P.E.; Parallel and excessive cutting, I.E.; Inclined and excessive cutting.

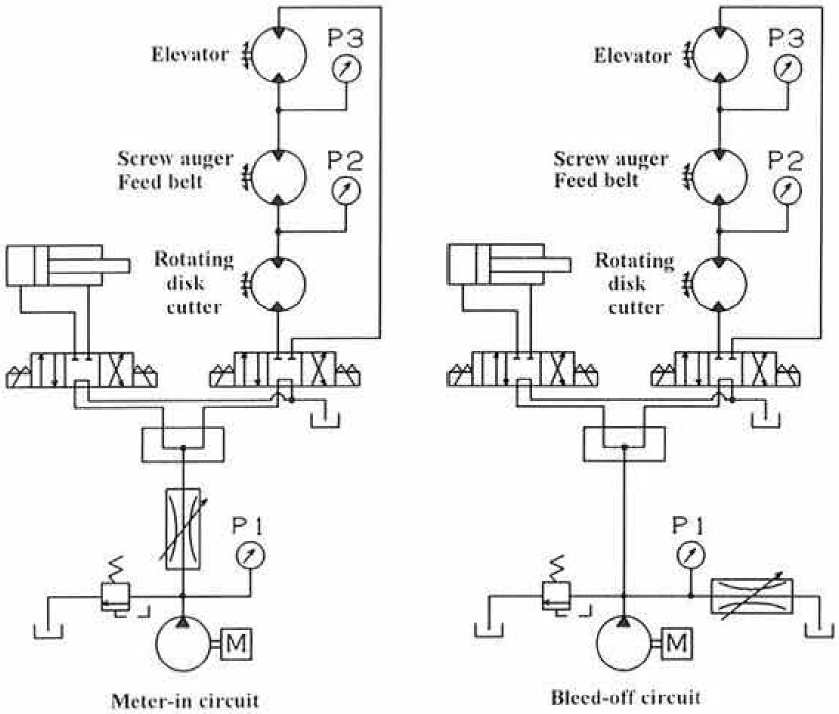

Fig. 4. Hydraulic circuit

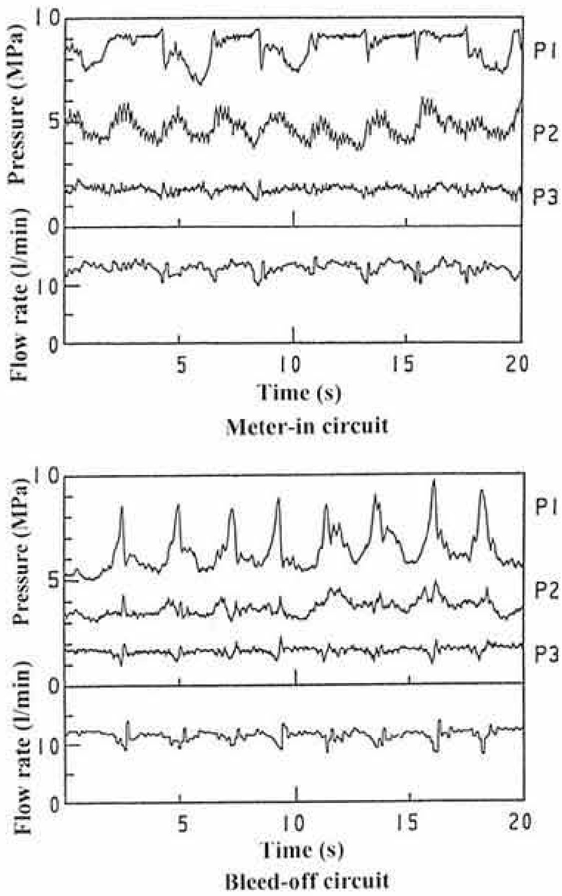

Fig. 5. Changes in rate of flow and pressure of hydraulic circuit

Height controller[3)]

A height control system was developed to improve the accuracy of the tractor-mounted harvester (Fig. 6). The system sets the proper relative position of the harvesting apparatus from the ridge surface with on/off control. Fig. 7 shows the block diagram of the height control system. The electronic circuit of this system is depicted in Fig. 8. The function of this system is as follows. The detective shoe follows up the surface of the ridge. The potentiometer (y), attached to the hydraulic cylinder, detects the position of the hydraulic cylinder. In the control box, there are five potentiometers. One potentiometer (n) sets the objective position of the hydraulic cylinder. Other two potentiometers (K1, K2) set the value of amplifiers. The others (H, L) set the upper and lower limit of the window comparator circuit. On the other hand, the potentiometer (r), attached to the shoe, detects the movement of the shoe. The difference between the values recorded in (y) and (n) is amplified by K2 times. The difference between the values recorded in (y') and (r) is amplified by K1 times. The output of differential amplifier (u) is compared to that of (H) and (L) by using the window comparator circuit.

Where $y' = K2(y-n)$, $u = K1(r-y')$.

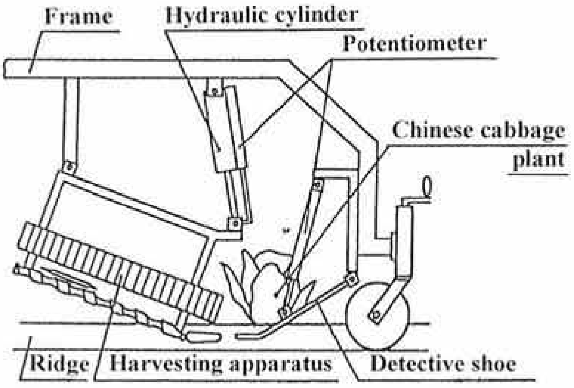

Fig. 6. Schematic representation of height control system

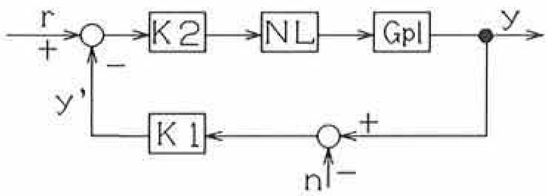

Fig. 7. Block diagram of height control system

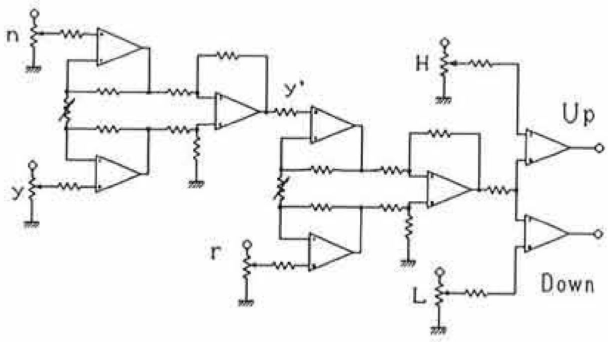

Fig. 8. Electronic circuit of height control system

If the (u) value is higher than (H), the hydraulic cylinder is extended. Then, the harvesting apparatus is lifted up. On the other hand, if the (u) value is lower than (L), the hydraulic cylinder is contracted. Then, the harvesting apparatus is brought down.

Fig. 9 shows the step response, input of potentiometer attached to the shoe (r) and output of differential amplifier (u) and potentiometer attached to the hydraulic cylinder (y).

The value of amplifiers (K1, K2), upper and lower limits of window comparator circuit (H, L) and hydraulic flow rate are important parameters for adjusting the control system. After adjustment of these parameters, the response of the height control system was stable when the detection shoe passed a

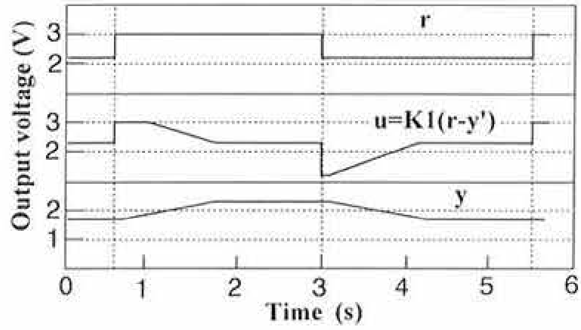

Fig. 9. Example of step response of height control system

60 mm level difference simulated in a moving soil bin, though the operation lag was 0.2–0.5 s when the dead band was equivalent to 10 mm movement of the tip of the harvesting apparatus.

Field tests and results

A tractor-mounted-type harvester was tested in farmers' fields in Tatebayashi City and Ora district, Gunma Prefecture.

Table 3 shows the plant conditions tested. Table 4 shows the operating conditions and the results of the tests on the quality of work. It was easy to set the height by using the automatic control system. The control system operated well when tested on the Ryutoku variety whose wrapper leaves were bound. The wrapper leaves sometimes tended to cling to the detection shoe when tested on the Hokuyo variety. In this case, the automatic control was operated when setting the height, and was stopped during the harvest work. There was no loss of head in either cases, and all the heads were shipped to the market by retrimming.

Table 5 summarizes the data on the working rate. The work speed was about 2.5 s/head. However, the field work efficiency was low, 41%, as a large amount of time was required to carry the heads out of the field and transfer them to the trucks and remove them. The time required for two operators to cut the heads, carry them out of the field and transport them to the truck was 4.9 h/10 a, and retrimming by hand required 20.4 man-h/10 a. The total harvesting work rate was about 30 man-h/10 a which was almost the same as that of conventional work.

Conclusion

We developed a once-over Chinese cabbage harvester. The tractor-mounted-type harvester was able

Table 3. Dimensions and mass of Chinese cabbage plants

Variety	Plant (mm)		Head (mm)		Head mass (kg)	No. of wrapper leaves	Pulling force (N)	Ridge height (mm)	Row space (mm)	Hill space (mm)
	Height	Diameter	Height	Diameter						
Hokuyo	431	718	301	197	2.49	8.6	162	98	583	481
Ryutoku	437	294	278	205	2.50	9.2	259	154	759	515

Table 4. Test of performance of machine — Cutting quality

Variety	Test no.	C.[a] (mm)	Speed (m/s)	Height control	Cutting quality[b] (%)				
					M.	P.I.	I.I.	P.E.	I.E.
Hokuyo	1	6	0.20	off	58	32	10	0	0
	2	12	0.20	off	70	28	2	0	0
	3	12	0.25	off	60	40	0	0	0
Ryutoku	4	6	0.20	on	0	75	25	0	0
	5	6	0.20	off	0	60	40	0	0

a), b): See Table 2 for the abbreviations.

Table 5. Test on work rate

Speed (m/s)	No. of workers	Harvesting time[a] (h/10 a)				Retrimming by hand (h/10 a)
		H.	C.	T.	Total	
0.20	2	2.0	0.6	2.3	4.9	10.2

a): H.; Harvesting, C.; Carry the head out of the field, T.; Transfer to the trucks.

to cut the wrapper leaves and carry heads out of the field. Retrimming and packing were performed by hand after harvesting by machine. The performance of the harvester is satisfactory if the head diameter is medium. For practical use, it is necessary to reduce the handling and retrimming labor.

References

1) Kanamitsu, M. et al. (1993): Development of a Chinese cabbage harvester. (Part 1) Fundamental research and development of harvesting mechanism. *J. Jpn. Soc. Agric. Mach.*, **55**(**5**), 133-140 [In Japanese].
2) Kanamitsu, M. et al. (1993): Development of a Chinese cabbage harvester. (Part 2) Tractor-attached type experimental harvester. *J. Jpn. Soc. Agric. Mach.*, **55**(**6**), 121-128 [In Japanese].
3) Kanamitsu, M. et al. (1994): Development of a Chinese cabbage harvester. (Part 3) Development of height controller and field test of harvester. *J. Jpn. Soc. Agric. Mach.*, **56**(**2**), 127-133 [In Japanese].
4) Statistics and Information Department (1994): Statistics on agriculture, forestry and fisheries. Association of Agriculture and Forestry Statistics, Ministry of Agriculture, Forestry and Fisheries, Tokyo, pp. 570 [In Japanese].

(Received for publication, Jan. 17, 1995)