Studies on the Development of a Tea Harvesting Machine

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SUMMARY

A "plucking rolls device" was developed in this study to improve the quality of harvested tea leaves. In this report, the outline of the system and the results of performance experiments in our laboratory are discussed. Two kinds of performance experiments were carried out. The first experiment checked harvesting accuracy by using a plucking unit that was developed for harvesting machine installation. The second experiment was a harvesting experiment which utilized a front bar in order to prevent cutting of the tea buds which had been a problem in precious experiments. As a result of the first experiment, it was confirmed that selective harvesting obtained high quality tea leaves. But a cutting problem that, when the harvesting speed was faster than the working speed, which was non-selective harvesting, was also seen. In the second experiment, the cutting rate decreased to a maximum of 50 % level, when tea buds most bent ahead by the front bar. The effect was seen that cutting problem was alleviated from this.

Keywords: plucking rolls device, selective harvesting, plucking unit, harvesting speed, working speed, harvesting accuracy, cutting problem, front bar

INTRODUCTION

Green tea is the most popular drink in Japan. At present, although production volume of tea has shown a reduction trend, the consumer desires tea of higher quality. There are two methods of harvesting tea in Japan. One is manual plucking and the other is mechanical harvesting. There is a problem that the quality of tea leaves by the manual plucking method is higher than by the mechanical harvesting method. Mechanical harvesting uses devices of a reciprocating knife, a spiral knife and, a rotating knife, etc. The form of tea shrubs using mechanical harvesting is arranged in a circular arc or a flat form to be easy to work. When tea buds are harvested by the aforementioned devices, harvested tea leaves are uniformly cut by non-selective harvesting. When there is uneven growth of tea buds, mechanically harvested tea leaves include woody parts of stems, old leaves, etc. On the other hand, manual harvesting can obtain the high quality of tea leaves, without the woody part of stems and old leaves.

The purpose of this study is to develop a new harvesting device to improve the quality of tea leaves from current machine harvesting. A "plucking rolls device" was developed in order to achieve this purpose. First, an outline of this system is shown in this report. Next, the results of two performance experiments using this system are reported.

OUTLINE OF THE PLUCKING ROLLS DEVICE

Fig.1 is an outline figure of the plucking rolls device. This system inserts the lower part of the tea bud to into a circular hole (plucking hole) which slight larger than the diameter of a stem and makes this hole move in the direction of the bud top. This action happens to be the same action as manual plucking, leaving the woody part of the stem and harvesting only the tea leaves. The plucking rolls consist a pair of cylinders which have spiral, grooves semicircular carved right and left individually. The plucking hole is continuously formed at grooves which made axle lines which combine the phase of two cylinders like Fig.1(a) and parallel and made contact with the side. The top of a cylinder is the form of a cone in order to facilitate induction of tea buds to the plucking hole, as the pitch of the spiral groove becomes smaller with top. The plucking hole formed in the top direction to rotates in the direction of the arrows which show these cylinders in a figure individually to move toward the end. The tea buds move by this from the top of the plucking rolls in the direction of the end. Moreover, the plucking rolls slant forward, advancing toward the tea buds at a constant speed like Fig.1(b). Then the plucking hole which is formed in the top direction acts toward the top of the tea bud while grasping the lower part of the tea bud and moving in the direction of the end and harvesting tea leaves.

PURPOSE OF PERFORMANCE EXPERIMENTS

A plucking unit was developed in some fundamental experiments that used the plucking rolls device of the prototype and use in field. Experiment A shows the harvesting accuracy from laboratory experiments that used the unit. Experiment B is a harvesting experiment that attached the front bar in plucking rolls front in order to resolve cutting phenomenon of tea buds occurs which were a problem in experiment A. The condition under which cutting is important, in which the tea bud bent, induced by the plucking hole and there occurs a strong plucking action. The cutting phenomenon is thought to be tea buds of erection style makes contact with screw thread processed by the acute angle in the roll front part. The front bar has a faculty which bends the tea bud ahead, as it becomes that is not cut in the screw thread. The most appropriate establishment location of the front bar was found out in this experiment.

OUTLINE OF THE EXPERIMENTAL APPARATUS

Experiment A The plucking unit shown in Fig.2 has three faculties which induct and harvest the tea buds, and remove the harvested tea leaves. Four plucking rolls made of polyacetar (POM) that is easy to process are equipped this unit. The design element has an overall length of 150 ㎜ (length 30 ㎜ of front part is included.), a diameter of 20 ㎜, a spiral groove of two threaded of pitch 6 ㎜ and lead 12 ㎜ and a plucking hole diameter of 4 ㎜. The diameter of the plucking hole is set by a smaller than two stems diameter and is bigger than one stem that the plucking hole should not oppress the tea stems. Also, the spiral groove of two threaded improves processing ability. That is, two threaded plucking rolls forms two plucking holes in one rotation. The overall length of a roll is designed by length that the plucking roll top touches in a plane the same as the base of the plucking

unit.

The nozzle of the plucking rolls lower part injects air under the plucking rolls from the aspect and the front, makes the harvested tea leaves float and then they are remove to unit backward. The cone type divider of the nozzle top is divided in the direction of the right and left so tea buds aren't induced to a central part which rotates in the opposite direction. The drive shaft of the plucking roll is connected by a timing pulley through the gear and universal joint. Using some timing pulley and a timing belt moves some plucking units simultaneously and can correspond to the surface of wide tea shrubs.

An experimental apparatus is shown in Fig.3. This device is composed of a harvesting section that drives at a location fixed plucking units, a supply section that moves tea buds of erection style in a belt conveyer and makes the supply to the harvesting section. Three plucking units are fixed, and move together in the middle of spring steel plate. The timing pulley for drive and tension is composed of the extension of the timing belt and the rotation power is transmitted by motor through a flexible shaft on the drive pulley. A spring steel plate is fixed on the base where the harvesting height of plucking units can be adjusted to the tea buds. By the way, the revolution of plucking rolls on this device is adjusted to 1,200rpm.

The supply section uses a carrier which has 45 rubber plates (a plate thickness of 4 ㎜) arranged in order to fix edges under some tea buds. The carrier is equipped with a hook of the falling type, in which the hook falls to the hole of the conveyer belt and hangs. From this, the carrier run by moving a belt on the frame top of the conveyer. Also, the plucking rolls makes a force in the direction that draws up the tea buds and tries to raise the carrier. Because of this, the upper rails was attached on the frame of conveyer. Buds density ρ is adjusted in the count of sheets that holds the rubber plate among tea buds.

Experiment B The experimental apparatus is constructed the same as experiment A. Differences are the stick (front bar) in the hole of the front of the plucking rolls that shows Fig.4 and make the forward direction bend the tea buds. The location of holes are set at 8 points of the intersection of a grid which is located at the base line of 30 ㎜ vertically and 20 ㎜ horizontally from the top of the plucking rolls and pulled the 2 horizontal and the 4 perpendicular lines from each base line at intervals of 20 ㎜. The size of the bending tea bud has been changed by this. By the way, the specification of plucking rolls and harvesting angle are the same as experiment A.

CONDITIONS OF EXPERIMENTS

Experiment A Experiment conditions are shown in Table 1. The harvesting height of the plucking rolls was the 4th leaf that was a location where 4 leaves of tea buds from the top were counted in order to pluck at a high quality. Harvesting speed v_1 expresses, when it does the lead of plucking rolls L ㎜ and it does revolution N rpm, like the following expression.

$$v_1 = L \cdot N \cdot \cos\theta \ \text{[m/s]} \qquad \cdots(1)$$

Also, speed ratio s is a ratio of processing speed v_1 to working speed v_2 (= advancing

speed of carrier) of the plucking rolls device. Harvesting speed v_1 becomes 0.21m/s by using expression (1) from the setting revolution of rolls at 1,200rpm and the harvesting angle θ at 30°. Working speed v_2 was set to 7 stage among 0.08 (s=2.63)～ 0.24 (s=0.78) m/s.

An area of tea buds is an square which make the straight line of inserted 10 tea buds on the carrier and 2 rolls diameter which minimum working width. After this, buds density ρ will be a value which divided the tea buds count in this area. An this time, ρ was set to 2 stages, at 0.21 (the average) and 0.63 buds/cm^2 (the dense). Leaf angle shows an angle to do with axle line of plucking rolls and the main range of the 4th leaf of harvesting height. The case when both became 90° and 0° so that there was the 4th leaf on the side of the plucking rolls and became almost parallel were set in this experiment. Because of this, in the case of 0° a condition in which the 4th leaf can be induced in comparison with 90° to plucking hole was realized. By the way, 3 times repeated the experiments in each conditions.

Plant breeding which used this experiment is "Yabukita" that are suited green tea and are grown in Japan. In Japan, there are three harvest times from April to August. Growth is remarkable and the quality is the highest as for harvested tea buds in the first time of among these varieties. In this time, bud length did use above 110 mm in spite of being 3rd time harvested buds which have low quality.

Experiment B Harvesting speed v_1 and working speed v_2 were set to 0.21m/s (revolution of plucking rolls is 1,200rpm) and 0.08m/s (s=2.63) that most happened cutting phenomenon in experiment A. The location of the front bar will be able to do " Ⅰ - ①" description, if it expresses the perpendicular line in Ⅰ～Ⅳ from the closest to the top of the roll location sequentially and the horizon similarly shows ①～②, too. In this experiment, the tea bud was supplied one bud at one time and 10 times repeated in each conditions. "Kanayamidori" which has a bud length above 110 mm was obtained among first and 3rd harvesting time was used. Harvesting height of 50 mm was the same as experiment A.

RESULTS AND DISCUSSION

Experiment A It is important for this experiment to confirm that tea buds are induced surely the plucking hole before examining harvesting performance. But induction of tea buds is evaluated in induction rate that is the proportion of harvested tea buds count to the supplied count in this time, because confirmation is difficult. Induction rate became in the minimum 97% and showed a good induction situation.

The classification of harvested tea leaves is classified into three kinds by deficit length that is shown in Fig.5 and each kind of leaves is counted. Normal buds that were cut with no stem damage were included in normal leaves also. Harvesting accuracy is compared and examined in four kinds of data that the proportion of each classified leaves which included the no-harvested leaves. Analysis of variance by three-way classification was carried out at every proportion of classified leaves, and the interaction in speed ratio s, buds density ρ, and leaf direction were checked.

Fig.6(a) filmed the condition of tea buds that were attached to the carrier and the same (b) filmed the condition of harvested tea leaves in the wire net and harvested tea stems on the carrier. A condition of harvested tea buds that remained on the carrier shows selective harvesting that obviously left stems and only harvested the leaves.

Fig.7 and 8 shown the results. The cutting rate is the proportion of the cut tea buds (normal buds) count to the provided tea buds count. Fig.7 shows the relation with speed ratio s, the proportion of each classified leaves and the cutting rate. It was normal leaves and cutting rate that the proportion increased with an increase of speed ratio s, and the significant difference was shown at a significance level of 1%. Significant difference of same standard saw a decreasing in each proportion of great cut tea leaves and no-harvested leaves. There are these trends that cutting tea buds shown at normal buds often happens with an increase of speed ratio s. There are cases of breaking by plucking action, and the case cut by acute screw thread as for cutting the tea buds. When the speed ratio s is moreover big, tea bud is induced in a form which shows a broken line of Fig.1(b). And this time, it is thought that tea stems make contact with the screw thread of the under roll, which rotates in the direction that bites and the stems are cut. Breaking by plucking action has not included a stem which hardened in order to happen at the location of a soft stem before. But two other kinds of cutting methods are not appropriate in order to cut stems which are hardened. From this, resolving the cutting mechanism of tea buds on plucking rolls device is important in order to obtain high quality tea leaves.

Fig.8 showed the relation with buds density ρ, proportion of classified leaves and the cutting rate. When buds density ρ was high, the proportion of small piece leaves and no-harvested leaves became low, and the proportion of cutting rate and normal leaves was high. Tea buds are induced to the plucking hole through a part where the complete plucking hole of the roll front part is not formed. When buds density ρ was high, cutting phenomenon of tea bud was seen at this part. This part screw thread becomes to an acute angle, because a spiral groove makes the pitch smaller, and it is easy to cut the tea stems. It is thought that this was a reason of the previous result.

Experiment B Fig.9 and 10 are experimental results of last year's 3rd harvesting time and this year's first harvesting time, respectively. The figures show the relation with the location of the front bar, the cutting rate, the proportion of top-buds and the length of the remaining stem. Proportion of top-buds shows the proportion of the count of top-buds, which are still a shoot and two leaves, in cut tea buds. Also, the length of the remaining stem is the mean value that measured the stem left after harvesting.

When there is no front bar, the cutting rate was 90%, the proportion of the top-bud was about 20% and the length of the remaining stem was 60～70 ㎜. Almost all these data used a setting harvesting height of 50 ㎜ in this experiment so that tea buds are cut on the front part of the plucking rolls. On the other hand, when a location of line ① that was attached to the front bar was compared with the case without a front bar, cutting rate decreases about 50 %, the proportion of top-buds is the largest 65%, and the length of the remaining stem has a maximum longer than 25 ㎜. It can obviously be seen that cutting of tea bud is restrained. But the result in a location of line ② except the proportion of top-buds nearly resembled the case without a bar. Moreover, when location follows to change from line Ⅰ to Ⅳ, a tendency was seen in line ① that the cutting rate decreased, the

proportion of top-buds went up and the length of the remaining stem was extended. Bending of tea buds became greater in a location of line ① than ② and line Ⅳ than Ⅰ. From this, point Ⅲ－① and Ⅳ－① that the most bending of tea buds are most appropriate at a location of the front bar which prevents the effect of cutting. Also, it can be said in this location that harvested tea quality is high because of the increase in the proportion of top-buds.

CONCLUSION

An outline of the "plucking rolls device" that was developed for improving the quality tea leaves harvested by a machine was discussed in this report. And, the plucking rolls device was developed, and two kinds of experiments in the laboratory were carried out using the device and the following results were obtained.

1. As a result of the experiment, selective harvesting without the woody parts of stems which was a development purpose of this system, was confirmed. But it was seen that a cutting phenomenon of tea buds that was non-selective harvesting when harvesting speed became faster than working speed.
2. An effect which restrained cutting of tea buds in establishing the front bar in a location which gave greater bending to tea buds as a result of other experiments was confirmed.

From now on, the above results are consulted and a harvesting machine for fields where less cutting of tea buds will be developed.

REFERENCES

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Table 1 Conditions of experiment A

Type of plucking roll	Two threaded plucking roll (P=6 ㎜,L=12 ㎜,D=ϕ 20 ㎜, Plucking holes diameter:ϕ 4 ㎜)
Harvesting angle θ [°]	30
Harvesting height	4th leaf
Rotating speed of rolls [rpm] (Harvesting speed [m/s])	1200 (0.21)
Working speed [m/s] (Speed ratio s)	0.27(0.78),0.25(0.84),0.23(0.91), 0.21(1.00),0.17(1.24),0.13(1.62),0.08(2.56)
Buds density ρ [buds/cm ^{2}] (Interval length of buds [mm])	0.21(12), 0.63(4)
Leaf angle [°]	0,90
Plant breeding	Yabukita (3rd harvesting time)

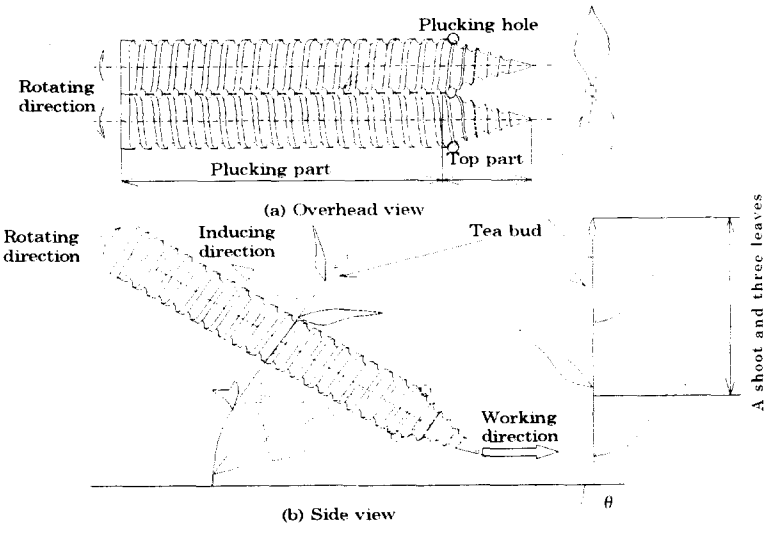


Fig. 1 Plucking rolls

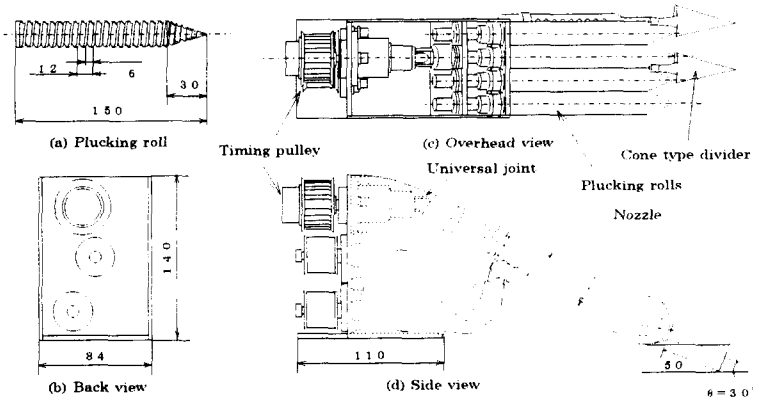


Fig. 2 Plucking unit

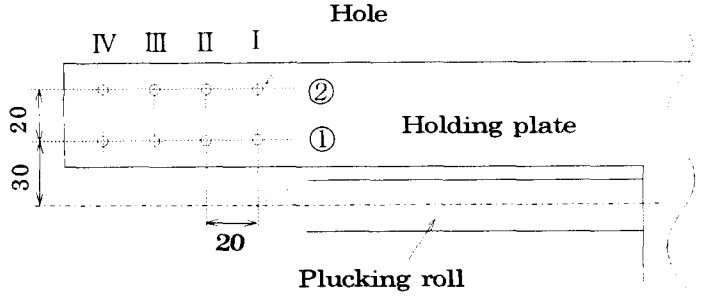


Fig. 4 Location of the front bar

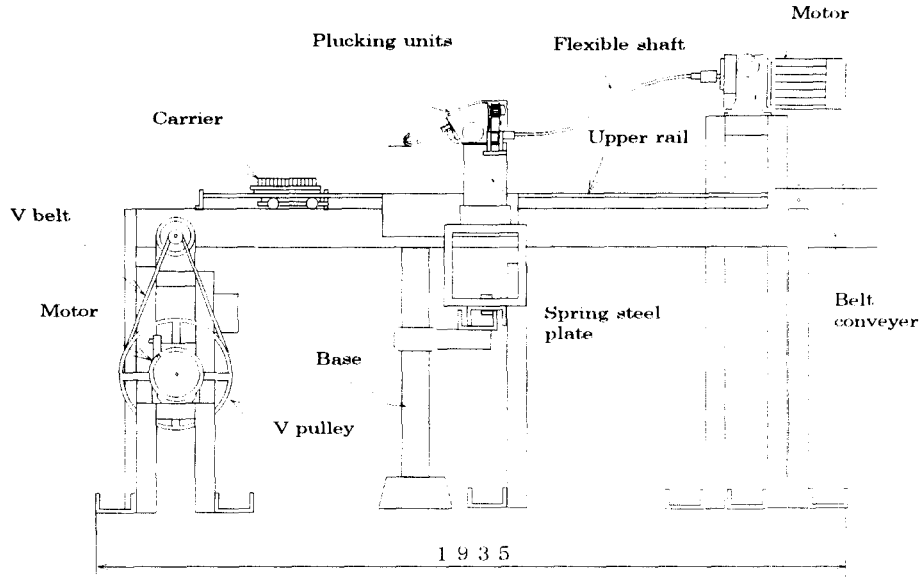


Fig.3 Experimental apparatus for experiment A (Side view)

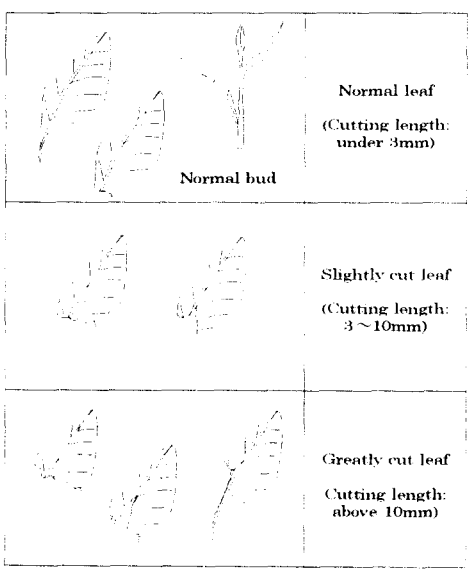
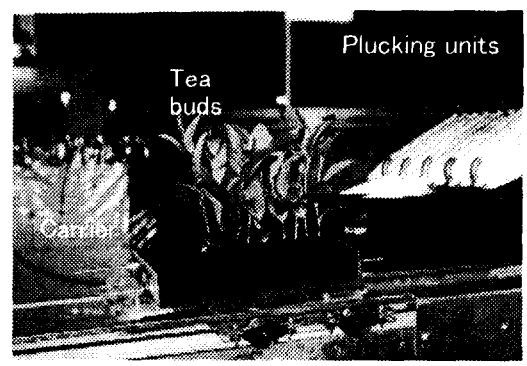
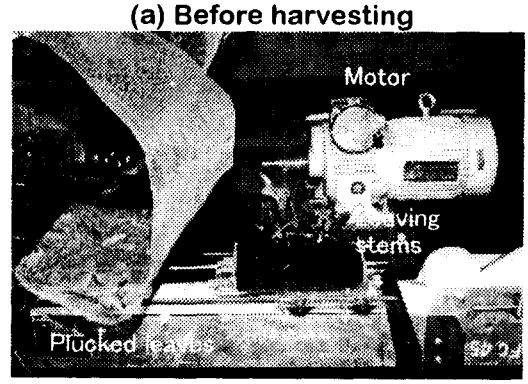


Fig. 5 Classified plucking tea leaves



(a) Before harvesting



(b) After harvesting

Fig.6 Appearance of plucking tea buds

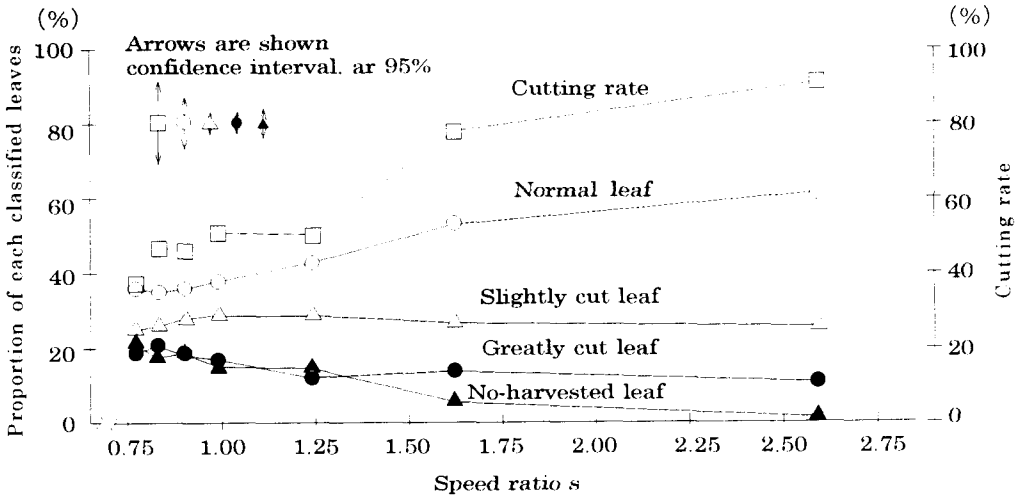


Fig. 7 Relationship between the speed ratio s and the proportion of each classified leaves, and the cutting rate

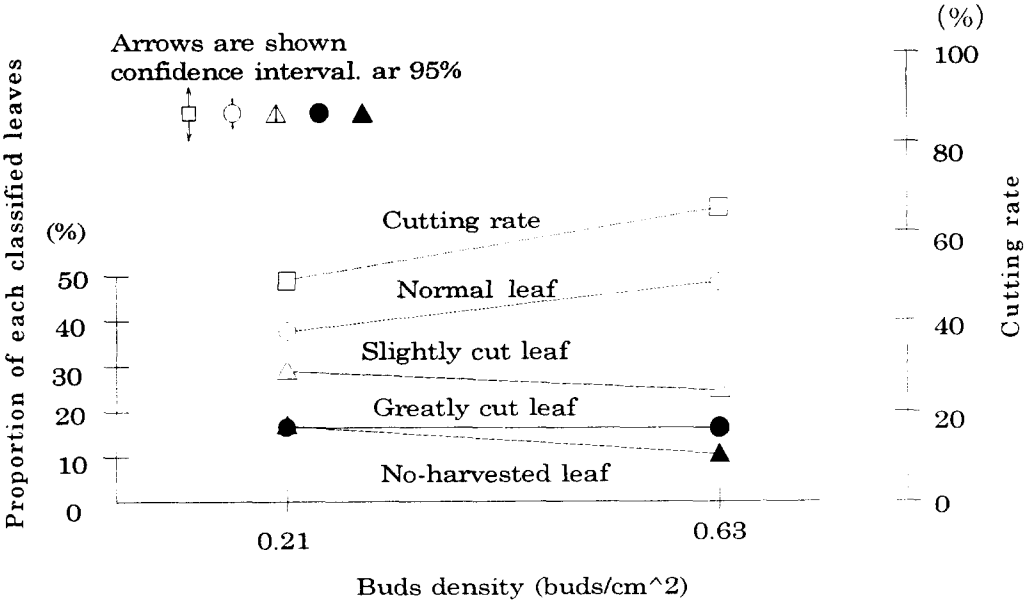


Fig. 8 Relation between the buds destiny and the proportion of each classified leaves and the cutting rate

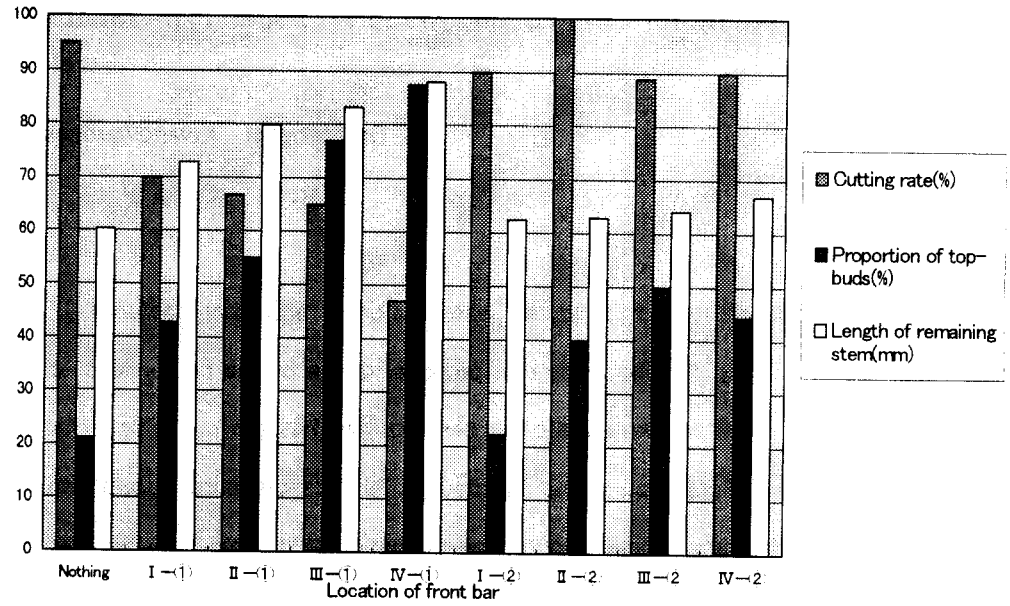


Fig.9 Relationship between the location of front bar and each results (θ=30°, 3rd harvesting time)

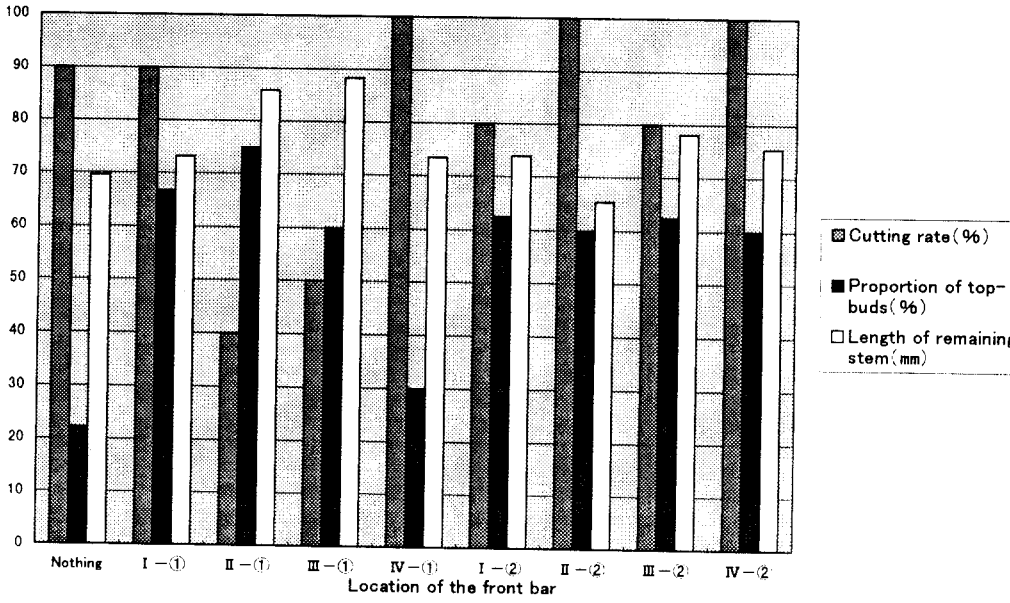


Fig.10 Relationship between the location of front bar and each results (θ=30°, 1st harvesting time)