STUDIES ON THE UTILITY OF RATOON TRAITS OF RICE AS THE INDICATOR OF AGRONOMIC CHARACTERS IN BREEDING

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CONTENTS

PREFACE

It is the starting point of breeding to discriminate the individuals or the lines fit for breeding objective from the others by means of appropriate measures. The measures presently used may roughly be classified into three types, i.e., straight-, early- and indirect-diagnosis. Straight diagnosis is to straight take the measure of an objective character. Early diagnosis means to evaluate an objective character from its earlier-stage quality. Indirect diagnosis is the evaluation of an objective character by making use of the genetic correlation between the relevant character and some other related character.

Indirect diagnosis contributes much to shortening the term of breeding through the improvement of selection efficiency, and it is mainly applied to the estimation of physiological and ecological traits. In rice plant, for instance, cold resistance is diagnosed by the swelling of tapetal cell under low temperature (SAKAI 1947), root activity is evaluated by the α-Naphthylamine oxidation by root (YAMADA and OTA 1958), pre-harvest sprouting is estimated on the basis of the correlation between seed dormancy and tolerance to high-temperature treatment (MARUYAMA 1980), lodging resistance is judged by means of lodging index (MATSUO 1952; SEKO 1962) and lodging coefficient (ONO 1951), and drought resistance is determined by the toxic action of potassium chlorate in seedlings (YAMASAKI 1931). In the cases of wheat and barley, the examples can be found in estimations of baking quality by the gluten content of flour (IKEDA 1937), cold resistance by the tussock (KUSUNOKI and OSANAI 1959), Aluminum tolerance by hematoxylin staining of seedling roots (POLLE *et al.* 1978; TAKAGI *et al.* 1981), photosynthetic capacity by stomatal frequency (YOSHIDA 1976, 1978).

Rice breeders have placed major emphasis on selection for yield, heading date, time of maturity, plant type including culm length and panicle length, lodging resistance, percentage of ripened grains, disease resistance and grain quality. Of these characters, lodging resistance is most closely related to high yielding. This character can be estimated by indirect diagnosis, i.e., by the measurement of lodging index or lodging coefficient as described above. However, these indicators have rarely been applied in actual breeding program, because they require a great deal of labor. Percentage of ripened grains is also an important determinant of grain yield. On this character, however, no reports suggestive to breeding have been available yet, because of the necessity for enormous amount of scoring as well as the low heritability. Hence, at least for these two characters, it is expected that simple and exact methods for estimation, which may fall under the category of indirect diagnosis, are exploited as early as possible.

In rice plant, ratoon, that is, the shoot which grew out of resting bud on the stubble, is often observed after harvest. Though rice breeders have so far taken no notice of ratoon, it has been used as the second crop in a double-cropping system in many countries. Such ratoon cropping often brings some advantages; reduced cost of production resulting from no seeding and no transplanting, reduced crop cycle period, less requirement of irrigation water and fertilizer than main crop because of the shorter growth period.

As to the features of ratoon in rice, some investigations (IRRI Ann. Rep. 1975; BAHAR and DE DATTA 1977) have pointed out that grain yield in ratoon crop significantly differ with different cultivars. SATO (1968) suggested that ratoon growth could be used as an index for the physiological situation of rice plant. These findings suggest that the traits of ratoon may successfully be applicable to the estimation of various kinds of agronomic characters of rice plant. Up to date, however, there have not appeared any reports suggesting that the traits of ratoon are useful for the estimation of the agronomic characters.

From the viewpoint mentioned above, the author intended to make an indirect diagnosis of several agronomic characters of rice plant by means of three traits of ratoon, number of tillers, height of plant and weight of plant, and carried out a series of experiments extending from 1977 to 1981. First, the three traits of ratoon were investigated for the features, the varietal variation, and the relationships to the agronomic characters of mother plant, and the possibility of estimating the mother-plant characters by means of ratoon traits was discussed (CHAPTER I). Secondly, the effect of environment on the growth of ratoon was analysed with several internal and external environments, such as temperature, fertilizer level, water management and reserve substances contained in stem base (CHAPTER II). Thirdly, the relationship of two ratoon traits to the lodging resistance and its related characters of mother plant was examined (CHAPTER III). Finally, the effect of cutting height on the relationship of two ratoon traits to the percentage of ripened grains in mother plant was estimated and its variation with year was analysed (CHAPTER IV). From these investigations, it became clear that the percentage of ripened grains and the lodging resistance in mother plant could effectively be estimated by the percentage of tillers and height of ratoon, especially by percentage of tillers.

CHAPTER I.

RATOON TRAITS AND THEIR RELATIONSHIPS TO SOME AGRONOMIC CHARACTERS OF MOTHER PLANT

Introduction

Cultivated rice is annual and its life is generally brought to an end by cold and/or drought after harvest. Under suitable conditions, however, it is able to put forth some new shoots from harvested stubble. The shoots thus regenerated from the main crop (first crop), ratoon, can be used as ratoon crop (second crop) in a cropping system. Ratoon cropping has widely been practised and a number of studies on it have been carried out aiming at obtaining more vigorous second crop in many countries, such as India (GUPTA and MIRA 1948; SARAN and PRASAD 1952; GANGLY and RALWANI 1954; REDDY and PAWER 1959), Japan (ISHIKAWA 1964; YAMAMOTO 1973), the Philippines (RAMIREZ and DUMLAO 1961; IRRI Ann. Rep. 1975, 1978, 1979a, 1979b; BAHAR and DE DATTA 1977), Thailand (HASHIOKA 1963), China (PAN 1952; YANG 1958), Formosa (ISO 1954), the United States (EVATT 1958, 1966; EVATT and BEACHELL 1960; MENGEL and LEONARDS 1976), Colombia (GARCIA DURAN 1962, 1963), Swaziland (SZOKOLAY 1956; EVANS 1957) and Ethiopia (PRASHER 1970a,b). Some of these papers pointed out that the grain yield in ratoon crop significantly differed with different cultivars.

Plant breeders have not so far paid much attention to ratoon, and consequently not tried to exploit it in the breeding of rice, because they had no information about the use of ratoon. It is considered that a useful way for application of ratoon to breeding is to make use of ratoon as the measure for evaluating agronomic characters. From this viewpoint, three traits of ratoon were taken up, and their relationships to the agronomic characters of mother plant were investigated. To discuss the above relationships, however, it is an indispensable precondition that the objective characteristics of the ratoon are under genetic control, i.e., heritable. Based on this idea, the features of the three traits of ratoon were examined in parallel with their varietal variations at first.

Materials and Methods

Thirty rice cultivars (*Oryza sativa* L.) listed in Table 1 were used as materials. They were selected out of the recommended cultivars throughout Japan except Hokkaido district.

The experiment was conducted in Kagawa Prefecture in 1977. Thirty six-day-old seedlings were transplanted with a single plant per hill spaced at 30 x 10 cm on June 4. These cultivars were grown in a randomized block design with four

Table 1. Rice cultivars used.

	Name		Name		Name
1	Kinmaze	11	Minehikari	21	Mineyutaka
2	Yaeho	12	Harebare	22	Sachikaze
3	Nipponbare	13	Akinishiki	23	Tamayodo
4	Tosan No.38	14	Kusabue	24	Norin No.24
5	Akitsuho	15	Tsukubanishiki	25	Hakoda
6	Satominori	16	Norin No.29	26	Yachikogane
7	Akibare	17	Ginmasari	27	Akibae
8	Yamabiko	18	Koshijiwase	28	Suzukaze
9	Norin No.44	19	Chiyohikari	29	Sachiwatari
10	Chusei-shinsenbon	20	Azusa	30	Syurei

replications, each of which comprised 150 plants. Fertilizer with 1.0 kg N/*a*, 0.8 kg P_2O_5 /*a* and 1.0 kg K_2O /*a* was applied to the main crop as basal dressing, while no fertilization to the ratoon crop.

In each replication, 30 plants at a time were cut at 5 cm above the ground at four different growth stages, i.e., 10, 20, 30 and 40 days after heading, exactly after the heading date of the cultivar. The weight, height and number of tillers of ratoon were recorded at 40 days after cutting. The weight and the height were measured from plant to plant for dry matter and for the length from the ground level to the top of plant, respectively. As to the number of tillers, its percentage to the number of mother-plant tillers was calculated. With the residual non-cut plants (mother plants, 30 plants per replication), seven agronomic characters, culm length, panicle length, number of glumous flowers per panicle, percentage of ripened grains, thousand-kernel-weight, number of tillers per plant and grain yield, were recorded.

Results

From mother plant, a wide range of intervarietal variation was observed in each of agronomic characters examined. The earliest and the latest heading dates were

July 28 and August 30, respectively.

For ratoon, the means of 30 cultivars in weight, height and percentage of tillers at different cutting times were as shown in Fig. 1. In each character, the delay of the cutting time from 10 days to 20 days after heading brought about a conspicuous decrease of the value. But some increase was observed in subsequent cuttings, though the degree differed with characters. In each cutting time, a wide range of intervarietal variation was observed also for ratoon. In the case of cutting on the 10th day after heading, for instance, weight, height and percentage of tillers varied from 0.1 to 1.8 g, from 5 to 54 cm and from 5 to 71 %, respectively.

The results of variance analysis for the three traits of ratoon are as given in Table 2. They show that there were significant differences in each of the variances due to cultivar, cutting time and cultivar x cutting time interaction, suggesting that the traits of ratoon were heritable and that the change of each trait with the delay of cutting time differed with different cultivars. The fact that the traits of ratoon are thus heritable is of great importance in case of the ratoon traits as the indicators of mother plant characters.

Phenotypic correlation coefficients between the traits of ratoon and some agronomic characters of mother plant are given in Table 3. Significant positive correlations were seen in some cases of cutting at 10 and 20 days after

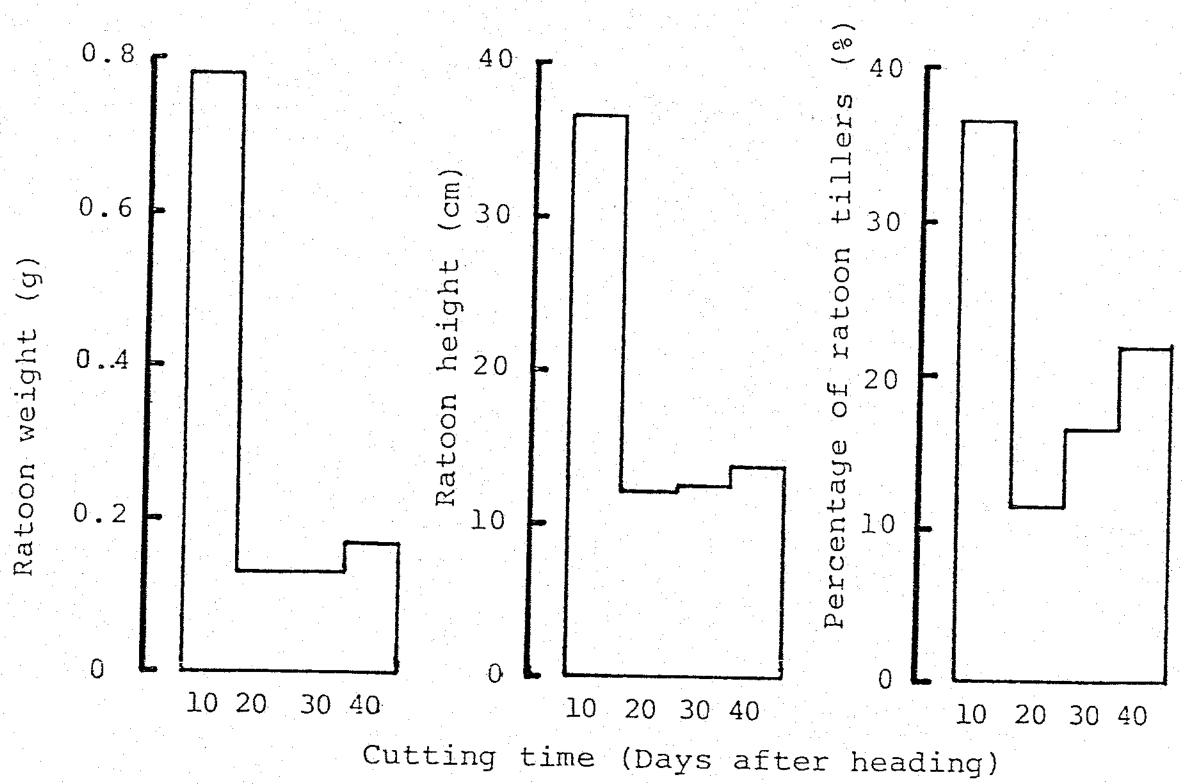

Fig. 1. Weight, height and percentage of tillers in ratoon crop at different cutting times

Table 2. Analysis of variance for ratoon traits.

Trait	Source	d.f.	M.S.
Ratoon weight	Cultivar(C)	29	0.36**
	Cutting time(T)	3	13.16**
	C × T	87	0.24**
	Error	360	0.06
Ratoon height	Cultivar(C)	29	823.58**
	Cutting time(T)	3	17021.03**
	C × T	87	192.99**
	Error	360	66.25
Percentage of ratoon tillers	Cultivar(C)	29	3363.81**
	Cutting time(T)	3	14167.89**
	C × T	87	301.08**
	Error	360	117.67

** : Significant at 1% level

Table 3. Phenotypic correlation coefficients between traits of ratoon and agronomic characters of mother plant.

Ratoon trait	Cutting time (Days after heading)	Agronomic character of mother plant						
		Culm length	Panicle length	Number of glumous flower per panicle	Percentage of ripened grains	Number of tillers per plant	Thousand -kernel -weight	Grain yield
Weight	10	-0.35	0.07	0.12	0.43*	0.01	0.23	0.38*
	20	-0.18	-0.23	0.01	0.40*	0.13	-0.14	0.32
	30	-o.33	0.18	0.19	0.15	-0.34	0.10	0.03
	40	-0.04	0.27	0.15	-0.02	-0.34	0.32	-0.07
Height	10	-0.20	0.15	0.18	0.58**	0.17	0.26	0.36
	20	-0.22	-0.32	-0.03	0.47*	0.13	-0.01	0.34
	30	-0.22	-0.12	0.11	0.15	0.01	-0.15	0.15
	40	-0.25	0.27	0.17	0.09	0.07	0.18	0.08
Percentage of tillers	10	-0.41*	-0.22	-0.08	0.59**	0.06	0.12	0.35
	20	-0.24	-0.21	-0.11	0.41*	0.15	-0.10	0.18
	30	-0.31	-0.25	0.05	0.20	0.00	-0.15	0.06
	40	-0.21	-0.10	0.17	0.17	-0.07	0.07	0.17

*,** : Significant at 5 and 1% levels,respectively

heading. Among them, those between the traits of ratoon and the percentage of ripened grains in mother plant are worth being noticed, because they imply that the percentage of ripened grains can be estimated from a ratoon trait. Phenotypic correlation coefficients tended to decrease with the delay of cutting time, and no correlations were observed in cuttings of the 30th and 40th day after heading for any traits and characters.

Genotypic correlation coefficients between the traits of ratoon and the agronomic characters of mother plant are shown in Table 4. In cuttings of 10 and 20 days after heading, all the ratoon traits had very high positive correlations with percentage of ripened grains, while had generally low correlations with the other characters.

Heritability estimates in broad sense of the traits of ratoon and the agronomic characters of mother plant are tabulated in Table 5. The estimates of heritability varied with cutting time for ratoon weight, but were almost constant for ratoon height and percentage of ratoon tillers. The estimates of heritability for percentage of ratoon tillers were higher than those for ratoon weight and ratoon height, and were nearly equal to those for culm length, panicle length and number of glumous flowers per panicle of mother plant.

Table 4. Genotypic correlation coefficients between traits of ratoon and agronomic characters of mother plant.

Ratoon trait	Cutting time (Days after heading)	Agronomic characters of mother plant						
		Culm length	Panicle length	Number of glumous flower per panicle	Percentage of ripened grains	Number of tillers per plant	Thousand -kernel -weight	Grain yield
Weight	10	-0.38	0.10	0.14	0.90	0.03	0.29	0.65
	20	-0.22	-0.26	-0.00	0.94	0.13	-0.22	0.58
	30	-0.48	0.21	0.23	0.48	-0.53	0.19	0.26
	40	-0.06	0.42	0.19	0.00	-0.54	0.46	-0.01
Height	10	-0.21	0.17	0.20	0.91	0.23	0.27	0.58
	20	-0.25	-0.35	0.05	0.95	0.14	-0.01	0.57
	30	-0.28	-0.15	0.13	0.36	0.01	-0.18	0.30
	40	-0.29	0.33	0.18	0.12	-0.17	0.20	0.10
Percentage of tillers	10	-0.63	-0.24	-0.09	0.94	0.06	0.10	0.55
	20	-0.26	-0.23	-0.13	0.76	0.18	-0.12	0.29
	30	-0.34	-0.28	0.05	0.38	0.01	-0.18	0.11
	40	-0.23	-0.09	0.19	0.26	-0.07	-0.11	0.22

Table 5. Broad sense heritabilities in traits of ratoon and agronomic characters of mother plant.

Trait of ratoon	Cutting time Days after heading	Heritability (%)
Weight	10	79.7
	20	69.2
	30	63.6
	40	67.1
Height	10	80.9
	20	82.4
	30	83.4
	40	82.4
Percentage of tillers	10	87.5
	20	90.0
	30	91.0
	40	90.0

Character of mother plant	Heritability (%)
Culm length	94.4
Panicle length	92.4
Number of glumous flowers per panicle	92.4
Percentage of ripened grains	34.9
Number of tillers per plant	61.6
Thousand-kernel-weight	78.4
Grain yield	45.4

Discussion

Three traits of ratoon, weight, height and percentage of tillers, decreased markedly with the delay of cutting time from the 10th to 20th day after heading, then turned toward increase. These changes are well corresponding to the changes of carbohydrate content in culm shown by SOGA and NOZAKI (1957), who reported that the carbohydrate content in culm of rice plant rapidly decreased during grain-filling period of the 10th to 25th day after heading and slightly increased after that period. These facts suggest that ratoon owes its most part of growth to the carbohydrates accumulated in the stem base of mother plant.

Significant differences were observed among cultivars in all of the three traits of ratoon. This shows that these ratoon traits are all heritable. PRASHER (1970a), YAMAMOTO (1973), and BAHAR and DE DATTA (1977) reported with the characteristics of rice ratoon that marked differences due to cultivars were observed also in grain yield.

Heritability estimate varied with ratoon trait, decreasing in descending order of percentage of tillers, height and weight. Throughout the three traits, however, the estimate was high enough to exceed its change due to the time of cutting: The heritability of percentage of ratoon tillers was much as high as those of culm length and panicle length.

The three traits of ratoon showed significant phenotypic- and high genotypic-correlations with the percentage of ripened grains in mother plant, when cutting was done after the 10th day from heading. Phenotypic correlation coefficients of the height and the percentage of tillers of ratoon to the percentage of ripened grains in mother plant were higher than that of the weight of ratoon. It may be concluded from the above facts that the percentage of tillers of ratoon obtained by the cutting after 10th day from heading could be used as an effective indicator for the percentage of ripened grains in mother plant. This finding will make a significant contribution to actual breeding of rice, because the percentage of ripened grains plays a very important part in constituting yield of rice plant, and rice breeders have not so far been provided with any useful selection measure for percentage of ripened grains due to its very low heritability as seen in Table 5.

Summary

This chapter was aimed at clarifying the features of three ratoon traits, their varietal variations and their relationships to the agronomic characters of mother plant.

Thirty cultivars of paddy rice were grown in a randomized block design with four replications, each of which comprised 150 plants. The rice plants were cut at 5 cm above the ground at four different stages, i.e., on the 10th, 20th, 30th and 40th day after heading. Three traits of ratoon, weight, height and percentage of tillers, were recorded on the 40th day after cutting, and their relationships to the several agronomic characters of mother plant were examined. The results obtained were as follows:

(1) In all the three ratoon traits, conspicuous decreases were observed when cutting was delayed from the 10th to 20th day after heading. However, some recovery occurred in the cuttings of 30th and 40th day after heading.

(2) Analysis of variance suggested that three ratoon traits were all heritable.

(3) In cuttings of the 10th and 20th day after heading, there were observed positive and highly significant phenotypic correlations between these three ratoon traits and the percentage of ripened grains in mother plant.

(4) Heritability in broad sense for the three ratoon traits became higher in ascending order of weight, height and percentage of tillers. Moreover, the heritability of percentage of ratoon tillers was as high as those of culm length and panicle length.

(5) Experimental results allowed to conclude that the percentage of ripened grains of rice plant can be estimated by the traits of ratoon, and the estimation can most

effectively be done by percentage of tillers among the three traits examined.

CHAPTER II.

EFFECTS OF INTERNAL AND EXTERNAL ENVIRONMENTS ON RATOON GROWTH

SECTION 1. EFFECTS OF LIGHT AND TEMPERATURE

Introduction

In rice, three traits of ratoon, weight, height and percentage of tillers, are of use for estimating some important agronomic characters of mother plant, as was suggested in the preceding chapter. However, these ratoon traits may be variable according to the internal and external environments of the stubble of which the ratoon grew out, though they are heritable, as already pointed out.

In herbage plants, the weight of new tops which grew out of stubble depends on the amount of reserve substances (EHARA *et al.* 1965a; MAENO AND EHARA 1970b) and on the condition of growth such as temperature (MAENO and EHARA 1970a; SATO and MATSUMOTO 1976). Moreover, according to EHARA *et al.* (1965c), the weight of the new tops increases when top-dressing of nitrogen is applied just before and just after cutting. In rice, the grain yield of ratoon crop increased when nitrogen manure was applied to the main crop between its early ripening stage and harvesting time (YAMAMOTO 1967; BAHAR and DE DATTA 1977; IRRI Ann. Rep.

1975). BAHAR and DE DATTA (1977) showed that the grain yield of low-cut ratoon crop decreased as the time between the harvest of main crop and the irrigation of ratoon crop was shortened. These studies on rice were carried out aiming at the improvement of the double-cropping of rice through ratooning. In rice, however, experiments for analysing the influences of internal and external environments on ratoon have not been made yet.

This section presents the effects of temperature and light on the weight, height and percentage of tillers of ratoon and also on the weight of stem base part of mother plant.

Materials and Methods

Rice cultivar Sachiwatari, which sprouts vigorous ratoon, was used. Thirty four-day-old seedlings were transplanted on June 4 to 1/5000 *a* Wagner pots with a single plant per pot. Compound synthetic fertilizer (N: 15 %, P_2O_5 : 12 %, K_2O : 15 %) was applied twice: 3.0 and 0.5 g per pot before transplanting and at boot stage, respectively. Material plants were cut at 5 cm above the ground on the 10th day after heading, then immediately transferred to four different environments; 30 ℃ and sunlight (30L), 30 ℃ and dark (30D), 20 ℃ and sunlight (20L), and 20 ℃ and dark (20D), where 'sunlight' and 'dark' mean natural condition and real dark throughout the day, respectively. Ratoon weight, ratoon height, percentage of ratoon tillers and besides the weight of stem base were noted on the day of cutting and on the 5th, 10th and 20th day thereafter. The stem base means the base part other than roots of mother plant below the cutting level, in which every leaf sheath of mother plant has been removed. The method for measuring the three traits of ratoon plant was the same as stated in preceding chapter.

Results

The heading date of Sachiwatari was August 15. Material plants were cut on August 25 and immediately transferred to the four different environments.

In Fig. 2, changes of ratoon weight against the time after cutting are shown for the four environments. As this figure shows, the weight was higher in lighter and warmer environments. The difference of weight was higher between 30 ℃ and 20 ℃ environments than between sunlight and dark environments. At each growth stage of ratoon, 30L produced the highest weight and 30D, 20L and 20D followed it in turn. On the 20th day, the difference of weight between 30 L and 30D was more remarkable than that between 20L and 20D. In the dark environments, some of the ratoon foliage withered

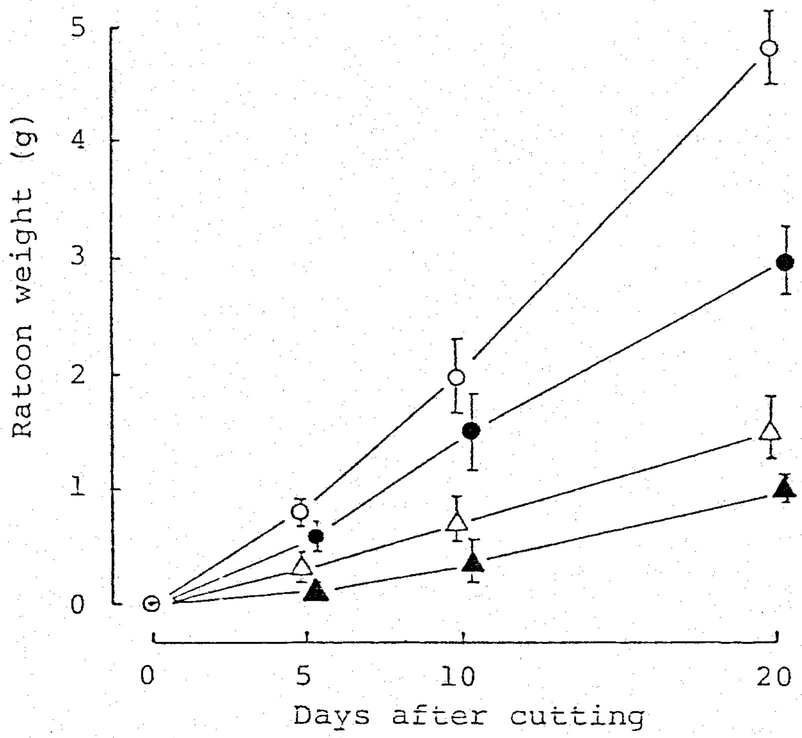

Fig. 2. Changes of ratoon weight for 4 different environments

○ : 30°C light chamber (30L)
● : 30°C dark chamber (30D)
△ : 20°C light chamber (20L)
▲ : 20°C dark chamber (20D)

Vertical line represents standard deviation

around the 20th day: The withering was more remarkable in 30D than in 20D. Therefore, it is supposed for the dark environments that on the 20th day, there would be little increase of the weight, if any. In sunlight environments, the foliage did not wither on the 20th day.

Changes of ratoon height are shown in Fig. 3. At every stage of development, the height was higher in 30 ℃ than 20 ℃, the former being approximately twice as high as the latter. There was observed no difference between sunlight and dark environments excepting a case of 30 ℃-20th day, where 30D plants were significantly higher than 30L plants. Toward the end of the 20-day observation period, heading was observed in almost all 30L plants and in some of 30D plants, while no panicle emergence was observed in 20L plants nor 20D plants. The age of ratoon plant on the 20th day was, if expressed by number of leaves, approximately three in 30 ℃ environment and two in 20 ℃.

Figure 4 shows the changes of the percentage of ratoon tillers. The maximum values were 131 %, 105 %, 88 % and 78 % in 30L, 30D, 20L and 20D, respectively. The time required for reaching these values were 5, 10, 20 and 20 days, respectively. Thus, the lower the temperature was, the lower both percentage of ratoon tillers and its rate of increase were.

Changes of stem base weight are shown in Fig. 5. Through the 20-day observation, a nearly linear decrease was

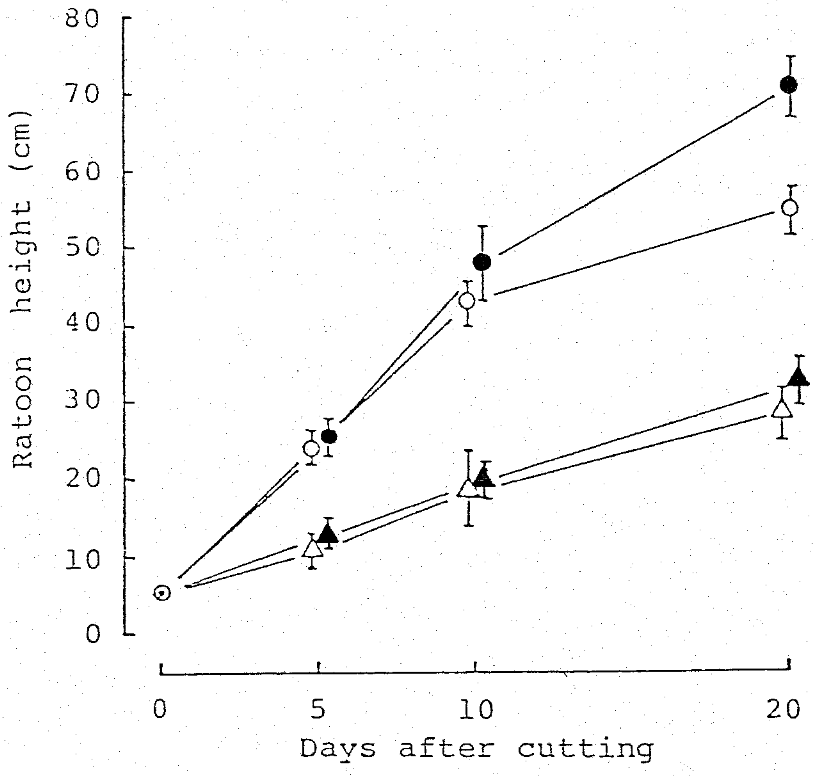

Fig. 3. Changes of ratoon height for
4 different environments

○ : 30°C light chamber (30L)
● : 30°C dark chamber (30D)
△ : 20°C light chamber (20L)
▲ : 20°C dark chamber (20D)

Vertical line represents standard deviation

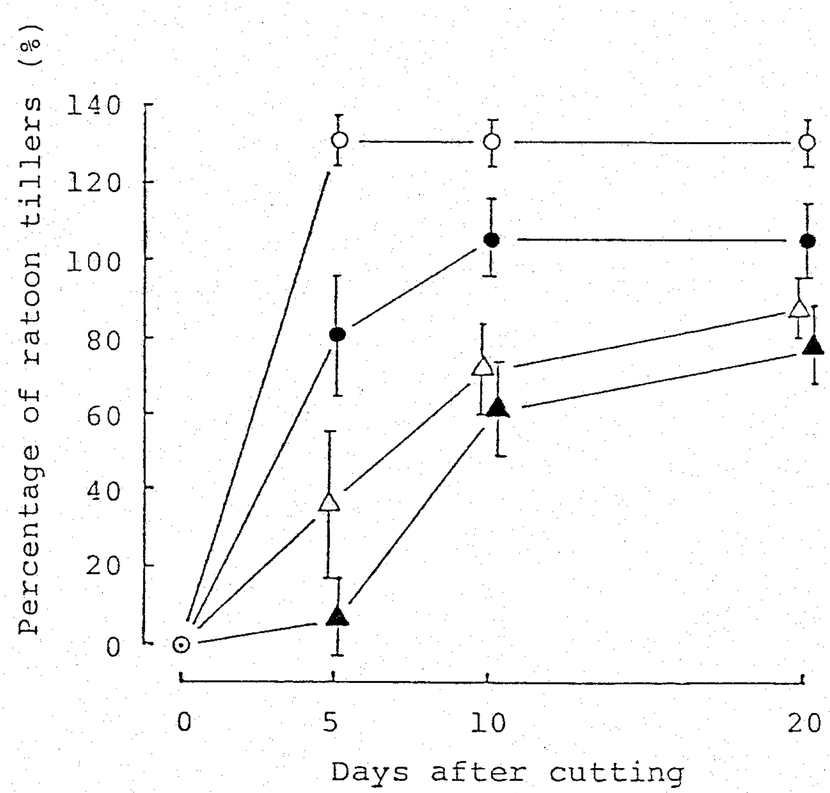

Fig. 4. Changes of percentage of ratoon tillers for 4 different envrionments

○ : 30°C light chamber (30L)
● : 30°C dark chamber (30D)
△ : 20°C light chamber (20L)
▲ : 20°C dark chamber (20D)

Vertical line represents standard deviation

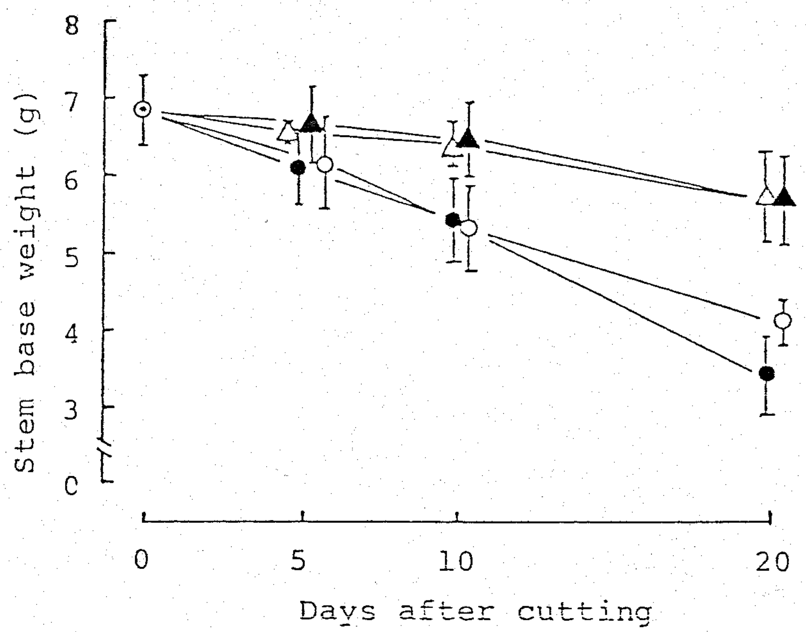

Fig. 5. Changes of stem-base weight for 4 different environments

○ : 30°C light chamber (30L)
● : 30°C dark chamber (30D)
△ : 20°C light chamber (20L)
▲ : 20°C dark chamber (20D)

Vertical line represents standard deviation

observed in each environment: The weight was always lower in 30 ℃ than in 20 ℃. The weight in sunlight was approximately equal to that in dark except for a case of 30 ℃-20th day, where an evident difference was observed between the two environments.

From the decrease of stem base weight (Fig. 5) and the increase of ratoon weight (Fig. 2), it is inferred that some substances contained in the stem base play an important role in the growth and respiration of ratoon plant. Figure 6 shows the changes in sum of stem base weight and ratoon weight. In three environments 30D, 20L and 20D, the sums were almost constant at around 7 g throughout the 20 days of observation. In 30L, on the other hand, the sum was nearly equal to those of the other environments until the 10th day, but then it soon increased to reach about 9 g on the 20th day. This suggests that after 10th day, the foliage of ratoon in 30L contributed the photosynthetic products to its own growth. In dark environment, since the substances contained in stem base should partly be consumed for respiration, the total weight may decrease after cutting. This decrease, however, was not so large during the 20-day observation period. Therefore, it seems that quantity of the substances consumed for respiration is quite little.

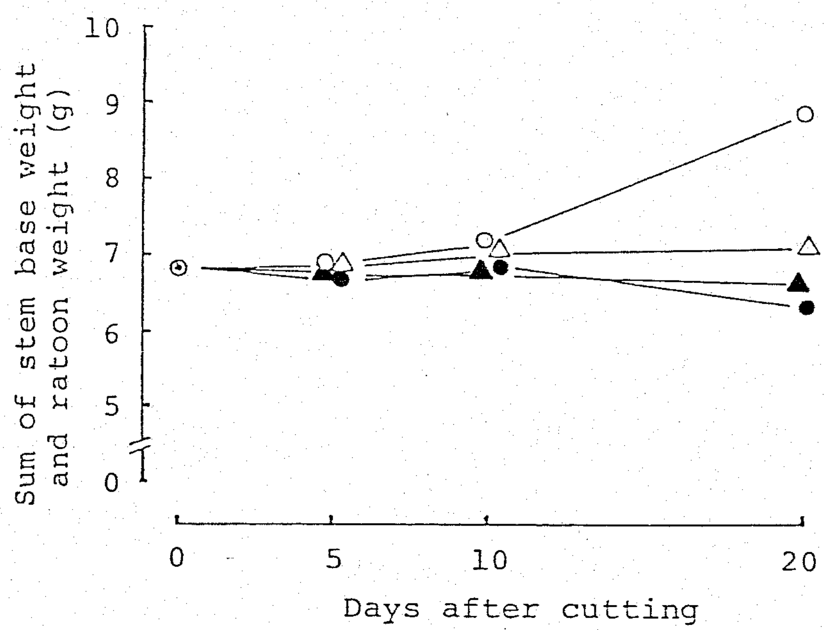

Fig. 6. Changes of stem base weight plus ratoon weight for 4 different environments

○ : 30°C light chamber (30L)
● : 30°C dark chamber (30D)
△ : 20°C light chamber (20L)
▲ : 20°C dark chamber (20D)

Discussion

On the 10th day after cutting, ratoon weight was larger in sunlight environment than in dark one, while stem base weight did not differ between the two environments. This may indicate that the growth of rice ratoon is promoted by photosynthetic products produced in the foliage even at early period after cutting, and that the products do not transfer to the stubble at this period. EHARA *et al.* (1965b), however, reported in their experiment with bahiagrass that during the first few days after defoliation, light had little effect on regrowth, but more on the stubble. This discrepancy is most likely to be due to the difference in material used.

Stem base weight decreased almost linearly throughout the 20 days after cutting in each environment (Fig. 5), and on the 20th day, became higher in 30L than in 30D. This difference between 30L and 30D may have been caused by the import of photosynthetic products from foliage to stubble. If so, it is expected that the weight started to increase after the 20th day.

Both weight and height of ratoon continued to increase in each environment throughout the period of 20 days following cutting (Figs. 2 and 3). Percentage of ratoon tillers, on the other hand, increased in each environment at latest by around the 10th day after cutting, but soon reached a constant value (Fig. 4). These facts indicate that percentage of ratoon tillers can be used for earlier evaluation of mother-plant characters than ratoon weight and ratoon height.

Summary

The effect of light and temperature on ratoon growth was investigated with a rice cultivar Sachiwatari.

Thirty four-day-old seedlings were transplanted on June 4 to 1/5000 *a* Wagner pots. Material plants were cut at 5 cm above the ground on the 10th day after heading, then immediately transferred to four different environments; 30 ℃ and sunlight (30L), 30 ℃ and dark (30D), 20 ℃ and sunlight (20L), and 20 ℃ and dark (20D). Weight, height and percentage of tillers of ratoon plant and stem base weight were noted on the day of cutting and on the 5th, 10th and 20th day thereafter. The results obtained are as follows:

(1) On each of the 5th, 10th and 20th day after cutting, ratoon weight and percentage of ratoon tillers showed higher values in 30 ℃ than in 20 ℃, and in sunlight than in dark. Ratoon height showed higher value in 30 ℃ than in 20 ℃, but no difference between sunlight and dark except a case of 30 ℃ on 20th day.

(2) In every environment, the time required for reaching the constant value was much shorter in percentage of ratoon tillers than in the other two. This suggested that percentage of ratoon tillers could more effectively used as the indicator for estimating the characters of mother plant than the other two.

(3) Sum of stem-base weight and ratoon weight was almost constant throughout the observation period in all the environments other than 30L. In 30L environment, the sum was equal to those in other environments until the 10th day after cutting, but then it soon increased. This suggested that after the 10th day, the foliage of ratoon in 30L contributed its photosynthetic products to its own growth. The fact that the sum in dark environments were almost constant throughout the 20 day-observation period, suggested that the substances contained in stem base was little consumed for respiration of ratoon plant.

SECTION 2. EFFECT OF MACRONUTRIENTS

Introduction

On the response of ratoon crop to macronutrients, YAMAMOTO (1967), IRRI Ann. Rep. (1975) and BAHAR and DE DATTA (1977) reported that the grain yield of the ratoon crop of rice increased when nitrogen manure was applied to the main crop between the early ripening stage and harvesting time. SU (1980) also showed with the application of nitrogen fertilizer to ratoon crop of rice that the earlier the application was, the higher the grain yield became. In these papers, however, they did not deal with the responses of tiller number and height of ratoon plant. Moreover, no reports on those responses have appeared yet.

The objective of this section is to determine the effects of the amount of nitrogen, phosphorus and potassium fertilizers and the timing of fertilization on the growth of rice ratoon.

Materials and Methods

Rice cultivar Ginmasari was used as material. Two hundred seedlings of 35-day-old were transplanted on June 25 in 1981 to 1/5000 *a* Wagner pots with a single plant per pot.

The transplanted plants were held with the gravel put in a plastic basket of 5 cm deep, and were grown in Kimura's B solution (the solution listed in Table 6 as "standard"). On the heading date of the cultivar, material plants were submitted to the treatment for determining the effect of macronutrient on ratoon growth, using six different nutrient solution shown in Table 6. The treatment was conducted for 20 days according to the design shown in Table 7, which involved ten kinds of culture. As also indicated in Table 7, material plants were cut 10 days after the heading date at 5 cm above the ground level (grave surface in pot) to make ratoons sprout. After the 20-day treatment finished, all the ratoon plants were cultured by the standard solution for further 30 days.

On the 10th day after cutting, percentage of ratoon tillers and ratoon height were noted. On the 40th day after cutting, percentage of ratoon tillers, ratoon height and ratoon weight were recorded. Ratoon height was expressed as the length from the cutting level to the top of plant. The other two traits were measured with the same manner as used in CHAPTER I.

Results

The heading date of Ginmasari was August 26.

Table 6. Nutrient solutions used.

(mg/l)

Solution (Abbreviation)	Symbol	Constituents									
		$(NH_4)_2SO_4$	K_2SO_4	KNO_3	$Ca(NO_3)_2$	$CaCl$ $2H_2O$	KH_2PO_4	$MgSO_4$	$FeC_6H_5O_7$ xH_2O	Na_2HPO_4	$NaNO_3$
Macronutrient deficient (NPK0)	000	—	—	—	—	—	—	65.9	3.5	—	—
Standard (NPK1)	111	48.2	15.9	18.5	59.9	—	24.8	65.9	3.5	—	—
Doubled (NPK2)	222	96.4	31.8	37.0	59.9	—	49.6	65.9	3.5	—	31.0
Nitrogen deficient (N0)	011	—	31.8	—	—	53.7	24.8	65.9	3.5	—	—
Phosphorus deficient (P0)	101	48.2	31.8	18.5	59.9	—	—	65.9	3.5	—	—
Potassium deficient (K0)	110	48.2	—	—	59.9	—	—	65.9	3.5	25.9	15.6

Table 7. Design for determining the effect of macronutrients on ratoon.

Treatment number	Symbol	Solution applied for 10 days	
		Until cutting*	After cutting*
1	000 / 000	NPK0	NPK0
2	111 / 111	NPK1	NPK1
3	222 / 222	NPK2	NPK2
4	000 / 111	NPK0	NPK1
5	222 / 111	NPK2	NPK1
6	111 / 000	NPK1	NPK0
7	111 / 222	NPK1	NPK2
8	111 / 011	NPK1	N0
9	111 / 101	NPK1	P0
10	111 / 110	NPK1	K0

*: Cutting was made at 10 days after heading.

Accordingly, the cutting of plants (mother plants) was made on September 5 (10 days later) and the treatment for determining the effect of macronutrients was conducted for the 20-day period from August 26 to September 15.

Figure 7 shows the responses of the three traits of ratoon, percentage of tillers, height and weight, to the total amount of macronutrients applied throughout the treatment. On both the 10th and the 40th day after cutting, percentage of tillers significantly increased with the increase of the amount of macronutrients applied. On the 40th day, the values in macronutrient-deficient and standard solution cultures became 77 and 88 % of the value in doubled solution culture, respectively. The value in macronutrient-deficient solution culture increased from the 10th day toward the 40th day, but those in standard and doubled solution cultures did not change, indicating that sufficient macronutrients promoted tillering.

The increase of height due to the increase of macronutrients was observed on both the 10th and the 40th day. Statistical significance was, however, observed only in the increase from macronutrient-deficient to standard solution culture. The weight on the 40th day responded to the amount of macronutrients applied, increasing significantly. The values in macronutrient-deficient and standard solution cultures were 75 and 90 % of the value in doubled solution culture, respectively. These ratios are

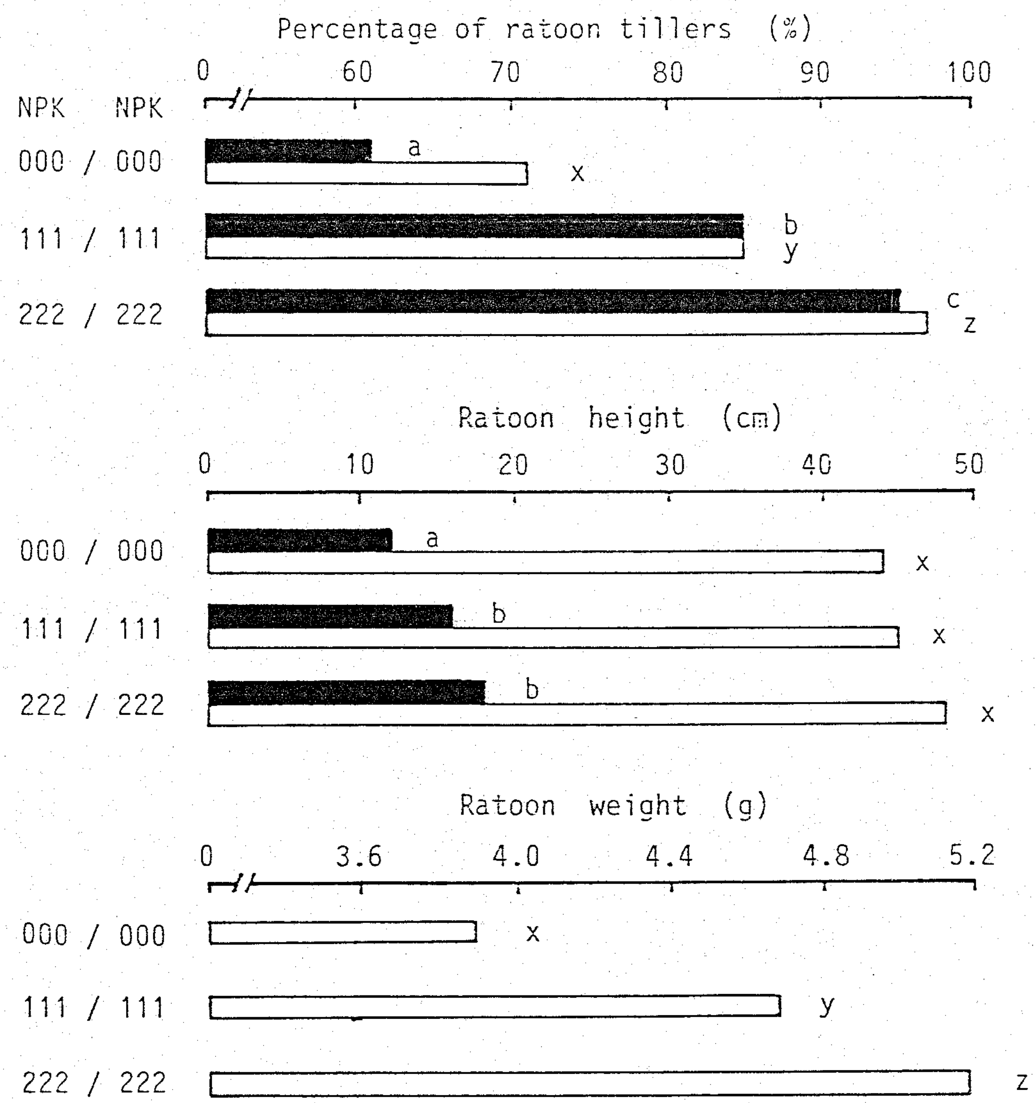

Fig. 7. Effect of the amount of macronutrients applied during 20 days following heading on three ratoon traits; cutting was done at 10 days after heading.

▬ : On the 10th day after cutting,
▭ : On the 40th day after cutting.

The means with the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

approximately equal to those observed in percentage of tillers.

Figure 8 shows the responses of the three traits of ratoon to the macronutrient application during 10 days prior to cutting. On both the 10th and 40th day after cutting, percentage of tillers tended to be higher in standard and doubled solution than in macronutrient- deficient solution, but statistically significant differences were not detected. Likewise, no significant differences were observed in height nor weight. Thus, fertilization of macronutrients during 10 days just before cutting proved not to have any significant influence on ratoon growth.

The responses of the three ratoon traits to macronutrient application during 10 days just after cutting are as shown in Fig. 9. On both the 10th and the 40th day after cutting, percentage of ratoon tillers significantly increased as the amount of macronutrients increased. On the 40th day, the values in macronutrient-deficient and standard solution culture reached 73 and 90 % of the value in doubled solution, respectively. These ratios are approximately equal to those in percentage of tillers shown in Fig. 7. Thus, the percentage of tillers in macronutrient-deficient solution was still far less than that in standard solution even on the 40th day after cutting, whereas ratoon plants had all been cultured in the same solution (standard solution) after the 10th day from cutting. This means that tillering of

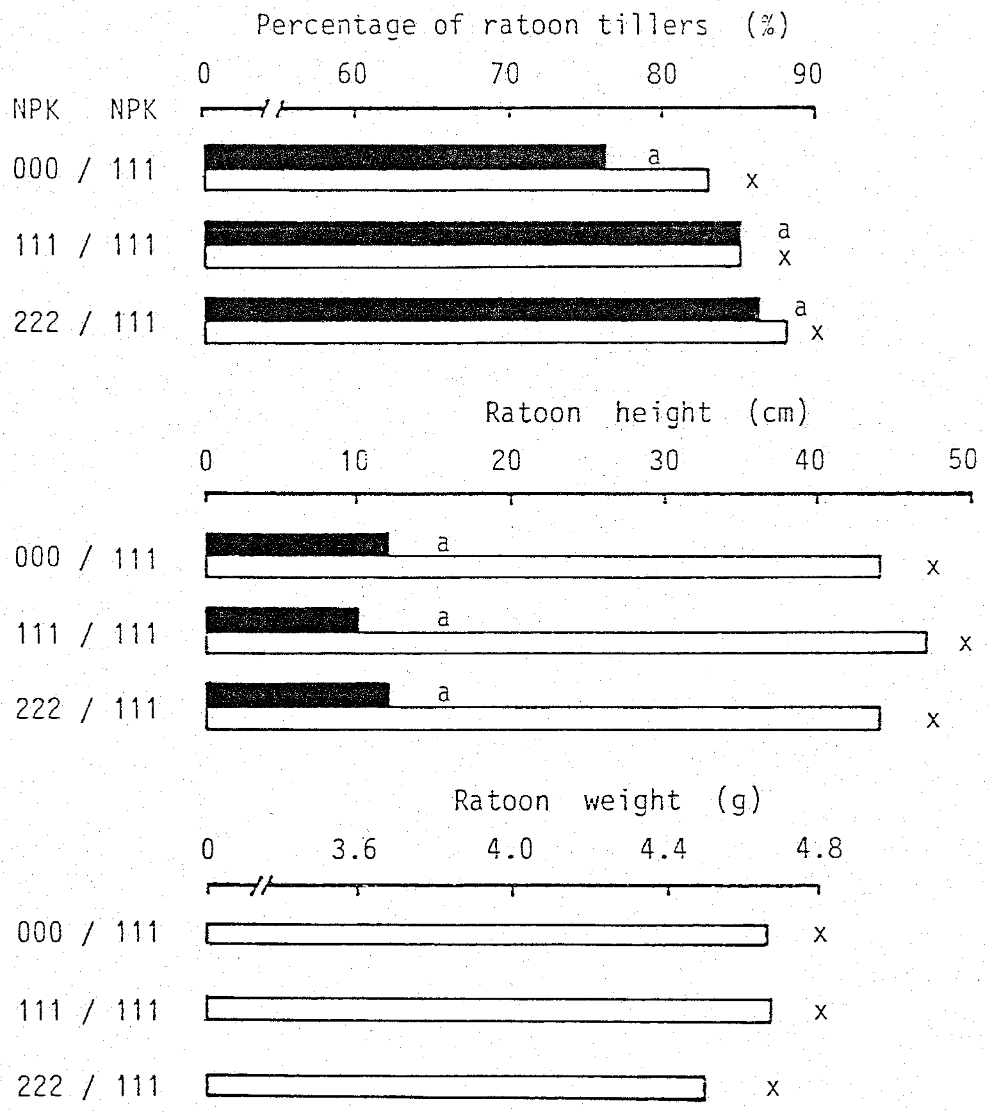

Fig. 8. Effect of the macronutrient application during 10 days before cutting on three ratoon traits.

■ : On the 10th day after cutting,
□ : On the 40th day after cutting.

The means with the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

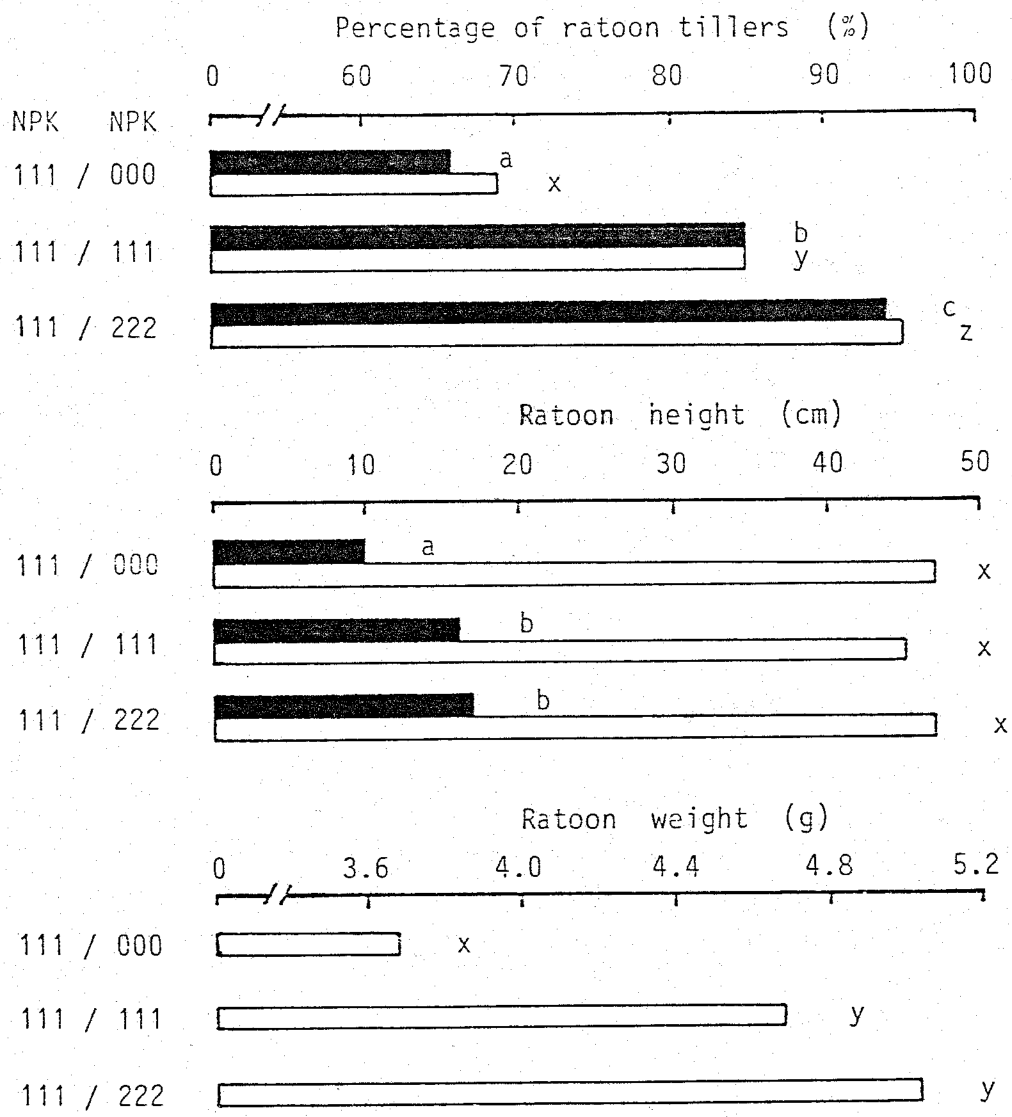

Fig. 9. Effect of the macronutrient application during 10 days after cutting on three ratoon traits.

■ : On the 10th day after cutting,
□ : On the 40th day after cutting.
The means with the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

ratoon is mostly determined by the amount of macronutrients existing during 10 days following cutting.

The height on the 10th day after cutting was significantly lower in macronutrient-deficient solution than in standard and doubled solutions. On the 40th day, however, such a significant difference disappeared. The weight was significantly increased in response to the dose of macronutrients. The values in macronutrient-deficient and standard solutions were 73 and 93 % of the value in doubled solution, respectively. These ratios were approximately equal to those in the percentage of tillers and weight shown in Fig. 7. Fertilizing during 10 days following cutting thus proved to have an important influence on ratoon, especially on percentage of tillers and weight.

The effects of nitrogen-, phosphorus- or potassium-deficiency on the three traits of ratoon are shown in Fig. 10. On the 10th day, after cutting, significant decrease of percentage of tillers was observed in nitrogen- and phosphorus-deficient solution, but not in potassium-deficient solution. On the 40th day, significant decrease of this trait was observed only in nitrogen-deficient solution, though an apparent decrease occured in phosphorus-deficient solution. Percentages of tillers in nitrogen-, phosphorus- and potassium-deficient solutions were 84, 92 and 101 % of that in standard solution, respectively. Over 10th and 40th days, significant

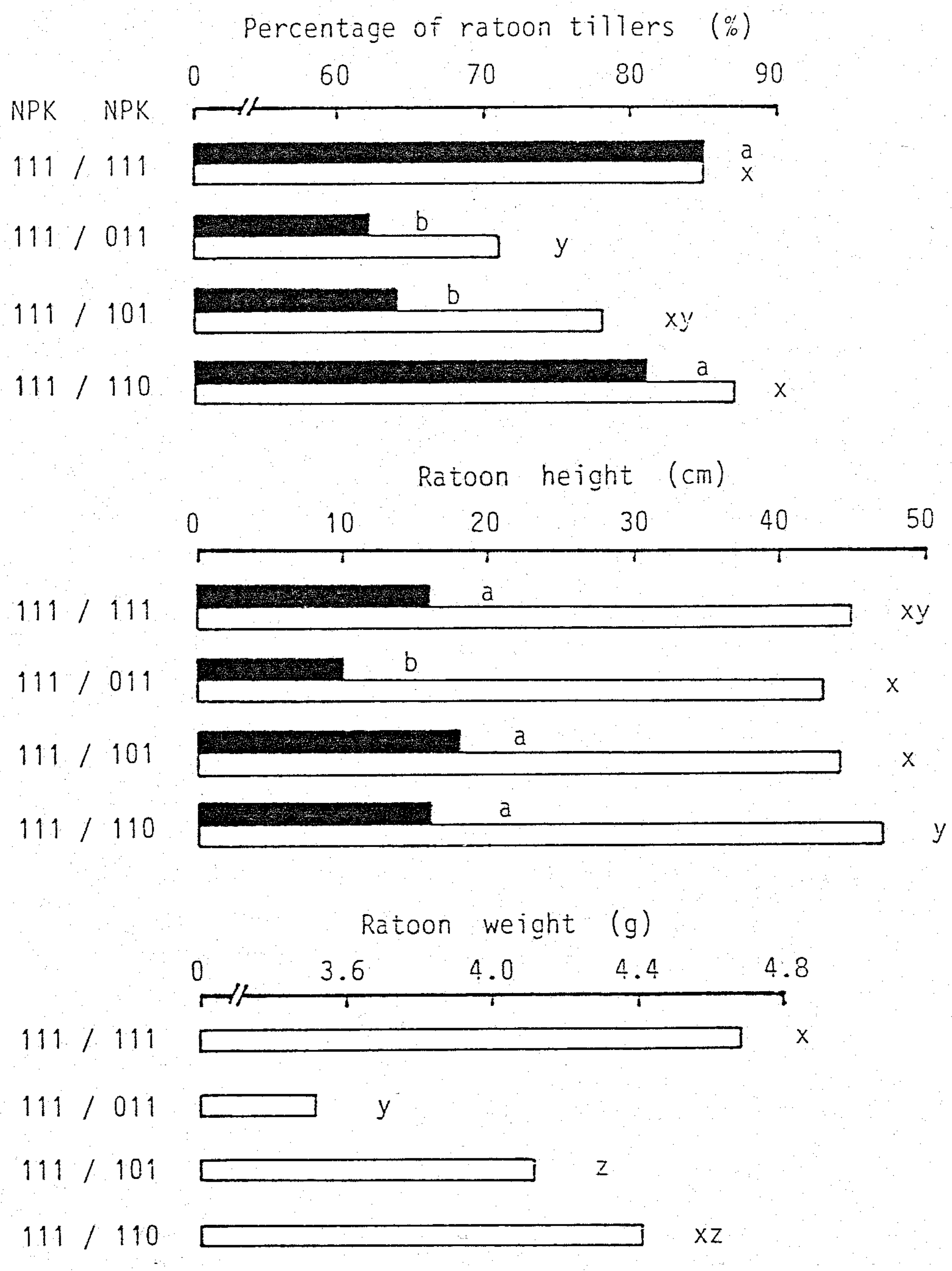

Fig. 10. Effect of the macronutrient deficiency during 10 days after cutting on three ratoon traits.

■ : On the 10th day after cutting,
□ : On the 40th day after cutting.
The means with the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

decrease of height was observed only on the 10th day and only in nitrogen-deficient solution. With the decrease of weight, nitrogen-deficiency ranked first, followed by phosphorus-deficiency, potassium-deficiency and standard in turn, and mutual differences were all significant except those between phosphorus-deficient and potassium-deficient solutions, and between potassium-deficient and standard solutions. The weights in nitrogen-, phosphorus- and potassium-deficiencies were 75, 88 and 95 % of that in standard solution, respectively.

Discussion

As can be seen from the observation on the 40th day after cutting, the application of macronutrients before cutting produced no significant effect on all the ratoon traits examined (Fig. 8), but that after cutting brought about considerable difference due to the applied amount in percentage of ratoon tillers as well as in ratoon weight, though not in ratoon height at all (Fig. 9). This means that the time of fertilization as well as the amount is of great importance for increasing percentage of ratoon tillers, but not for increasing ratoon height. According to BAHAR and DE DATTA (1977), however, when the rate of nitrogen applied to ratoon crop increased, the tiller number of ratoon plants did not show any significant increase. This discrepancy may be attributable to the difference between solution culture in pot and soil culture in field.

The result that macronutrient application before cutting had no significant effect on all the ratoon traits, may also suggest that macronutrient application before cutting produces no increase of the reserve substances in stem base. This consideration may be supported by EHARA *et al.* (1965a), who showed in Italian ryegrass and orchardgrass that the dry weight of new tops increased with the increase of reserve substances contained in stubble.

According to DE DATTA (1981), the symptom of nitrogen and phosphorus deficiencies in rice plants is 'stunted plants with limited number of tillers', while that of potassium deficiency is 'stunted plants with slightly reduced number of tillers'. SEKIYA (1963a,b, 1967) showed that the inhibitory effect on the tillering-bud development in rice plants was largest for nitrogen deficiency, second for phosphorus deficiency, third for potassium deficiency; especially the effects of nitrogen and phosphorus deficiencies were remarkable. EHARA *et al.* (1965c) indicated on the regrowth of bahiagrass that the effect of macronutrient deficiency in nutrient solution was by far larger for nitrogen than others and very slight for potassium, and there was no difference of the regrowth behavior between the plants grown in phosphorus-deficient nutrient solution and those grown in standard one. In the present experiment, the effect of macronutrient deficiency on percentage of ratoon tillers was largest for nitrogen, second for phosphorus, third and slight for potassium. These facts show that the deficiency of some macronutrient affects main crop and ratoon crop in the same manner.

The weight and tiller number of ratoon were influenced most remarkably by nitrogen (Fig. 10). This stands for the importance of nitrogen in ratoon crop of rice, since the weight and tiller number of ratoon directly take part in the grain yield of ratoon crop. BAHAR and DE DATTA (1977) and MENGEL and WILSON (1981) reported that significant increase of grain yield in ratoon crop of rice was obtained by the nitrogen fertilization following cutting. The same results were shown in sorghum by ESCALADA and PLICKNETT (1977) and TOUCHTON and MARTIN (1981). According to MAENO and EHARA (1970b), NADA and EHARA (1970) and WILMAN and WRIGHT (1978), ratoon weight also significantly increased by applying nitrogen fertilizer following cutting in oats, dallisgrass, Italian ryegrass, perennial ryegrass and orchardgrass. These indications that the application of nitrogen is needed for the ratoon cropping in rice and grasses seem to support the results of the present experiment.

As easily inferred from the above facts, the deficiency of nitrogen greatly reduced the growth of ratoon (Fig. 10). This reduction of ratoon growth is considered to be due to the inhibitory effect of nitrogen deficiency against the utilization of reserve substances accumulated in stem base, because all the plants submitted to the treatment for macronutrient deficiency (Fig. 10) were grown under the same nutritional condition from transplanting to cutting, and hence they should have had the same amount of the reserve substances at the cutting time. Thus it may be concluded that the nitrogen applied just after cutting plays a very important role in the utilization of reserve substances, eventually in the growth of ratoon plant. The above interpretation for the action of nitrogen is supported by the result of KUMAI and SANADA (1973) that in the regrowth of orchardgrass, nitrogen deficiency gave rise to the reduction of utilization efficiency of reserve substances.

Putting the results obtained from the present experiment together, in so far as the fertilizers are liquid ones, it can be said that the applications of nitrogen and phosphorus fertilizers immediately after harvesting of the main crop are most effective for ratoon production.

Summary

In this section, the effects of macronutrients on ratoon growth of rice were examined for the amount, kind and time of application.

Rice plants of a cultivar Ginmasari were grown in Kimura's B solution (standard solution). On the heading date of the cultivar, material plants were submitted to the 20-day treatment which consisted of ten kinds of culture with six different nutrient solutions. Material plants were cut 10 days after the heading date (in the middle of the treatment) at 5 cm above the ground level. After the 20-day treatment finished, all the ratoon plants were cultured by the standard solution for further 30 days. On the 10th day after cutting, percentage of ratoon tillers and ratoon height were noted. On the 10th and 40th day after cutting, percentage of ratoon tillers, ratoon height and ratoon weight were recorded. The results obtained are as follows:

(1) The macronutrient application during 10 days prior to cutting had no significant influence on all the three ratoon traits examined, but that during 10 days after cutting brought about considerable differences due to the applied amount in two traits, percentage of ratoon tillers and ratoon weight.
(2) With the decreases of percentage of tillers and weight, the effect of nitrogen deficiency ranked first, followed by phosphorus deficiency, potassium deficiency and standard solution in turn. The values of these traits in potassium deficiency did not differ from those in standard solution.

SECTION 3. EFFECT OF WATER MANAGEMENT

Introduction

Effects of external environments such as light, temperature and macronutrients on the growth of ratoon were discussed in the preceding sections. These discussions naturally lead to the interest that water management may also have significant effects upon the growth of ratoon. According to HARNAEZ (1958), irrigation immediately after harvest is liable to cause the stubble to rot. BAHAR and DE DATTA (1977) found that when the stubble was reflooded, the cutting height of the main crop had no influence on the grain yield of ratoon crop. That is, when the main crop was cut at the ground level, the yield of ratoon crop increase by delaying the flooding until 12 days after harvest. When the main crop was cut at 15 cm, on the other hand, the timing of the flood during the first 16 days after harvest had no effect on the yield of ratoon crop. MENGEL and WILSON (1981) reported that early flooding after harvest of the main crop resulted in a more rapid and uniform regrowth than delayed flooding.

The objective of this section to determine the effect of reflood timing on the growth of rice ratoon. The study consists of two experiments.

Materials and Methods

Experiment I.

Eighty plants each of two rice cultivars, Yaeho and Oseto, were used as materials. Thirty five-day-old seedlings were transplanted on June 17 in 1980 to 1/2000 *a* Wagner pots with two plants per pot. Transplanted plants were fertilized with 12.0 g of compound synthetic fertilizer (N: 15 %, P_2O_5 : 12 %, K_2O : 15 %). Five-sixth of the fertilizer was broadcasted before transplanting; the rest was applied at the boot stage. Material plants were cut at ground level and at 5 cm above the ground on the 10th day after the heading date of each cultivar. Immediately after the cutting, plants received two irrigation treatments; a continuous flooding 5 cm deep and a non-flooding. On the 5th, 10th, 20th and 40th day after cutting, percentage of ratoon tillers and ratoon height were measured by the same manner as stated in the preceding section.

Experiment II.

One hundred and fifty plants of a rice cultivar Koshihikari was used as materials. Thirty five-day-old seedlings were transplanted on June 18 in 1981 to 1/2000 *a* Wagner pots with two plants per pot. The transplanted plants were fertilized in much the same way as in *Experiment* I. Material plants were cut at 20 cm above the ground on the 10th day after the heading date of the cultivar. The plants received ten irrigation treatments which differed in the depth of water (drained, under 1 cm, 5 cm) and the period of flooding. Figure 11 shows the design of the experiment. Percentage of ratoon tillers and ratoon height were measured in the same way as in *Experiment* I.

Results

Experiment I.

The heading dates of Yaeho and Oseto were August 31 and August 26, respectively. Changes in percentage of ratoon tillers are shown in Fig. 12. Most of hills in either cultivar did not produce ratoons when the main crop was cut at ground level and the water depth was maintained at 5 cm. Flooding with 5 cm depth, however, did not affect the percentage of ratoon tillers when the main crop was cut at 5 cm. Reducing the cutting height from 5 cm to the ground level caused a significant decrease of ratoon number for Oseto, but not for yaeho. Percentage of ratoon tillers reached its highest value on the 20th day after cutting.

Figure 13 shows the changes in ratoon height following cutting. In the treatment where cutting height was the

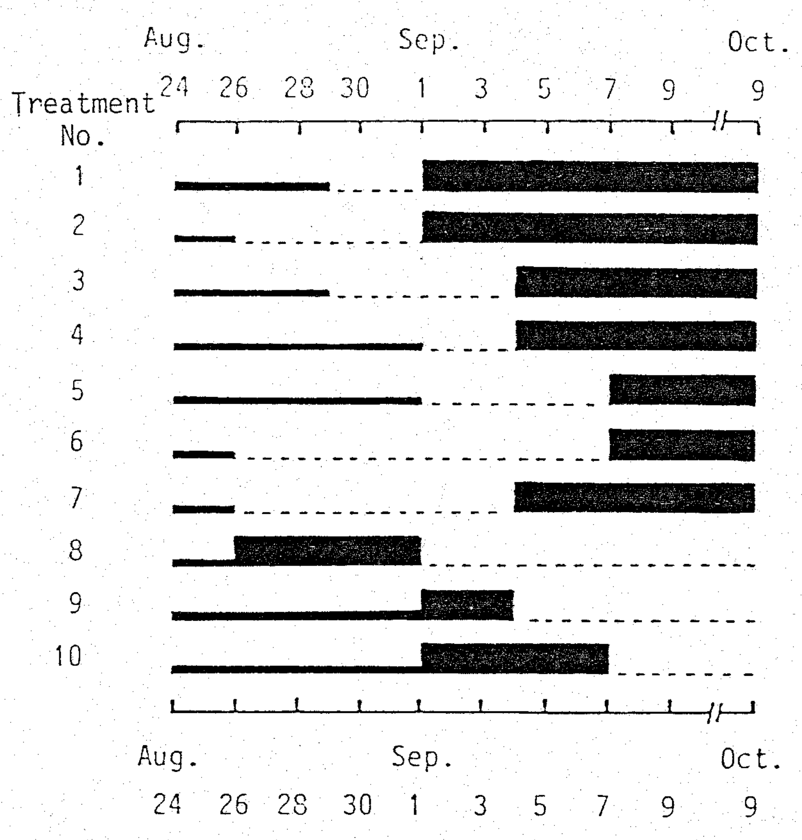

Fig. 11. Water management assigned.

----- : Drained
▬▬ : Under 1 cm of water
█ : At 5 cm of water

Material cutivar, Koshihikari, headed on August 22.
Cutting was made on September 1.

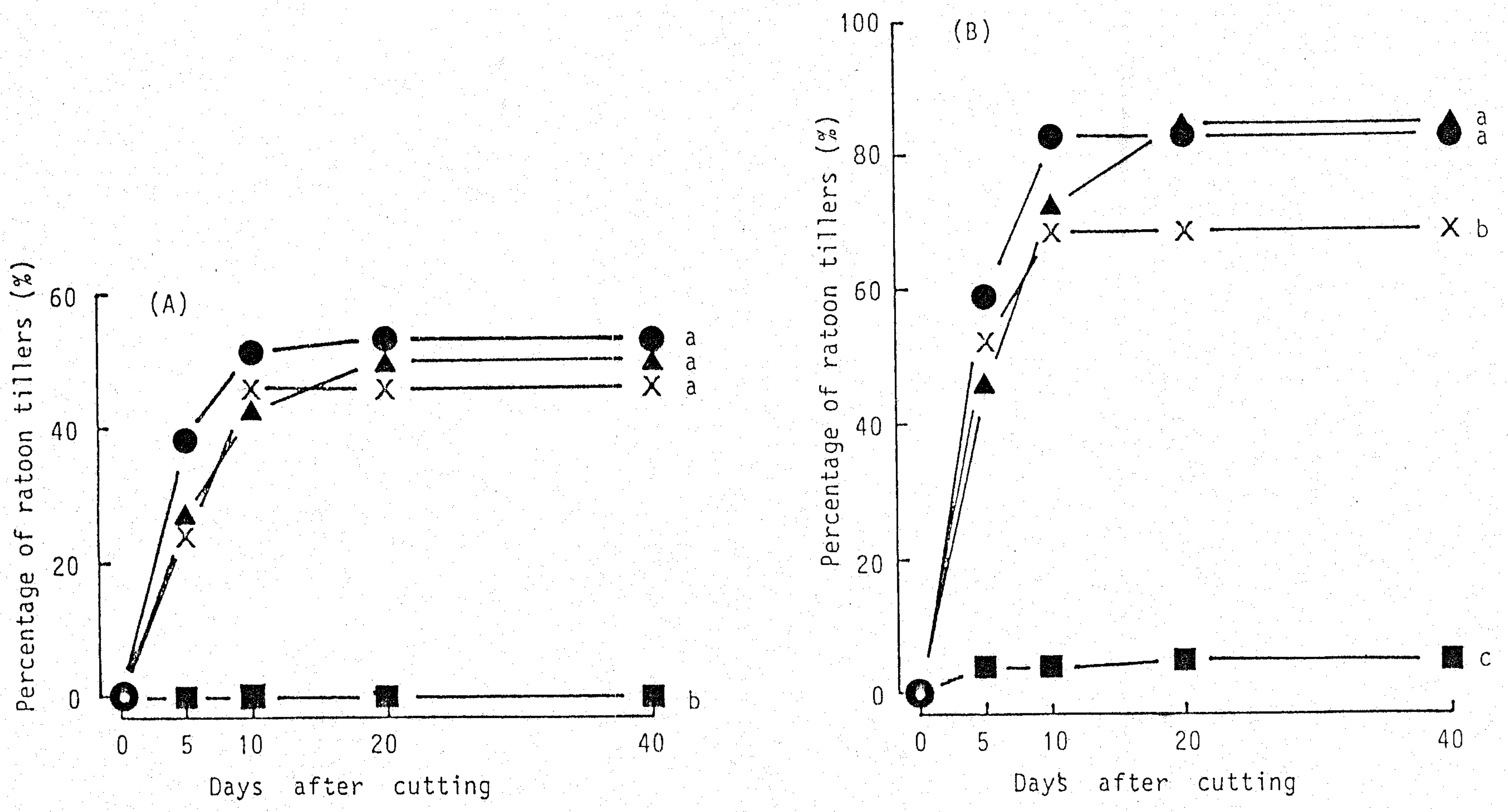

Fig. 12. Effects of cutting height and water management on percentage of tillers of ratoon in (A) Yaeho and (B) Oseto.

Means with the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

●: Cut at 5 cm above the ground and non-flooded
▲: Cut at 5 cm above the ground and flooded
×: Cut at the ground level and non-flooded
■: Cut at the ground level and flooded

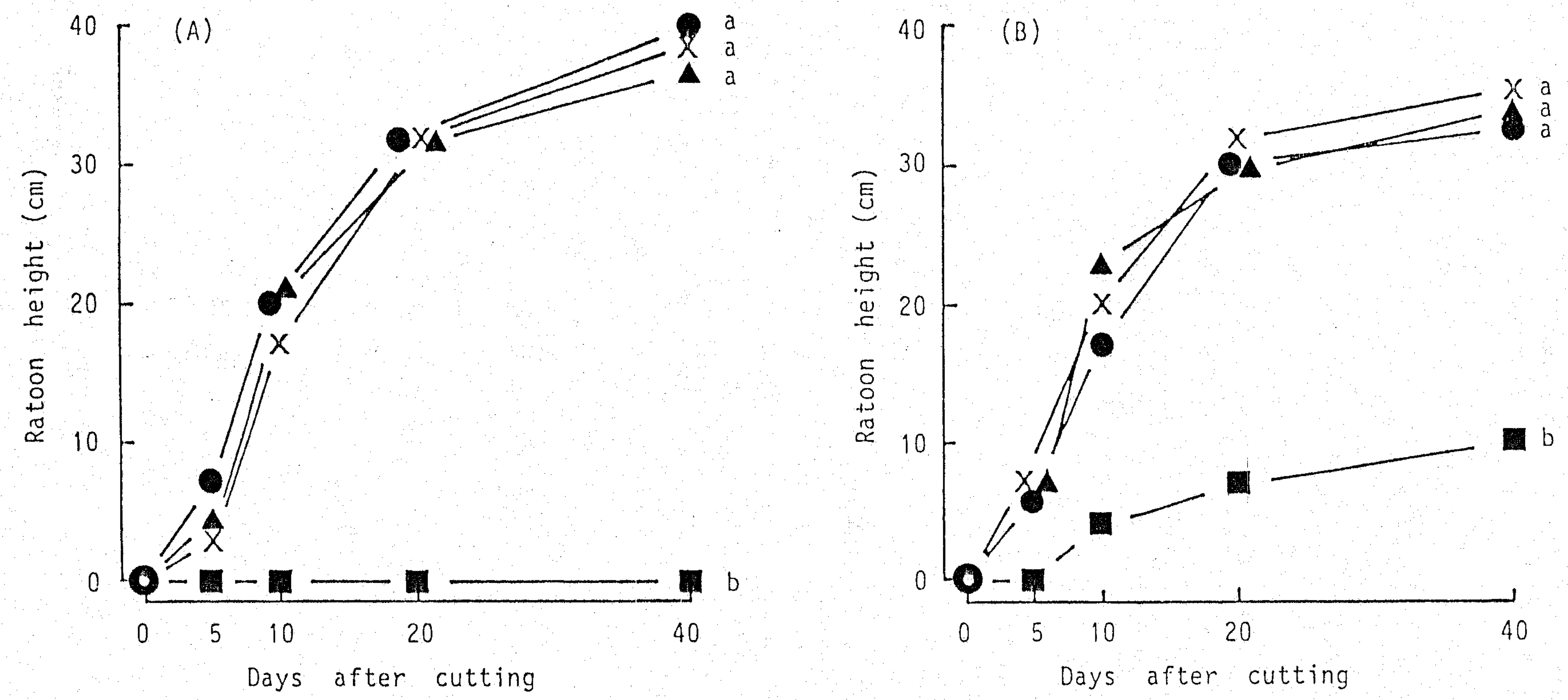

Fig. 13. Effects of cutting height and water management on height of ratoon in (A) Yaeho and (B) Oseto.

Means with the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

● : Cut at 5 cm above the ground and non-flooded
▲ : Cut at 5 cm above the ground and flooded
X : Cut at the ground level and non-flooded
■ : Cut at the ground level and flooded

ground level and water depth was 5 cm, there was observed extremely low ratoon height in Oseto, and was hardly observed ratoon growth in Yaeho. Among the other treatments, no significant differences of ratoon height were found in both cultivars. Flooding with 5 cm depth did not affect ratoon height when the main crop was cut at 5 cm above the ground level. Cutting height did not affect ratoon height, which reached the highest value within 35 days after cutting, in non-flooded treatments. Heading was observed in most treatments during the period from the 30th to the 35th day after cutting.

Experiment II.

The heading date of Koshihikari was August 22. Material plants received ten irrigation treatments (Fig. 11). The ratoon crop caused no missing hills. Percentage of ratoon tillers and ratoon height on the 5th, 10th, 20th and 40th day after cutting are shown in Table 8. Percentage of ratoon tillers was the highest on the 20th day from cutting, being the same as the result of experiment I. Percentage of ratoon tillers tended to be lower in the treatments which had flooded immediately after cutting than in those which had not flooded for a week following cutting. Ratoon height reached the highest value within 35 days after cutting alike experiment I, and did not differ much among all the treatments. The conclusions based on the variance analyses

Table 8. Percentage of ratoon tillers and ratoon height in different water managements.

Trait	Treatment number	Days after cutting			
		5	10	20	40
Percentage of ratoon tillers	1	20.8 ± 4.5	38.0 ± 6.1	47.0 ± 3.2	47.0 ± 3.2
	2	19.4 ± 1.4	38.6 ± 3.3	48.8 ± 2.6	48.8 ± 2.6
	3	21.0 ± 3.0	37.4 ± 2.9	52.2 ± 3.9	52.2 ± 3.9
	4	21.4 ± 2.9	36.8 ± 2.9	48.0 ± 1.3	48.0 ± 1.3
	5	31.2 ± 3.1	44.8 ± 4.2	57.0 ± 2.6	57.0 ± 2.6
	6	26.6 ± 3.1	41.2 ± 5.1	56.0 ± 5.0	56.0 ± 5.0
	7	20.4 ± 3.5	39.4 ± 3.9	57.4 ± 3.6	57.4 ± 3.6
	8	22.4 ± 4.1	34.8 ± 4.2	46.2 ± 3.5	46.2 ± 3.5
	9	20.4 ± 3.3	41.4 ± 4.0	47.0 ± 4.1	47.0 ± 4.1
	10	23.0 ± 3.6	35.6 ± 2.7	46.4 ± 2.7	46.4 ± 2.7
		NS	NS	NS	NS
Ratoon height	1	9.8 ± 1.8	17.0 ± 1.8	32.5 ± 1.9	42.6 ± 1.9
	2	10.6 ± 0.8	20.4 ± 0.8	36.0 ± 1.2	46.4 ± 0.9
	3	11.4 ± 1.2	22.8 ± 1.1	34.8 ± 1.4	45.8 ± 1.6
	4	9.6 ± 0.9	19.0 ± 0.8	37.2 ± 0.7	44.6 ± 1.5
	5	10.4 ± 1.1	18.4 ± 1.3	35.2 ± 1.6	44.2 ± 1.8
	6	9.0 ± 1.1	19.0 ± 1.1	34.4 ± 1.2	47.2 ± 0.8
	7	9.8 ± 1.3	19.8 ± 1.1	33.8 ± 1.5	44.8 ± 1.7
	8	9.4 ± 0.9	17.0 ± 1.3	30.6 ± 2.1	43.0 ± 2.0
	9	8.8 ± 0.3	18.4 ± 0.2	31.8 ± 1.0	44.4 ± 1.6
	10	8.4 ± 0.5	16.8 ± 0.8	33.0 ± 1.4	40.8 ± 1.2
		NS	NS	NS	NS

NS: Means within vertical column are not significantly different from one another at 5 % level, according to analysis of variance.

for percentage of ratoon tillers and ratoon height are given in Table 8 as "NS", showing that there were no significant differences of variance among the irrigation treatments. Thus, the water management as shown in Fig. 11 seems not to significantly affect the percentage of ratoon tillers nor ratoon height, when the cutting is made at as high as 20 cm.

Discussion

There were uniformly observed vigorous ratoons when mother plants were cut at 5 cm above the ground level. When the stubbles were submerged in water due to the cutting at the ground level, however, most of the hills did not produce ratoons (Fig. 12). On the other hand, BAHAR and DE DATTA (1977) observed also that missing hill increased as the time between harvest and irrigation as shortened. These facts suggest that the occurrence of missing hills are due to rotting of the resting buds of ratoon plant as HARNAEZ (1958) reported , and that large amount of oxygen are needed for regenerating of the resting buds, because the rotting is considered to be caused by a oxygen deficiency at the resting buds.

Water management did not affect percentage of ratoon tillers and ratoon height when the main crop was cut at 5 cm above the ground (Fig. 12 and Table 8). BAHAR and DE DATTA

(1977) also reported that the effect of water management was not significant on the grain yield of ratoon crop. According to MENGEL and WILSON (1981), however, early flooding after the harvest of main crop resulted in rapid and uniform growth of ratoon crop and consequently in increase of grain yield. This discrepancy may be due to the difference in the cultivar used as material and the condition of culture, especially the soil moisture at harvesting time of main crop.

In either cultivar used as material, percentage of ratoon tillers did not increase after the 20th day from cutting (Fig. 12 and Table 8). On the other hand, HSIEH and YOUNG (1959) and MAHIUL HAQUE and COFFMAN (1980) found in ratoon crop that tiller number related significantly and positively to grain yield. These facts show that in double-cropping through ratooning, number of tillers required for high grain yield should be ensured in the period from the day of cutting of main crop to the 20th day after cutting.

Summary

To determine the effect of water management system on the growth of rice ratoon, two experiments, which were different from each other in year of practice, cultivar

used, cutting height and irrigation condition, were conducted. Through the two experiments, material rice plants were grown in 1/2000 a Wagner pots and cut on the 10th day after heading. Cutting was made at the ground level and 5 cm above the ground in experiment I, and at 20 cm above the ground in experiment II. Water depth for irrigation was 5 cm in experiment I and under 1 cm and 5 cm in Experiment II. At 40 days after cutting, percentage of ratoon tillers and ratoon height were examined. The results obtained are as follows:

(1) When the main crop was cut at the ground level and the water depth was maintained at 5 cm above the ground, most of the hills did not produce ratoons.
(2) When the main crop was cut at 5 cm above the ground, water depth did not affect the percentage of ratoon tillers and ratoon height.
(3) When the main crop was cut at 20 cm above the ground, no significant effects of water management on the percentage of ratoon tillers and ratoon height were observed.
(4) Experimental results suggested that no special attention is needed for the water management in case of estimating agronomic characters of mother plant by ratoon traits.

SECTION 4. EFFECT OF RESERVE SUBSTANCES IN STEM BASE

Introduction

In the preceding section, the effects of some external environments on the growth of rice ratoon were studied. However, it is natural to consider that ratoon growth must be affected also by internal environments of the stubble and roots, such as the amount of reserve substances, the number and vigor of resting buds, and so on. With regard to this, EHARA *et al.* (1965a) reported that in herbage plants, the dry weight of new tops increased with the increase of reserve substances contained in the stubble. This may be the case with rice. However, the investigations concerning such internal environments have not so far been published to date in rice.

This section is to clarify the effect of reserve substances contained in stem base of rice plant on the growth of the ratoon.

Materials and Methods

Forty plants each of 6 rice cultivars, Ginmasari, Sachiwatari, Chiyohikari, Azusa, Satominori and Yaeho, were used as materials. Thirty five-day-old seedlings were transplanted to 1/5000 *a* Wagner pots with a single plant per pot on June 5 in 1980 and compound fertilizer (N: 15 %, P_2O_5 : 12 %, K_2O : 15 %) was applied at the rate of 3.5 g per pot as basal dressing. For 2 weeks from 4 days before heading to 10 days after heading, the plants were grown in the green house under three different environments; full sunlight (natural condition), about 50 % sunlight and about 25 % sunlight. The intensities of sunlight in these environments were 83, 41 and 21 x 10^3 lux, respectively. Regulation of sunlight was made aiming at artificial control of the amount of the reserve substances to be accumulated in the stem base of plant. The treatment was carried out by shading with black cheese cloth. The plants were cut at 5 cm above the ground on the 10th day after heading (exactly, the heading date of relevant cultivar). Immediately after cutting, the plants were transferred to dark environment (real darkness) of 25 ℃. No fertilizer was applied to the ratoon crop.

Ratoon height and percentage of ratoon tillers were noted on the 5th, 10th, 15th, 20th, 30th and 40th day, and ratoon weight was scored on the 40th day after cutting. Methods for measuring these traits were the same as those in CHAPTER I. On the day of cutting, on the other hand, stem bases of some plants were sampled and measured for dry matter weight to determine the stem base weight per hill and stem base weight per stem. Furthermore, the total available carbohydrate (TAC) content of stem base was analyzed in the manner suggested by MURAYAMA *et al.* (1955) and from the results obtained, TAC weight in stem base per hill and that per stem, and TAC content in stem base were determined.

Results

The heading dates of the six cultivars ranged from August 9 to August 20. The results of variance analysis for the five stem-base traits, i.e., stem base weight per hill and that per stem, TAC weight in stem base per hill and that per stem and TAC content in stem base, and those for the three ratoon traits, i.e., percentage of tillers, height and weight, are shown in Table 9. The variances due to cultivar were all significant. This suggests that the traits examined for stem base and ratoon are all heritable. The variances due to shading were also all significant and no variance due to cultivar x shading interaction were significant. This result means that all the traits examined varied with the extent of shading, and that no detectable differences in the varying existed among cultivars.

The means of five stem-base traits of the six cultivars in three different environments are given in Table 10. As seen from this table, the values of the five stem-base traits considerably and linearly increased with the

Table 9. Variance analysis for five stem-base characters of mother plant and three traits of ratoon plant.

Source	d.f.	Mean square in stem-base characters[1]				
		Stem base weight per hill	Stem base weight per stem	TAC weight in stem base per hill	TAC weight in stem base per stem	TAC content in sten base
Cultivar (C)	5	2.61**	0.0056*	0.442*	0.0029*	0.091**
Shading (S)	2	17.05**	0.0220**	3.227**	0.0163**	0.123**
C x S	10	0.51	0.0010	0.123	0.0007	0.055
Error	54	0.27	—	—	—	0.022

Source	d.f.	Mean square in ratoon traits[2]		
		Percentage of ratoon tillers	Ratoon height	Ratoon weight
Cultivar (C)	5	1452.2**	2015.4**	0.39**
Shading (S)	2	7887.4**	6885.8**	3.11**
C x S	10	85.8	61.5	0.04
Error	54	241.3	86.6	0.03

*,**: Significant at 5 and 1 % level, respectively.
1),2): Measurements were made on the day of cutting and on the 40th day after cutting, respectively.

Table 10. Five stem-base characters in 3 environments.

Trait	Full sunlight	50 % sunlight	25 % sunlight
Stem base weight per hill (g)	4.42	3.21	2.80
Stem base weight per stem (g)	0.303	0.215	0.185
TAC weight in stem base per hill (g)	2.69	1.68	1.29
TAC weight in stem base per stem (g)	0.185	0.109	0.085
TAC sontent in stem base (mg/g dry wt.)	605	492	456

intensity of sunlight.

Figure 14 shows that the changes of percentage of ratoon tillers and ratoon height in the three different environments. As shown in this figure, both the parameters increased logistically as the days after cutting increased. The greatest values were significantly different from each other among the three environments.

The greatest values in percentage of ratoon tillers were 71, 58, and 35 % in full, 50 %, and 25 % sunlight, respectively. The time required for reaching these greatest values did not vary with environment, being about 15 days. The greatest values in ratoon height were 64, 48, and 30 cm in full, 50 %, and 25 % sunlight, respectively. The time required for reaching these greatest values was decreased with reducing intensity of sunlight; 30, 25, and 20 days in full, 50 %, and 25 % sunlight, respectively.

Figure 15 shows ratoon weight in the three different environments on the 40th day after cutting. As seen from this figure, the weight was conspicuously decreased with the decrease of sunlight intensity. Both the five stem-base traits and the three ratoon traits increased with the increase of the intensity of sunlight. This tendency was statistically verified by the results shown in Table 11, which indicates that every one of the correlation coefficients between the five stem-base traits and the three ratoon traits was positive and significant. Of the five

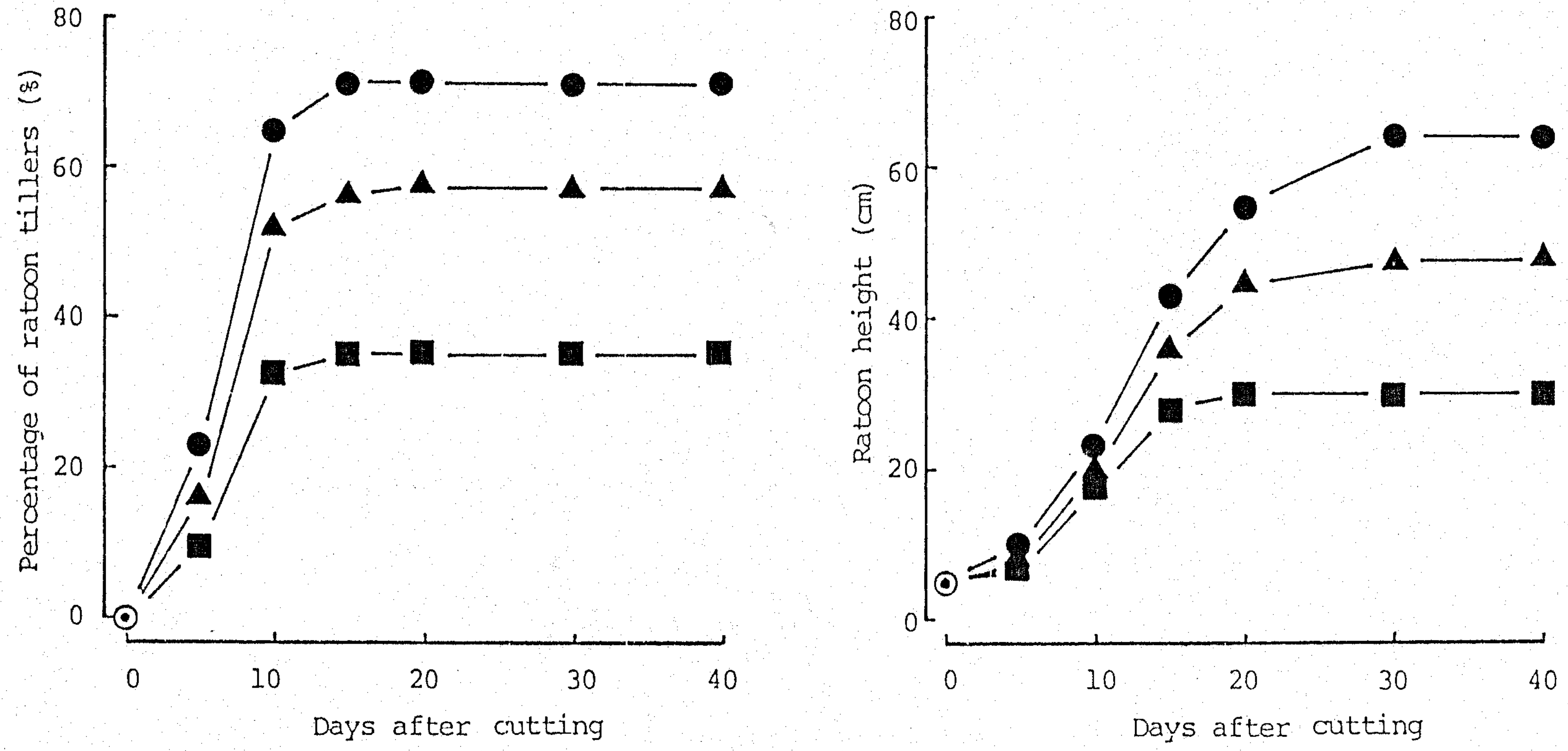

Fig. 14. Changes in percentage of ratoon tillers and ratoon height in 3 different environments.

●: Full sunlight, ▲: 50 % sunlight, ■: 25 % sunlight.

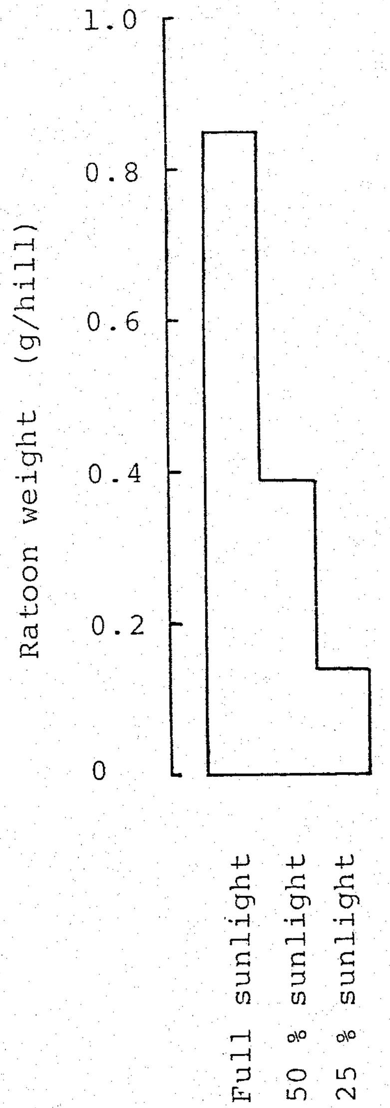

Fig. 15. Ratoon weights in three environments; measured on 40th day after cutting.

Table 11. Correlation coefficients between stem-base characters and ratoon traits.

Trait	Percentage of ratoon tillers	Ratoon height	Ratoon weight
Stem base weight per hill	0.798**	0.806**	0.912**
Stem base weight per stem	0.793**	0.828**	0.902**
TAC weight in stem base per hill	0.754**	0.820**	0.879**
TAC weight in stem base per stem	0.760**	0.846**	0.900**
TAC content in stem base	0.491*	0.636**	0.600**

*,**: Significant at 5 and 1 % level , respectively.
Ratoons were grown in the dark environment for 40 days after cutting.
The three traits shown in Table were examined on the 40th day after cutting.
Correlation coefficients were obtained from the 18 values with 3 environments and 6 cultivars.

stem-base traits, those other than TAC content were correlated with the three ratoon traits more highly than TAC content. As to the three ratoon traits, on the other hand, ratoon weight had the highest coefficients of correlation with the five stem-base traits, followed by ratoon height and percentage of ratoon tillers in turn. Thus, it is expected that the ratoon weight in darkness can most successfully reflect the traits of stem base and, eventually, the amount of reserve substances at the time of cutting.

From the facts that growth of ratoon thus depends largely upon the weight of stem base and that of TAC in stem base, it is supposed that no ratoon plants can grow out when stem base and TAC in stem base are too small in weight. Relationships of ratoon weight to stem-base weight per stem and TAC weight in stem base are shown in Fig. 16, where stem-base weight 'per hill' was not taken up to avoid the influence of varietal difference in number of tillers. This figure suggests that no ratoon plants grow when stem-base weight per stem is under 0.17 g or TAC weight in stem base per stem is under 0.07 g.

Figure 17 shows the relationship between stem-base weight per stem and TAC weight in stem base per stem. As seen from this figure, both had very high and significant correlation with each other: All values form each cultivar were located almost on a straight line. Since reserve

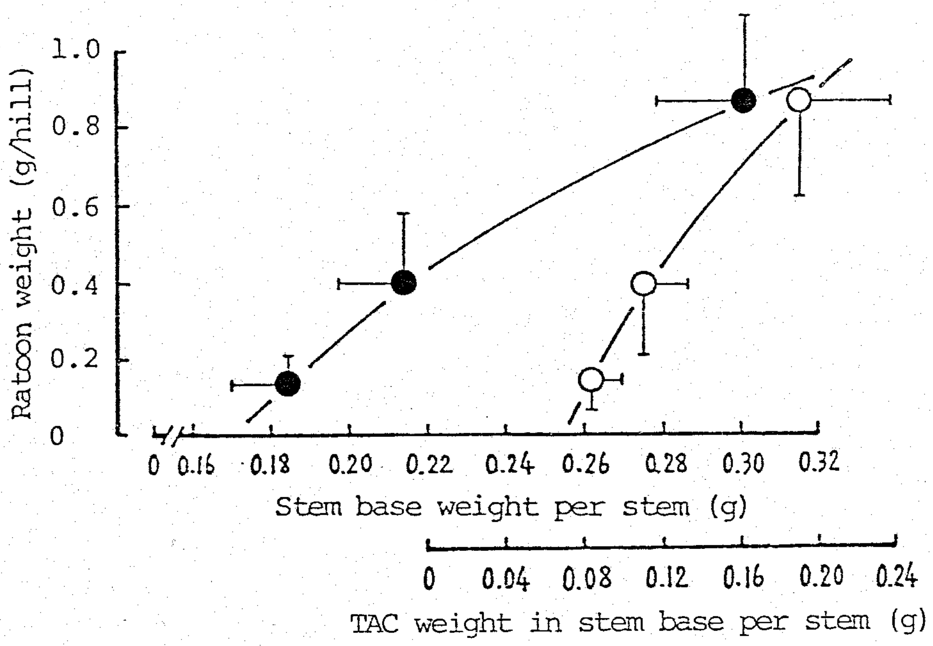

Fig. 16. Relationships of ratoon weight to stem-base weight per stem and TAC weight in stem base per stem.

●: Stem base weight per stem,
○: TAC weight in stem base per stem.
Vertical and horizontal lines show standard error.

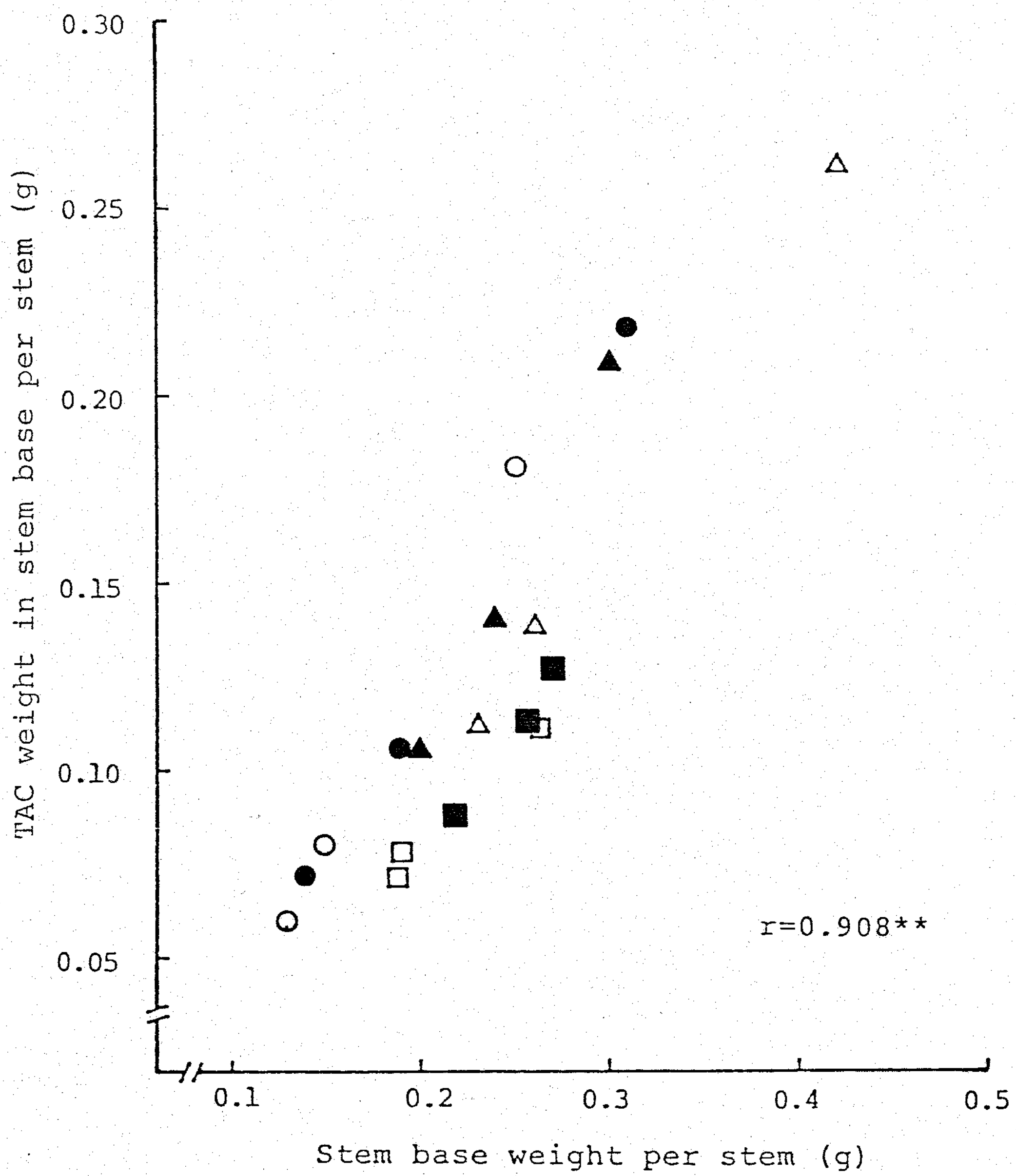

Fig. 17. Relationship between stem-base weight and TAC weight in stem base per stem. Data from three different environments are plotted each.
● : Ginmasari, ○: Azusa,
▲ : Sachiwatari, △: Satominori,
■ : Chiyohikari, □: Yaeho.

substances in plant are mainly composed of TAC (WEINMANN 1940), this result implies that the amount of reserve substances contained in stem base can be easily estimated by stem-base weight. This is supported by the finding of MORAN *et al.* (1953) in some herbage plants that both stem-base weight and root weight are highly correlated with the amount of reserve substances.

Discussion

In this experiment, three traits of ratoon, i.e., percentage of tillers, height and weight, exhibited positive significant correlations with TAC weight in stem base per stem and TAC content in stem base, and the former correlation coefficients were higher than the latter ones. These results suggest that ratoon growth of rice plant largely depends on the amount of reserve substances, especially on TAC weight in stem base. EHARA *et al.* (1965b) reported in herbage plants of *Gramineae* that ratoon growth depended on the amount of reserve substances in stem base and roots. According to YOSHIDA and TAKAHASHI (1958), roots of rice plant did not have a role as a storage organ. WEINMANN (1940) found that reserve substances in plant were mainly composed of TAC. It may be gathered from these findings inclusive of the present experimental result that ratoon growth of rice depends on the amount of TAC in stem base alone, at least at the early stage of growth.

In order to evaluate the reserve substances in stem base by means of some ratoon traits, it seems of importance to choose the trait available. In dark environment, ratoon weight, ratoon height and percentage of ratoon tillers were all closely related to the amount of reserve substances in stem base (Table 11). In sunlight environment, on the other hand, the growth of ratoon after the 10th day from cutting were affected not only by the amount of reserve substances in stem base but also by photosynthetic products in foliage (Fig. 6). However, the dependence on the photosynthesis in foliage is considered far less in percentage of ratoon tillers than in ratoon weight and ratoon height, because percentage of ratoon tillers reached a constant value after cutting far rapidly compared with ratoon weight and ratoon height (Figs. 2, 3, 4 and 14). From these facts, it can be said that percentage of ratoon tillers is most useful as a tool for evaluating the amount of reserve substances among the three traits of ratoon.

In ratoon cropping of rice, grain yield depends highly on the number of tillers of ratoon plants. However, the number of ratoon tillers rapidly reaches a constant value after the harvesting of mother plants, as stated above. Therefore, the cultivars which provide a large quantity of reserve substances at the harvesting time, such as

Satominori in the case of this study (Fig. 17), may be advantageous for ratoon cropping.

Summary

This section was aimed at elucidating the effect of reserve substances on the growth of ratoon in rice.

In order to regulate the amount of the reserve substances in the stem base of plants, potted rice plants were grown for two weeks from 4 days before heading to 10 days after heading under three different environments; full sunlight, about 50 % sunlight and about 25 % sunlight.

The plant was cut at 5 cm above the ground on the 10th day after heading. Stem-base weight and TAC amount in the stem bases of some mother plants were measured on the day of cutting.

Immediately after cutting, the plants were transferred to a dark environment of 25 ℃. Ratoon height and percentage of ratoon tillers were noted 6 times during 40 days after cutting. Ratoon weight was recorded on the 40th day after cutting. The results obtained are as follows:

(1) Five stem-base traits including stem-base weight per stem and TAC weight in stem base per stem, and the three ratoon traits significantly increased with increasing

intensity of sunlight (Table 10, Figs. 14 and 15).

(2) Every one of the correlation coefficients between the five stem-base traits and the three ratoon traits was positive and significant. And ratoon weight had the highest coefficients of correlation with the five stem-base traits. Therefore, the ratoon weight in darkness can most successfully reflect the amount of reserve substances on the time of cutting (Table 11).

(3) The amount of reserve substances contained in stem base can be easily estimated by stem-base weight (Fig. 17).

CHAPTER III.

RELATIONSHIP BETWEEN RATOON TRAITS AND LODGING RESISTANCE OF MOTHER PLANT

Introduction

Lodging damages grain yield directly by interfering with the accumulation of dry matter, and reduces the yield indirectly by causing many difficulties in case of harvest. Lodging also affects grain quality disadvantageously. These are the reasons why lodging resistance has ever been one of the most important breeding objectives also in rice plants. However, a close selection for lodging resistance is often hindered by a lot of difficulties involving the necessity of much time and labor for measurement of the trait. Thus the exploitation of an effective method for estimating lodging resistance has become an important problem imposed on breeding research. From this point of view, the possibility for estimating the lodging resistance of rice plant by means of some trait of ratoon was investigated in this chapter. For this purpose, the experiment was carried out aiming at clarifying the relationships of the traits of ratoon to the lodging resistance of mother plant.

A number of investigations have so far been carried out on lodging resistance and its related characters. For instance, SEKO (1962) found that lodging resistance largely depended on the breaking resistance of culm. MATSUO (1952) reported that the resistance closely related to stem-base weight. According to SATO (1957), the resistance varied with the starch content of culm, which is a major component of reserve substances. Moreover, it was observed by KONO and TAKAHASHI (1961) the breaking resistance of culm was associated with the starch content.

As suggested from the above mentioned findings, there seem to be provided various approaches to estimate the lodging resistance through the relationship between the traits of ratoon and the lodging resistance as expressed by lodging index; estimating directly through the correlation between some ratoon trait and lodging resistance, and indirectly through that between some ratoon trait and each of the mother-plant characters associated with lodging resistance, such as breaking resistance of culm, culm length, internode weight, stem-base weight, starch content in culm, and so on.

In this study, stress was placed on clarifying the relationships of ratoon traits to lodging index, breaking resistance and stem-base weight, and on assessing whether ratoon traits are really fit for the use as the indicators for estimating the lodging resistance of mother plant.

Materials and Methods

Twenty one rice cultivars (*Oryza sativa* L.) listed in Table 12, supposed to be different in lodging resistance, were used as materials. Experiment was carried out in the farm of Kagawa University in 1980. Thirty four-day-old seedlings were transplanted on June 17 with a single plant per hill spaced at 30 x 10 cm. These cultivars were grown in a randomized block design with two replications. Each replication comprised 150 plants. They were fertilized with 1.0 kg N/*a*, 0.8 kg P_2O_5 /*a* and 1.0 kg K_2O /*a* as basal dressing. No fertilizer was applied to the ratoon crop.

The 21 cultivars were cut at 5 cm above the ground at five different growth stages, i.e., the day of heading of each cultivar, and 10, 20, 30 and 40 days after the heading. Two ratoon traits, height and percentage of tillers, were noted on the 40th day after cutting. On the other hand, four mother-plant characters associated with lodging, breaking resistance of culm, stem base weight, internode weight and lodging index, were recorded every 10 days from the day of heading to the 40th day after heading. Heading date and culm length were also scored individually.

Ratoon height was expressed as the length from the cutting level to the top of plant. Percentage of ratoon tillers was determined by the same manner as used in CHAPTER I. Breaking resistance was measured for culm after all leaf

Table 12. Rice cultivars used

	Name		Name		Name
1	Koganemasari	8	Hokuriku No.108	15	Minenishiki
2	Kanto No.116	9	Chubu No.34	16	Norin No.22
3	Kanto No.120	10	Ginmasari	17	Kyoto-asahi
4	Ooseto	11	Chiyohikari	18	Sasanishiki
5	Chubu No.35	12	Sachiwatari	19	Yaeho
6	Saikai No.144	13	Nipponbare	20	Koshiji Wase
7	Chugoku No.68	14	Koshihikari	21	Azusa

sheaths were removed from the material plant, by means of the straw fracture tester Model EO-3 (Kiya Seisakusho Ltd.), with 6 cm spacing between fulcrums. With four cultivars of the 21 cultivars, Chugoku No. 68, Minenishiki, Kyoto-asahi and Yaeho, however, internode with leaf sheaths was also subjected to the measurement of breaking strength on the 30th and 40th day after heading, to determine the effect of leaf sheath on breaking resistance. Internode weight was measured for the dry matter weight per unit length of 3rd or 4th internode from the uppermost internode, using the materials whose breaking resistance had already been recorded. Stem-base weight was obtained as the dry matter weight per stem. Lodging index, which was suggested MATSUO (1952) and SEKO (1962), was expressed as the ratio of moment (plant height x plant weight) to breaking resistance of the internode concerned.

Results

In Fig. 18, the change of character value (mean value for the 21 cultivars) with the advance of growth stage is shown for four mother-plant characters, internode weight, stem-base weight, breaking resistance and lodging index. In three characters other than lodging index, the values increased for the first 10 days following heading time, then

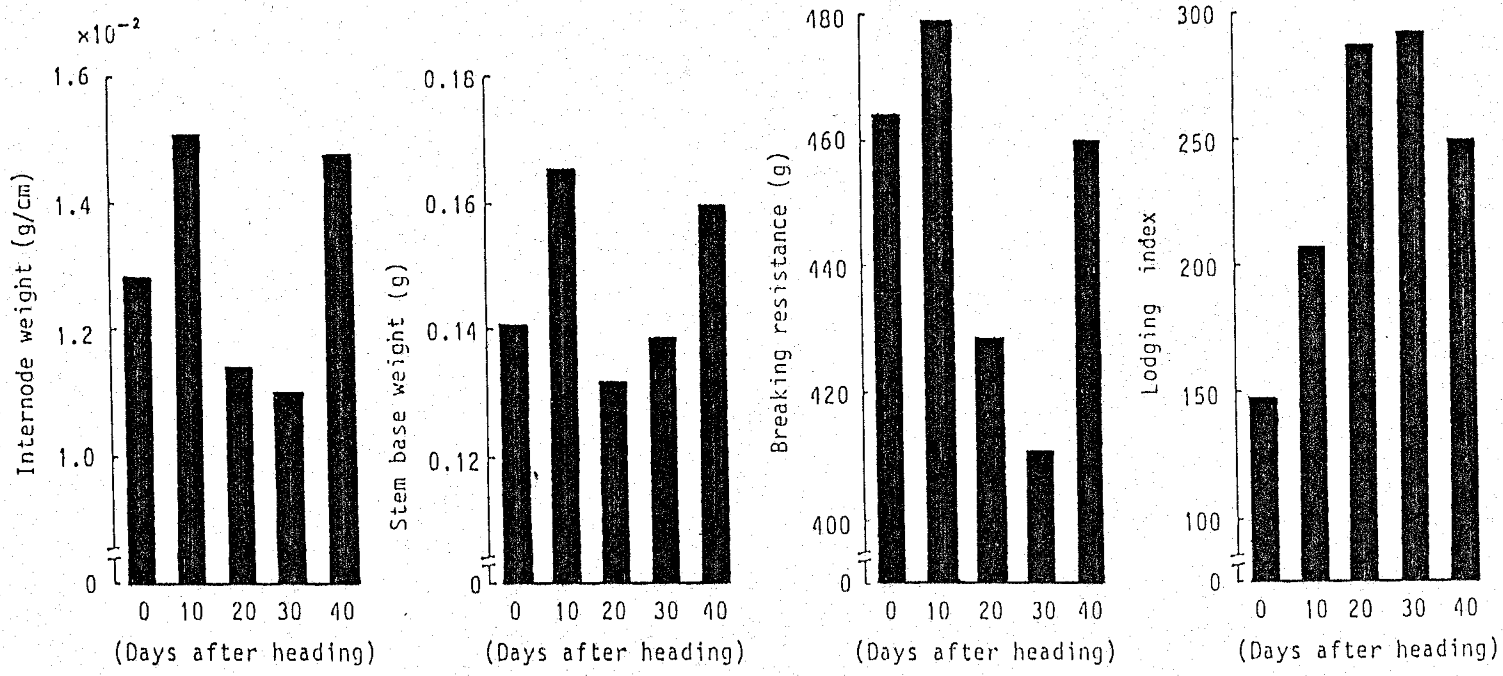

Fig. 18. Changes of mother-plant chracteristics associated with lodging with the advance of growth stage.

declined for the succeeding 10 or 20 days and finally, on the 40th day after heading, recovered or exceeded the initial levels. In each of these characters, the growth stage the largest value appeared was observed on the 10th day after heading. On the other hand, lodging index continued to increased for 30 days following heading time, then declined. This shows that rice plants are most susceptible to lodging around 30 days after heading.

In Fig. 19, the change of varietal mean value with the delay of cutting time is shown for two ratoon-plant traits, percentage of tillers and height. The change of percentage of ratoon tillers was similar to those of internode weight, stem-base weight and breaking resistance. Percentage of ratoon tillers was highest in the cutting of the 10th day after heading and lowest in that of the 30th day. Ratoon height was somewhat different from percentage of ratoon tillers in the tendency of response to the delay of cutting time. However, the difference of the tendency was observed only in the cutting of 10th day after heading. The tendency common to these two traits is similar to that shown in the result of CHAPTER I (Fig. 1), whereas the cultivars used and the year of experiment were both different each other.

In both of mother plant and ratoon plant, a wide range of variation among cultivars was observed in every character examined. For instance, the range of heading dates was 27 days from August 12 to September 7. Of these characters, the

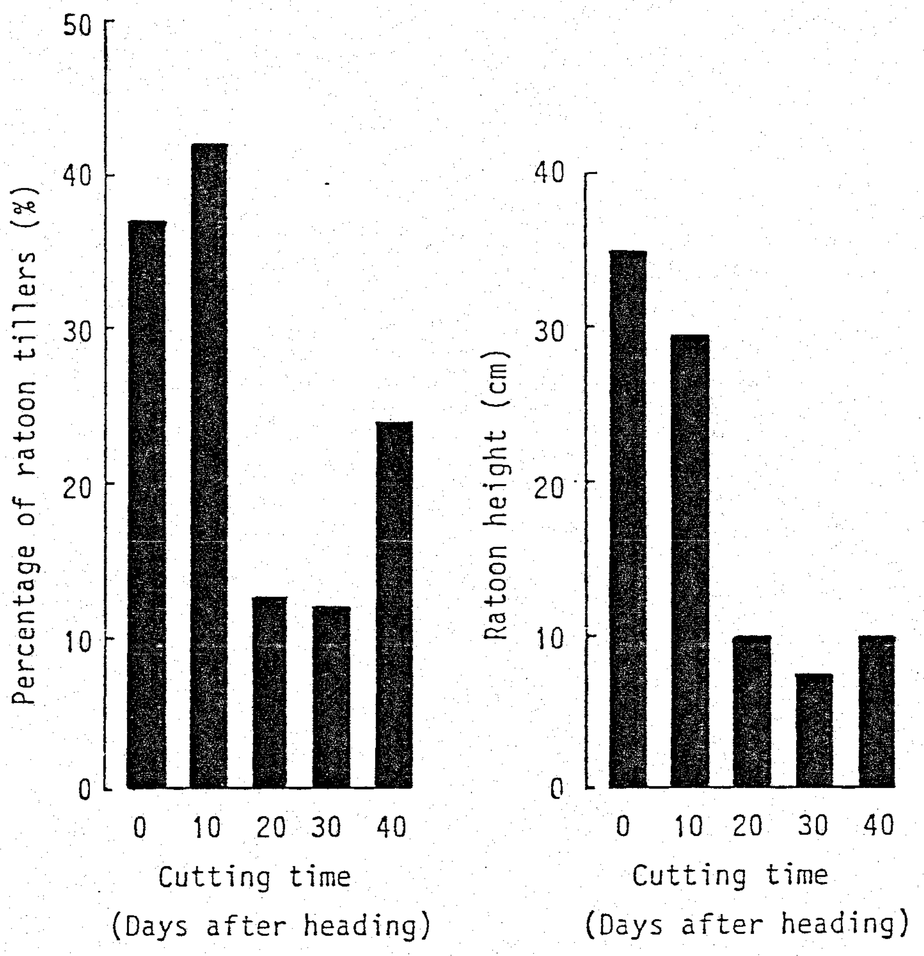

Fig. 19. Changes of percentage of ratoon tillers and ratoon height with the delay of cutting time.

six ones taken up in Figs. 18 and 19 were analysed for their variances. The results are given in Table 13. As this table indicates, the variance due to cultivar, growth stage and cultivar x growth stage-interaction in the four mother plant's characters were highly significant. This was the case also for the variances due to cultivar, cutting time and cultivar x cutting time-interaction in the two ratoon traits, as suggested from the results obtained in CHAPTER I (Table 2).

The phenotypic correlation coefficients between four characters concerned with lodging resistance in mother plants and two ratoon traits are given in Table 14. As the table shows, of all the eight combinations between mother plant characters and ratoon traits, seven combinations exhibited significant correlations in some cuttings. However, it is most noteworthy that both the traits of ratoon showed significant negative correlations with lodging index extending from the cutting of the 20th to that of 40th day after heading.

Table 15 shows the phenotypic correlation coefficients among three characters concerned with lodging in mother plant. As seen from this figure, correlation were significant in all cases. Among those, the significant positive correlations between internode weight and breaking resistance may deserve attention.

Breaking resistance was largely affected by the leaf

Table 13-a. Analysis of variance for the chracters concerned with lodging in mother plant.

Source	d.f.	Mean of square			
		Internode weight	Stem base weight	Breaking resistance	Lodging index
Cultivar (C)	20	0.671**	0.0162**	73349.0**	11470.1**
Growth stage (G)	4	1.499**	0.0391**	32018.8**	130076.5**
C X G	80	0.081**	0.0014*	5868.9**	1335.2**
Error	105	0.037	0.0009	2771.5	675.0

Table 13-b. Analysis of variance for the traits of ratoon plant.

Source	d.f.	Mean of square	
		Percentage of ratoon tillers	Ratoon height
Cultivar (C)	20	2374.8**	484.3**
Cutting time (T)	4	7954.6**	7036.5**
C X T	80	251.1**	66.8**
Error	105	122.6	30.5

*,**:Significant at 5 and 1 % level, respectively.

Table 14. Phenotypic correlation coefficients between ratoon traits and characters concerned with lodging in mother plant.

Ratoon plant	Cutting time (Days after heading)	Mother plant			
		Internode weight	Stem-base weight	Breaking resistance	Lodging index
Percentage of tillers	0	0.03	0.37	0.03	-0.41
	10	0.39	0.67**	0.28	-0.38
	20	0.61**	0.63**	0.44*	-0.76**
	30	0.47*	0.43	0.00	-0.65**
	40	0.44*	0.43	-0.13	-0.61**
Height	0	0.01	0.34	0.03	-0.33
	10	0.19	0.60**	0.15	-0.10
	20	0.55**	0.64**	0.38	-0.72**
	30	0.28	0.39	-0.16	-0.62**
	40	0.28	0.24	-0.24	-0.57**

*,**: Significant at 5 and 1 % level, respectively.

Table 15. Phenotypic correlation coefficients among some characters concerned with lodging in mother plant

	Days after heading	Stem base weight	Breaking resistance
	0	0.79**	0.85**
	10	0.81**	0.74**
Internode weight	20	0.91**	0.85**
	30	0.73**	0.76**
	40	0.87**	0.78**
	0		0.70**
	10		0.54*
Stem base weight	20		0.81**
	30		0.76**
	40		0.74**

*, **: Significant at 5 and 1 % level, respectively.

sheaths wrapping culm. In Fig. 20, the rates of contribution of leaf sheath to breaking resistance on 30th and 40th day after heading are shown with four cultivars. The contribution rates depended on the cultivars and the growth stages and ranged from approximately 40 % to 15 %, being larger on 30th day than on 40th day after heading. The analysis of variance for the contribution rates revealed that there were significant differences among the cultivars and between the two growth stages.

Discussion

It is very interesting that there were high significant correlations between lodging index and two ratoon traits, percentage of tillers and height, because these correlations imply that the ratoon traits can be effectively used as the indicators for the lodging resistance of mother plant.

The above two traits of ratoon were also closely related to the amount of total available carbohydrate (TAC) contained in stem base (SECTION 4 in CHAPTER II). This suggests that lodging resistance is related also to the amount of TAC in stem base. On the relationship between lodging resistance and TAC content, ESECHIE *et al.* (1977) showed in sorghum that the correlation between TAC content and lodging degree was negative and significant, namely,

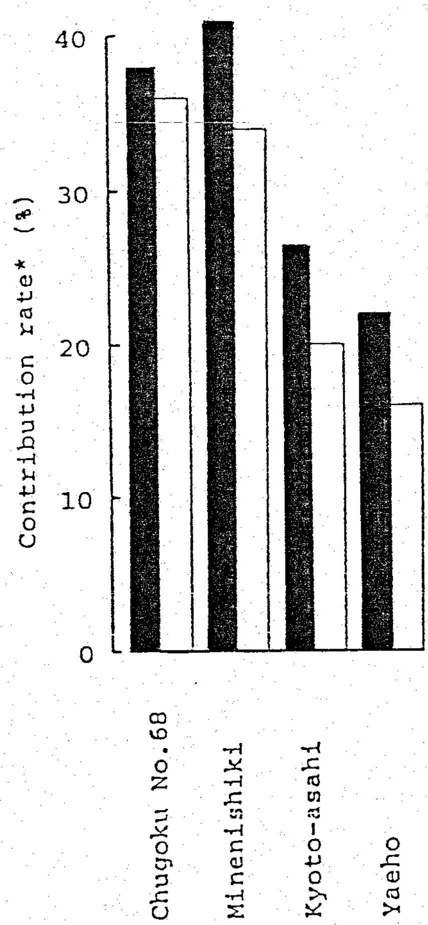

Fig. 20. The rate of contribution of leaf sheath to breaking resistance.

*: ((Breaking resistance with leaf sheath - Breaking resistance without leaf sheath) / Breaking resistance with leaf sheath) x 100.

■ : On 30 days after heading

□ : On 40 days after heading

lodging resistance increased with the increase of TAC content. Similar results were reported also in corn (CAMPBELL 1964). However, ESECHIE *et al.* (1977) showed also that lodging degree was positively correlated with the content of Potassium (K), namely, lodging resistance decreased with the increase of K content. From these results, they inferred that TAC content was only an indication of the healthiness and vigor of plant rather than a factor directly affecting the lodging. The result in the present experiment that ratoon traits, which reflected TAC content of stem base, were related not to breaking resistance of culm but to lodging resistance, can be explained by their inference.

Breaking resistance, a component of lodging index, was markedly affected by the existence of leaf sheath, being much higher in the internode with leaf sheath than in that without leaf sheath. The contribution rate of leaf sheath to breaking resistance varied with cultivar and growth stage of plant, ranging approximately from 15 % to 40 %. According to MATSUO (1952), IRRI Ann. Rep. (1963, 1964), and MIYASAKA and TAKAYA (1982), the contribution rate varied with cultivar, ranging from 30 to 70 %, from 20 to 40 % and from 20 to 60 %, respectively. HITAKA (1968) reported in the growth stage after heading that the contribution rate at yellow-ripe stage and maturing stage was 30 % and 15 %, respectively. Their findings that the contribution rate varied with cultivar and growth stage of plant agree with the result of the present experiment. The present experiment also showed that the contribution rate itself was not affected by the intrinsic lodging resistance or culm length of cultivar.

Summary

The relationship between ratoon traits and lodging resistance was investigated with 21 paddy cultivars.

The plant was cut at 5 cm above the ground at five different growth stages, i.e., the day of heading, and 10, 20, 30 and 40 days after heading. Two traits of ratoon plant, height and percentage of tillers, were measured on the 40th day after cutting. Four mother-plant characters associated with lodging, breaking resistance of culm, internode weight, stem-base weight and lodging index, were noted every 10 days starting from the day of heading. The results obtained are as follows:

(1) Internode weight, stem-base weight and breaking resistance increased with the increase of days after heading for the first 10 days following heading, then declined for the succeeding 10 or 20 days and finally, on the 40th day after heading, recovered or exceeded the initial level.

Lodging index continued to increase for 30 days following heading, then declined.

(2)The change of percentage of ratoon tillers with the increase of days after heading was similar to those of internode weight, stem-base weight and breaking resistance of mother plant. Ratoon height also showed a similar change in the period after the 10th day from heading.

(3) Both ratoon traits, percentage of tillers and height, showed significant negative correlations with lodging index extending from the cutting of the 20th to that of 40th day after heading. This suggests that these two traits of ratoon can be effectively used as the indicators for lodging resistance of mother plant. Both the traits exhibited significant correlations also with each of breaking resistance, stem-base weight and internode weight in one to three cutting times. Regarding the correlations with breaking resistance, for instance, they were all very low and not significant excepting a case.

(4) The contribution rate of leaf sheath to breaking resistance depended on cultivar and growth stage, ranging from approximately 40 % to 15 % in response to the two factors. It was larger on the 30th day than on the 40th day after heading.

CHAPTER IV.

EFFECT OF CUTTING HEIGHT ON RELATIONSHIP OF RATOON TRAITS TO THE PERCENTAGE OF RIPENED GRAINS IN MOTHER PLANT

Introduction

Percentage of ripened grains is one of the final determinants of grain yield and, hence, one of the characters on which breeders have so far placed major emphasis for selection. To date, however, no devices for effective selection of this character have never appeared due probably to the difficulties concerned with scoring and the low heritability of this character. Thus it is now in earnest expected to exploit an effective method for estimating this character. It was shown in CHAPTER I that two traits of ratoon could be used as the indicators of the percentage of ripened grains in mother plant, when the ratoon was obtained from the plant cut soon after heading time. However, there still remain a question to be solved in that the values as indicators may be varied with cutting height.

According to some researchers, however, the traits of ratoon themselves vary with the cutting height on mother plant. For instance, PRASHER (1970b) reported that tiller number increased with increased cutting height, but BAHAR and DE DATTA (1977) showed that cutting height did not significantly affect this trait. On the other hand, BAHAR and DE DATTA (1977) and MAHIUL HAQUE and COFFMAN (1980) reported that grain yield increased with increased cutting height, but PRASHER (1970b) showed contrary results, and besides ISHIKAWA (1964) and BALASUBRAMNIAN *et al.* (1970) represented that cutting height did not affect grain yield.

These findings, though full of variety of result, seem to suggest that for an effective use of a ratoon trait as the indicator, the effect of cutting height should be checked for the value of the trait as the indicator. According to the results so far obtained in the present studies, the value of the trait as the indicator may most effectively be determined by the degree of its relationship to the percentage of ripened grains in mother plant.

From this point of view, this chapter is aimed at determining the effect of cutting height on the relationship between ratoon traits and the percentage of ripened grains in mother plant. Elucidation of the variations of ratoon traits with year is the additional purpose of this chapter.

Materials and Methods

Experiment was conducted at Kagawa University in 1980. Thirty rice cultivars (*Oryza sativa* L.) listed in CHAPTER I were used as materials. Thirty four-day-old seedlings were transplanted with a single plant per hill spaced at 30 x 10 cm on June 6. The materials were grown in a randomized block design with two replications, each of which consisted of 125 plants. A basal fertilizer was applied to the main crop at a rate of 1.0 kg N/a, 0.8 kg P_2O_5 /a and 1.0 kg K_2O /a. No fertilizer was applied to the ratoon crop.

The 30 cultivars were cut on the 10th day after heading at four different heights, i.e., at the ground level, and at 5, 10 and 20 cm above the ground. The percentage of ratoon tillers and ratoon height were noted on the 40th day after cutting. The former and the latter were determined by the same methods as used in CHAPTER I and CHAPTER III, respectively. Percentage of ripened grains in mother plant was scored on the 40th day after heading.

Results

The results of variance analysis for percentage of ratoon tillers and ratoon height are given in Table 16. There were observed significant variances due to cultivar, cutting height, and cultivar x cutting height-interaction. These results indicate that these traits of the ratoon vary with cultivar and with cutting height, and that variations of these traits with cutting height also differ with

Table 16. Analysis of variance for ratoon traits.

Trait	Source	d.f.	Mean of Square
Percentage of tillers	Cultivar (C)	29	1118.79**
	Cutting height (H)	3	17336.32**
	C × H	87	112.22*
	Error	120	80.88
Height	Cultivar (C)	29	209.06**
	Cutting height (H)	3	7000.90**
	C × H	87	76.18**
	Error	120	33.69

*,**: Significant at 5 and 1 % level, respectively.

cultivars. Differences of the ratoon trait values among cultivars were significant as the results of CHAPTER I showed (Table 2).

The averages of 30 cultivars in the percentage of ratoon tillers and the ratoon height at four cutting heights are shown in Fig. 21. Both the traits rapidly increased with increased cutting height. However, the increase of the traits was not significant for the increase of cutting height from 10 to 20 cm. In one-third of the 30 cultivars used, most of the hills cut at the ground level did not produce ratoons. Such missing hills significantly decreased in frequency when cutting height was 5 cm above the ground, and came not to be observed at the height 10 cm above the ground.

As revealed in CHAPTER I, both the traits, percentage of ratoon tillers and ratoon height, are closely related to the percentage of ripened grains in mother plant when the main crop was cut at the height of 5 cm. Therefore, the above result may allow to assume that the relationship between the two ratoon traits and the percentage of ripened grains in mother plant also varies with cutting height of the main crop. In Table 17, the phenotypic correlation coefficients between the ratoon traits and the percentage of ripened grains in mother plant are shown with the four cutting heights. As seen from this table, the correlation coefficients between percentage of ratoon tillers and

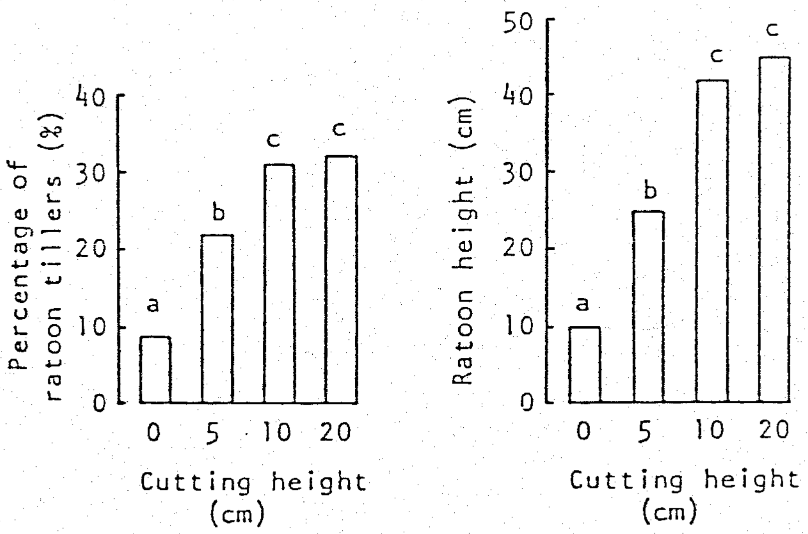

Fig. 21. Percentage of ratoon tillers and ratoon height at four cutting heights.

The respective means indicated by the same letter are not significantly different from one another at 5 % level, according to Dancan's Multiple Range Test.

Table 17. Phenotypic correlation coefficients between ratoon traits and percentage of ripened grains in mother plant at four cutting heights.

Cutting height (cm)	Percentage of ratoon tillers : Percentage of ripened grains	Ratoon height : Percentage of ripened grains
0	-0.03	-0.03
5	0.16	0.04
10	0.38*	0.09
20	0.52**	-0.03

*,**: Significant at 5 and 1 % level, respectively.

percentage of ripened grains grew higher at higher cutting, and became significant at 10 and 20 cm above the ground. Ratoon height, on the other hand, showed no obvious relationship to the percentage of ripened grains at any height of cutting.

Heritability estimates in the broad sense are tabulated for percentage of ratoon tillers and ratoon height in Table 18. The estimates for percentage of ratoon tillers were high and constant irrespective of cutting height, while those for ratoon height widely differed with cutting height, ranging from 51 to 91 %.

Variation of ratoon-trait value with year

The variations from year to year of ratoon-trait values observed in the present study are worth paying much attention, because such variations are rather normal and sometimes not little.

The values of two ratoon traits observed in 1980 were compared with those in 1977, based on the fact that the experiments conducted in these two years were the same or common in many respects, such as the field used for experiment, the cultivars used as materials, the times of seeding and transplanting, and the method and criterion for cutting, which was done at 5 cm above the ground on the 10th day after heading.

Temperature, solar radiation and rainfall at the

Table 18. Broad sense heiritability (%) of two ratoon traits at four cutting heights.

Cutting height (cm)	Percentage of tillers	Height
0	85.4	90.7
5	78.7	51.3
10	88.7	51.9
20	84.5	82.7

experimental field in the period from May to October in 1977 were nearly normal compared to the mean for the 10 years from 1966 to 1975. In the period from July to August in 1980, temperature and solar radiation were 2 ℃ and 20–30 % less, respectively, than those in normal year, and rainfall was twice as much as normal amount. Therefore, the 1980 was called a year of cool-weather damage.

In Table 19, the values of two ratoon traits are compared between 1977 and 1980. They were obtained at 40 days after cutting, with the ratoons whose mother plants were cut at 5 cm above the ground on the 10th day after heading. Percentage of ratoon tillers was 12.2 % less and ratoon height was 11.7 cm less in 1980 than in 1977, and these differences were each significant. Figure 22 illustrates the between-year correlations in the two ratoon traits. As seen from this figure, there were observed significant positive correlations in both the traits, and the correlation coefficient was larger in percentage of ratoon tillers than in ratoon height.

Discussion

In the present experiment, which was conducted in 1980, percentage of ratoon tillers exhibited significant correlation with the percentage of ripened grains in mother

Table 19. Comparison of ratoon-trait values between 1977 and 1980.

Year	Percentage of tillers (%)	Height (cm)
1977 (A)	36.7	36.5
1980 (B)	24.5	24.8
A - B	12.2**	11.7**

**: Significant at 1 % level.

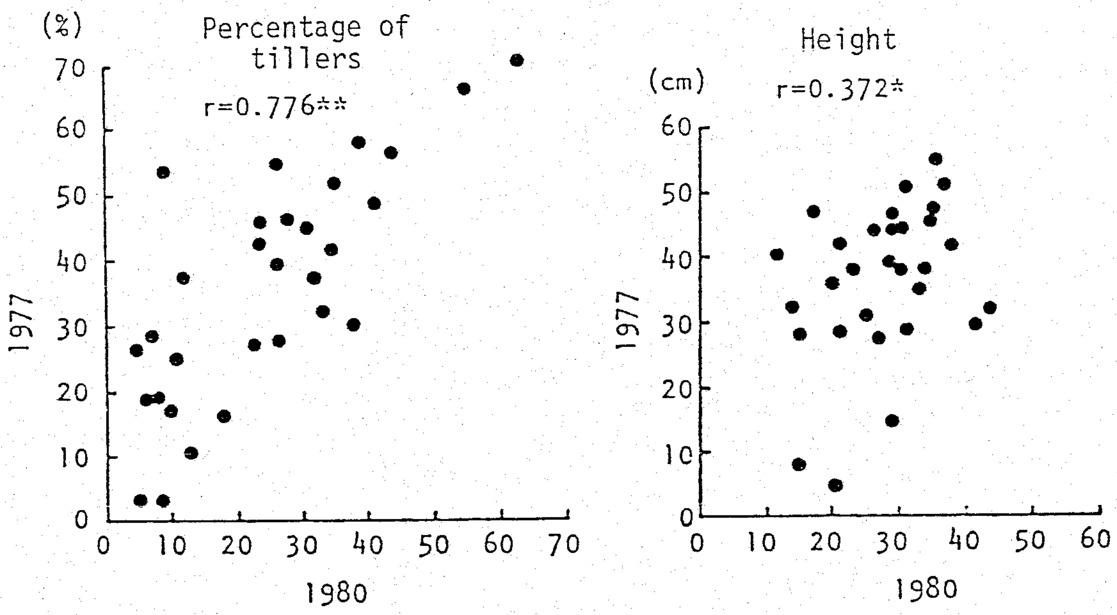

Fig. 22. Correlation of ratoon-trait values between 1977 and 1980.
*,**: Significant at 5 and 1 % level, respectively.

plant when cutting was done at 10 and 20 cm above the ground, but never at 0 and 5 cm, while ratoon showed no correlation with the percentage of ripened grains at any cutting heights (Table 17). In the experiment carried out in 1977 (CHAPTER I), however, both percentage of ratoon tillers and ratoon height exhibited significant correlations with the percentage of ripened grains in spite of 5 cm in cutting height (Table 3). Putting the results from these two experiments together, it is suggested that percentage of ratoon tillers can more steadily be used as the indicator of the percentage of ripened grains in mother plant than ratoon height.

Percentage of tillers and height of ratoon plant were significantly lower in 1980 than in 1977 (Table 19). These differences can primarily be attributed to the differences in temperature and solar radiation: Temperature and solar radiation in the summer of 1980 were both anomalously lower than usual. Such low temperature and low solar radiation in 1980 most probably gave rise to little accumulation of the reserve substances in stem base, and much negatively influenced the growth of ratoons, which was proved to be dependent on the amount of the reserve substances in SECTION 4 in CHAPTER II (Table 11).

Summary

The effect of cutting height on the relationships between two ratoon traits, percentage of tillers and height, and the percentage of ripened grains in mother plant was determined in 1980 using 30 paddy cultivars. The variations with year of the two ratoon traits were also investigated on the basis of the data obtained in 1977 and 1980.

Material plants were cut on the 10th day after heading at four different heights, i.e., at ground level, and at 5, 10 and 20 cm above the ground. Percentage of ratoon tillers and ratoon height, and the percentage of ripened grains in mother plant were noted on the 40th day after cutting, and on the 40th day after heading, respectively. The results obtained are as follows:

(1) The ratoon traits rapidly increased with increased cutting height, though the increase of the traits was not significant when cutting height increased from 10 to 20 cm.
(2) The correlation between percentage of ratoon tillers and the percentage of ripened grains in mother plant grew higher at higher cutting, and became significant at 10 and 20 cm above the ground, while ratoon height showed no obvious relationship to the percentage of ripened grains at any height of cutting. Thus, it was concluded that the percentage of ratoon tillers at the cutting heights of 10

and 20 cm could be effectively used as an indicator of the percentage of ripened grains in mother plant.

(3) Percentage of tillers and height of ratoon plant differed from year to year. There were observed significant correlations between 1977 and 1980 in both the traits. Correlation coefficient was larger in percentage of ratoon tillers than in ratoon height.

CONCLUSIONS

Based on the idea that the traits of ratoon can possibly be used as the effective indicators for estimating some agronomic characters of mother plant, and in consequence may significantly contribute to the selection of plants in breeding program, three ratoon traits, percentage of tillers (percentage of tiller number of ratoon plant to that of mother plant), height (length from the ground level or cutting point to the top of ratoon plant) and weight (dry matter weight of ratoon plant), of many cultivars of rice were examined for their genetic variations, their relationships to the characters of mother plant, and the effects of external and internal environments of ratoon plant and ratooning on the relationships. The studies have yielded some interesting results as follows:

1. Estimation of the agronomic characters of mother plant by means of ratoon traits.

The three traits of ratoon, percentage of tillers, height and weight, all widely varied with the cultivars used, indicating that they were significantly controlled by the genotypes of respective cultivars (Tables 2, 9, 13 and 16).

The heritability estimates of these traits were high enough to exceed their changes by the time and height of cutting: The estimates in percentage of tillers were much as high as those of culm length and panicle length of mother plant, being the highest among the three traits, followed by those of height and weight in turn (Tables 5 and 18).

All the three ratoon traits examined showed high significant correlations with each of the five stem-base characters, standing for the amount of reserve substances in stem base, of mother plant when the ratoon was grown under dark condition after cutting (Table 11).

Two of the three traits, percentage of tillers and height, showed highly significant correlations with the percentage of ripened grains in mother plant when cutting was done at 10 days after heading (Table 3), and also showed highly significant correlations with the lodging resistance of mother plant when cutting was done after the 20th day from heading (Table 14).

From the results mentioned above, it was concluded that the reserve substances in stem base of mother plant could be determined by all the three traits of the ratoon which was grown under dark condition after cutting, the percentage of ripened grains in mother plant could be estimated through percentage of tillers and height of the ratoon which grew out of the stubble cut at 10 days after heading, and the lodging resistance of mother plant could be evaluated by the two traits of the ratoon raised from the stubble cut after

20th day from heading.

2. Main factors affecting ratoon traits.

Number of days after cutting: The values of three traits of ratoon increased as the days after cutting increased, and the time required for attaining to the final constant value proved to be shortest in percentage of tillers, second in height and longest in weight, indicating that percentage of tillers was best to early determine the final trait value (Figs. 2, 3, 4, 12, 13 and 14).

Reserve substances in stem base: The ratoon growth during the first 10 days after cutting depended exclusively on the reserve substances in stem base, then it gradually came to be dependent on the photosynthetic products yielded by the ratoon plant itself (Fig. 6). Among the three traits, percentage of tillers was the only trait that was determined by the reserve substances alone (Figs. 2, 3, 4, 6 and 14).

Temperature: The temperature after cutting had not a little influence on the growth of ratoon (Figs. 2, 3 and 4), suggesting that a rigid comparison of ratoon traits should be made between the lines whose heading dates are not so much different from each other, because a great difference of heading time is associated with a significant difference of temperature.

Cutting height: The cutting height of mother plant considerably influenced on the growth of ratoon (Fig. 21). Lower cutting height decreased the relationships of percentage of ratoon tillers to the percentage of ripened grains in mother plant (Table 17).

Putting the results obtained in the present studies together, two traits of ratoon, percentage of tillers and height, can effectively be used for the estimation of two agronomic characters of mother plant, percentage of ripened grains and lodging resistance. When the two traits of ratoon are compared with each other, however, percentage of tillers evidently exceeds height, so far as judged from the degrees of correlations with the above two agronomic characters of mother plant (Tables 3 and 17), the time required for determining the final trait value (Figs. 3, 4, 12, 13 and 14), and the ability for repetition (Fig. 22). Either way, in case of the use of these ratoon traits as the indicators of mother plant characters, attention should always be paid to the time and height of cutting so that the estimation may be more effective.

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