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ABSTRACT

With respect to the problem of growth duration, it was found that the length of growth duration of photoperiod-sensitive native varieties was influenced greatly by the time of transplanting and that the length of growth duration had a significant implication on growth and yield of rice in Thailand.

A further study was made on this problem from the standpoint of plant nutrition. Results proved that it is possible to produce comparatively small plants with high nutrient content by shortening the growth duration as a results of adjusting transplanting time, and thus, the nutritional conditions of plants in the latter growth period can be improved which is directly connected to increased yield.

CONTENTS

INTRODUCTION

It has been known that the length of growth duration of photoperiod-sensitive tropical rice varieties shows a great range of variation depending upon the time of planting: the earlier the planting time, the longer the growth duration. A growth duration longer than six months is not seldom observed.

J. TAKAHASHI *et al.* made clear with photoperiod-sensitive native varieties of Thailand that the length of growth duration is shortened regularly with the delay in transplanting time and that the length of growth duration exhibits the significant implication on growth and yields of rice. They proved that there exists an optimum length of growth duration, with which existing local varieties are able to give very high grain yields.

As the authors considered that the nutritional research on rice plants in relation to growth duration is necessary in order to improve rice culture in Thailand, and yet nothing has been known on this aspect, the plant nutritional study on the significance of growth duration was carried out.

Acknowledgement

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I. Plant Growth, Nutritional Conditions and Recovery Rate of Fertilizers as Affected by Methods of Fertilizer Application and Time of Transplanting

J. TAKAHASHI *et al.* showed that, contrary to the general belief, photo-sensitive Indica varieties are capable of producing very high yield, if proper cultural practices are adopted. They succeeded in gaining high yield by delaying transplanting time and thereby shortening the growing duration of photoperiod-sensitive Indica varieties as well as improving the fertilizer dressing method. The purpose of the present investigation is to clarify the change of plant growth, the nutritional conditions and recovery rate of fertilizer as affected by different methods of fertilization practiced in relation to delaying transplanting time. Emphasis has been placed to offer physiological explanation for the mechanisms of yield increase derived from the shortening of the growing duration of photoperiod-sensitive Indica varieties caused by delayed transplanting.

Nutritional research on rice plants in relation to transplanting time is very important in order to find out the most appropriate time of transplanting under the tropical climate which permits rice cultivation throughout the year.

METHOD

1) Location of experiment:

This experiment was carried out in the paddy field of Bangkhen Rice Experiment Station in Thailand.

2) Variety:

Puang Nahk-16. Late, non-glutinous photoperiod-sensitive local rice variety in Thailand.

3) Spacing: 20×20 cm

4) Number of seedlings: three per hill

5) Treatment of fertilizer application:

The design of experiment is shown in Table 1.

The total dosage of fertilizer is same with all treatment plots and phosphorous and potassium were applied as basal dressing, but nitrogen was applied by the following three methods.

a) Basal application—A whole dosage of 75 kg/ha of nitrogen was dressed one day before transplanting as basal dressing.

b) Two-time-split application—One half was dressed as basal dressing and the other half at the initiation of panicle primordia about 25 days before flowering.

c) Three-time-split application—One third applied as basal dressing, one third at one month after transplanting to boost the tillering, and the rest at the initiation of panicle primordia. The basal fertilizers were applied by deep placement in all cases.

6) Transplanting time:

The above treatments of fertilizer application were tested in combination with four different transplanting times, *viz.*, the first day of July, August, September, and October.

7) Plant protection:

Necessary sprayings to protect the crop against insects and pests were conducted.

Table 1. Design of fertilizer application

Trans-planting time	Treatment	Basal dressing N	Basal dressing P_2O_5	Basal dressing K_2O	1st top-dressing N	1st top-dressing P_2O_5	1st top-dressing K_2O	2nd top-dressing N	2nd top-dressing P_2O_5	2nd top-dressing K_2O
July	Control	—	—	—	—	—	—	—	—	—
	All basic	75	75	75	—	—	—	—	—	—
	Split-2	37.5	75	75	—	—	—	37.5	—	—
	Split-3	25	75	75	25	—	—	25	—	—
Aug.	Control	—	—	—	—	—	—	—	—	—
	All basic	75	75	75	—	—	—	—	—	—
	Split-2	37.5	75	75	—	—	—	37.5	—	—
	Split-3	25	75	75	25	—	—	25	—	—
Sept.	Control	—	—	—	—	—	—	—	—	—
	All basic	75	75	75	—	—	—	—	—	—
	Split-2	37.5	75	75	—	—	—	37.5	—	—
	Split-3	25	75	75	25	—	—	25	—	—
Oct.	Control	—	—	—	—	—	—	—	—	—
	All basic	75	75	75	—	—	—	—	—	—
	Split-2	37.5	75	75	—	—	—	37.5	—	—
	Split-3	25	75	75	25	—	—	25	—	—

8) **Replication**: Three times.
9) **Area of one plot**: 25 m^2 (5 m×5 m)
10) **Sampling**:

Plant samples were taken at the one month intervals, including flowering and harvesting time. At least 20 hills were taken for one sample.

11) **Measurement of growth process**:

Plant height and number of tillers were measured immediately after sampling and weight of dry matters was determined after drying the samples.

12) **Chemical analysis**:

All the plant samples were subject to chemical analysis. Methods of analysis were as follows:

Nitrogen: determined by semimicro Kjeldahl distillation method.[2)]

Digestion: Wet combustion was employed using $HClO_4$, HNO_3, and H_2SO_4.

Phosphorous: Determined by Ammonium Vanado-Molybdate method.[3)]

Potassium: Determined by Dr. Lange's flamephotometer at the wave length of 768 mμ.

RESULTS

A) Plant growth pattern

Owing to the lower soil fertility, the plant growth was well affected by fertilizer. The results of the plant growth were as follows:

1) Plant height

As shown in Fig. 1, plant heights varied clearly by different method of fertilizer application. During the vegetative growth, nitrogen applied as basal-dressing always caused

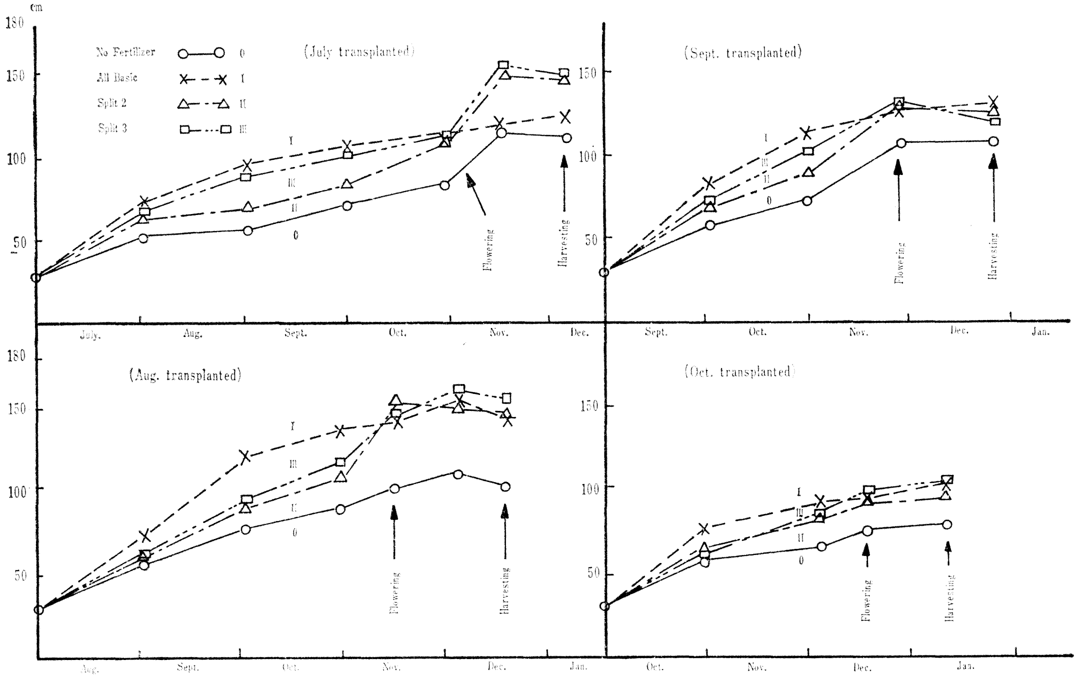


Fig. 1. Plant height

the highest plant height, and control plots no fertilizer showed the lowest height. Thus the order of plant height being as follows: All basic>Split-3>Split-2>non-fertilized. This order reflects the total amount of nitrogen dressed within this growth period.

During the reproductive stage, split-2 and split-3 plots showed the increase in plant height, because these plots received nitrogen at the primordia initiation stage, *i.e.* about 25 days before headings. So that, the order of plant height became different from that of vegetative stage. As to the relation between the plant height and the time of transplanting, it is evident that the later the transplanting time, the lower the plant height, and the plant height well correlates to the total duration of growth, within a range not exceeding 170 days.

2) Number of tillers

As to the number of tillers in relation to the method of fertilizer application, the order of the number of tillers was exactly identical with that of plant height during the vegetative growth. However, in the generative growth the number of tillers gradually decreased. This decrease initiates at about 2 months later after transplanting. The rate of this decrease depends not only upon the length of total growth duration as affected by the time of transplanting but also upon the methods of nitrogen application as shown in Fig. 2. When the plants were transplanted earlier and the full dosage of nitrogen was applied basically, the plants showed good tillering at the initial stage of growth. However, after two months, a remarkable decrease in number of tillers took place, accompanied with a lot of dead leaves, and finally the number of tillers became almost equal to that of non-fertilized plot. On the other hand, when the full dosage of nitrogen was applied as basal dressing to the plants transplanted in later season a decrease in number of tillers was not so severe and almost 70% of the tillers could remain up to the harvesting time.

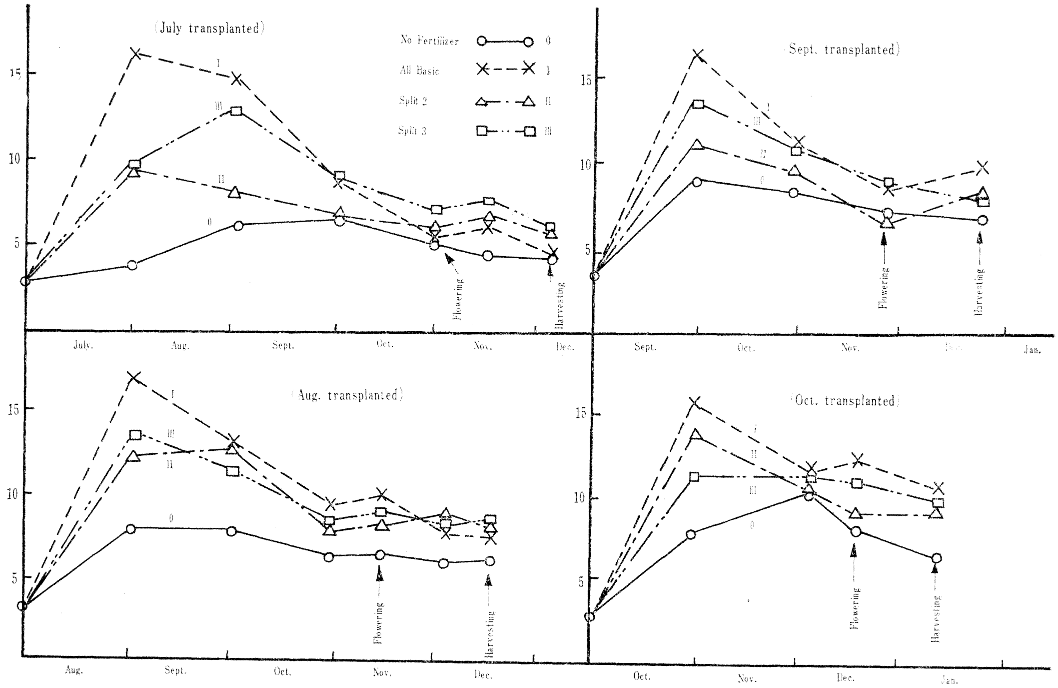


Fig. 2. Number of tillers per hill

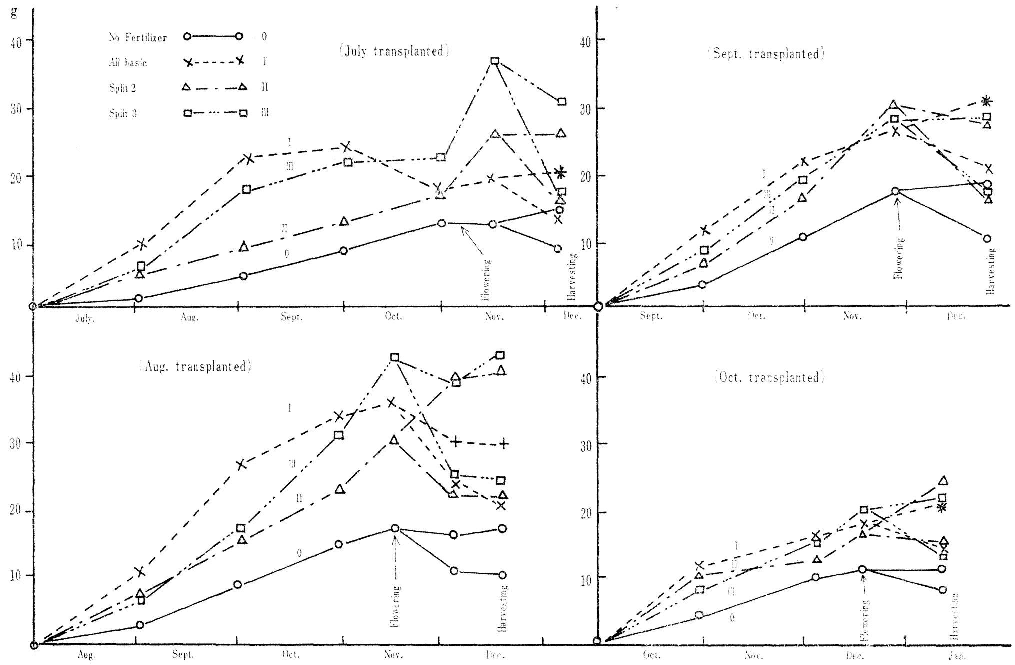


Fig. 3. Weight of dry matter per hill

The results indicated clearly that the nitrogen applied at the initial stage of growth boosted the tillering, but this effect continued only for two months. Therefore, if subsequent nutrient supply was not sufficient, the decrease in number of tillers took place at the later stages of growth. Under the tropical climatic condition, the rate of the decrease was found to be greater than that under the temperate condition. In the light of this fact, it can be said that an additional supply of nitrogen as top dressing is indispensable to acquire enough number of tillers under tropical conditions, especially in the case of longer growth duration.

3) Dry matter production

General tendency of dry matter production in relation to methods of nitrogen application and time of transplanting was quite similar to that of the plant height.

As shown in Fig. 3 the total weight of dry matter was clearly affected by the methods of the fertilizer application. During the vegetative growth, dry matter production was found to be correlated with the total amounts of nitrogen dressed in this stage of growth with the

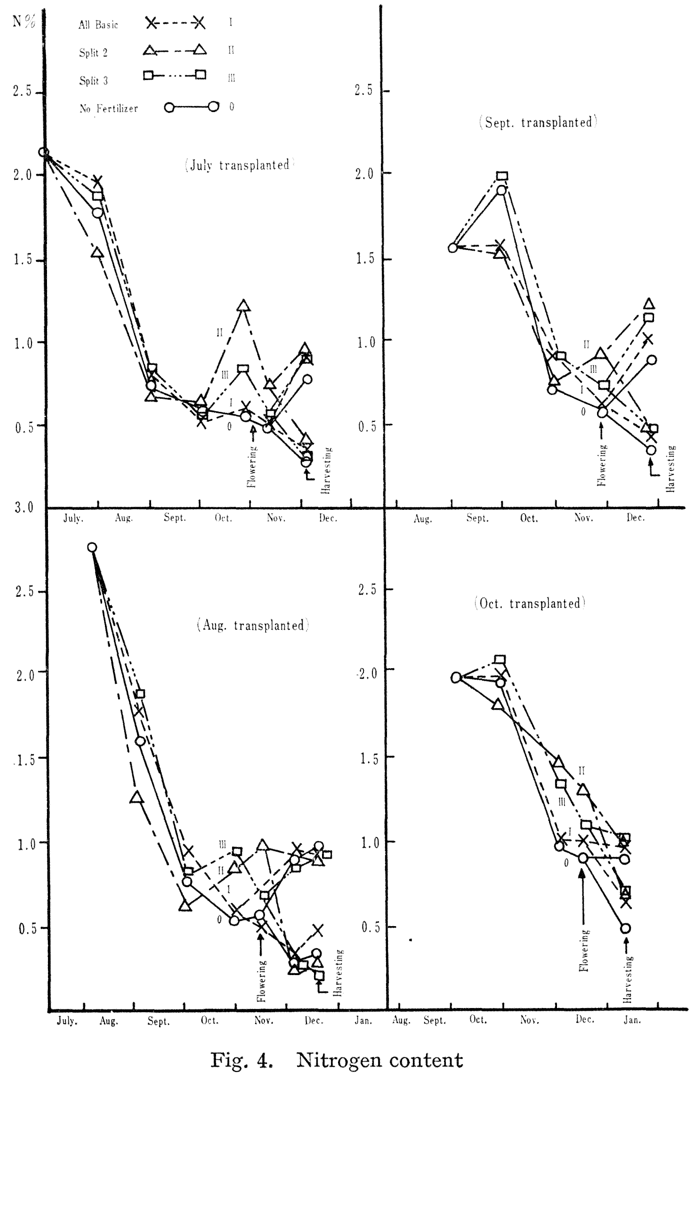


Fig. 4. Nitrogen content

basal application plot showing the greatest dry matter. At the generative growth stage, however, the basal application plot showed a remarkable decrease in dry matter due to the decrease in number of tillers with increased dead leaves. Under the condition of this experiment, this change was clearly observed at three months after transplanting.

A clear relationship that the shorter the duration of plant growth, the smaller the dry matter, was observed except when the growth duration exceeded over about 170 days. With such a long growth duration as more than 170 days the nutrient supply might be insufficient even though 75 kg/ha of nitrogen were applied by splitting at three times.

B) Nutritional conditions

On account of lower soil fertility, nutritional conditions of rice plant especially of nitrogen and phosphorus also well corresponds to the methods of fertilizer application.

1) Change in nutrient content

a) Nitrogen

Nitrogen content of rice plants showed a gradual decrease with the progress of growth. In the vegetative growth stage, the content of nitrogen is not well correlated to the total amounts of nitrogen applied within this growing period. As shown in Fig. 4, data sometimes showed rather reverse correlation. It can be explained that nitrogen was mainly utilized to produce dry matter rather than to increase nitrogen content. On the contrary, in the generative growth stage the nitrogen content of the plant well corresponds to the amount of nitrogen applied within this growing period. It can be said that the nitrogen applied at the pancile primordia initiation stage was utilized mainly to increase its content rather than to increase dry matter.

Effect of nitrogen applied at the panicle primordia initiation stage in nitrogen content of plants was more remarkable when the plants were transplanted earlier.

As shown in Fig. 4, the split-2 plot which received a half of the full dosage of nitrogen at the primordia initiation stage showed a higher nitrogen content at the flowering stage than the split-3 plot which received one third of full dosage. Thus the order of the nitrogen content at the flowering stage is

Split-2>Split-3>All basic>No fertilizer.

It is interesting to note that all the plots of late-transplanting gave always higher nitrogen content of plants at the reproductive stage than plots transplanted earlier. Furthermore, the decrease in nitrogen content at the vegetative-lag stage was almost negligible or very small with late-transplanted plots, while it was much more remarkable with early-transplanted plots.

b) Phosphorus

There is no close relationship between the phosphorus content of rice plant and the methods of fertilizer application. At the vegetative growth stage, the non-fertilized plot has the lowest content. As an equal dosage of phosphorus was applied as basal dressing to all the plots, in this experiment any difference in phosphorus content in plants is likely to be caused by the difference in the methods of nitrogen application.

As shown in Fig. 5 when rice plants were transplanted in July, the phosphorus content in plants showed good correlation with the dose of nitrogen at the early stage of plant growth. On the other hand, plots of later transplantation did not show such a tendency. Unlike nitrogen, there was no big difference in the phosphorus contents at the generative growth stage. In general the phosphorus content during the vegetative stage showed an increase with the delay of the transplanting time. There was no remarkable change in phosphorus contents from transplanting to flowering stage when plants were transplanted in early season, whereas a marked decrease was observed when transplanted in later season, though the levels of phosphorus contents were higher than those of earlier transplanted plants. Thus, phosphorus content at the flowering stage was higher with late-transplanting than early-planting.

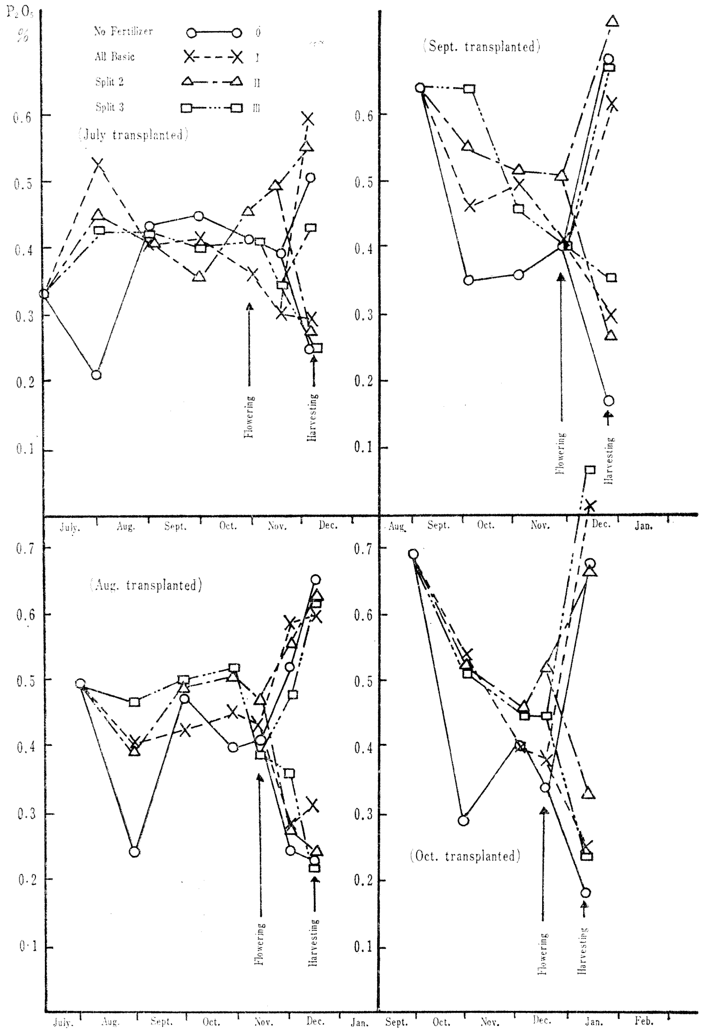


Fig. 5. Phosphorus content

c) Potassium

The uptake pattern of potassium was similar to that of nitrogen. As all the plots received the same amounts of potassium basically, the change in its content in plants was likely to be largely affected by the methods of nitrogen application.

As shown in Fig. 6 potassium content increased constantly with the plant growth in the early stage, reached to the maximum point at one month after transplanting and then tended to the marked decrease.

2) Pattern of nutrient uptake

a) Nitrogen

Figure 7 shows that the amount of nitrogen absorbed by plants in the vegetative growth stage is well correspond to the amount of nitrogen applied for that stage. Since the split-2 treatment received a half of the total dosages of nitrogen and split-3 plot received one third of the dosage for the reproductive growth stage. The former showed a more remarkable

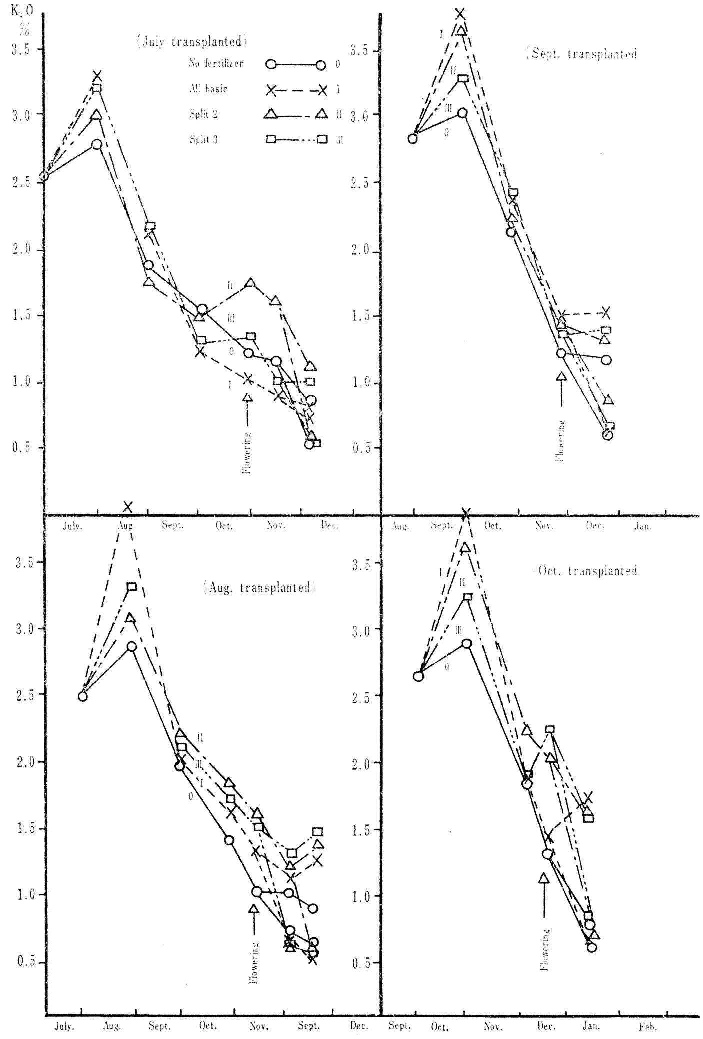


Fig. 6. Potassium content

increase in the nitrogen uptake during that stage than the latter plot.

Figure 8 illustrates clearly a relationship between methods of nitrogen dressing and amount of nitrogen uptake in plant by expressing nitrogen absorption by the curve of either increment or decrement at 10 day intervals.

The uptake of nitrogen was active at the early stage of growth and it reached the maximum about 20 days after dressing. However, the loss of nitrogen from the plants subsequently occurred from 50 days after transplanting.

Such a nitrogen loss or slow down of its absorption at the vegetative-lag phase (idle period) is clearly observed when rice plants were transplanted in the early season, or nitrogen was predominantly dressed at the vegetative stage of growth. As to the relationship between the nitrogen uptake and the time of transplanting, it was observed that nitrogen was utilized mainly to increase dry matter production, when transplanting was made earlier while nitrogen is utilized mainly to increase nitrogen content of the plant when transplanting

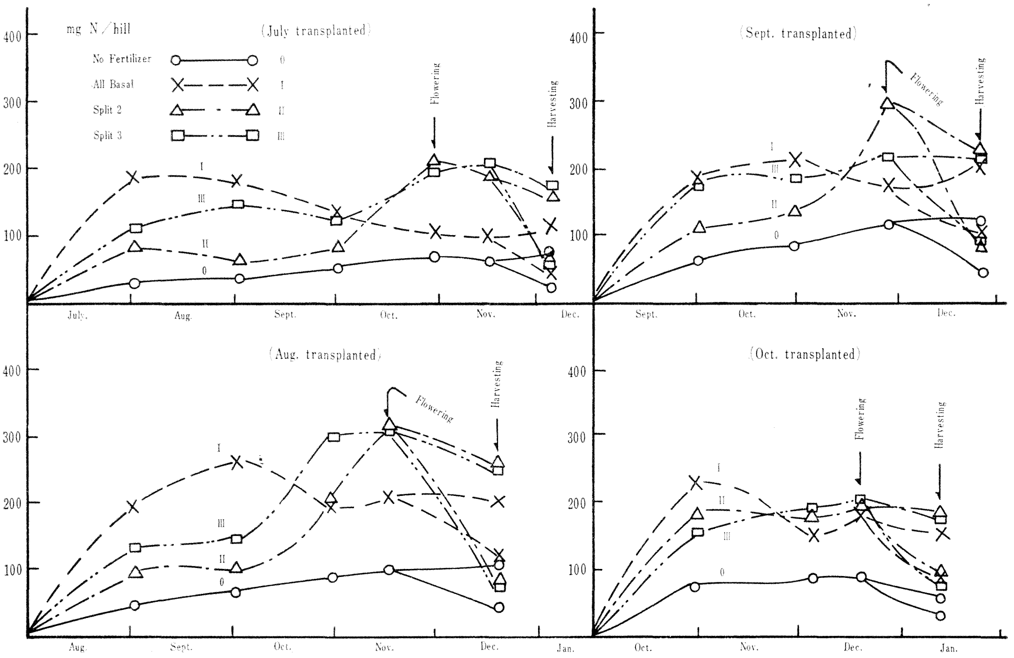


Fig. 7. Pattern of nitrogen uptake

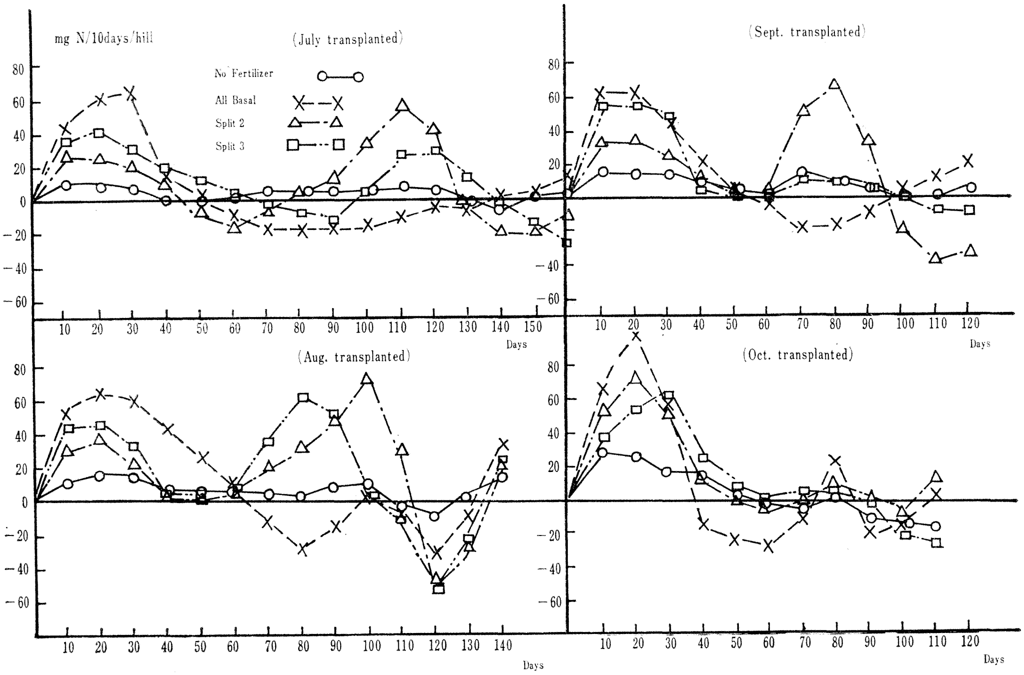


Fig. 8. Increment or decrement of nitrogen absorbed by plants at 10 days intervals

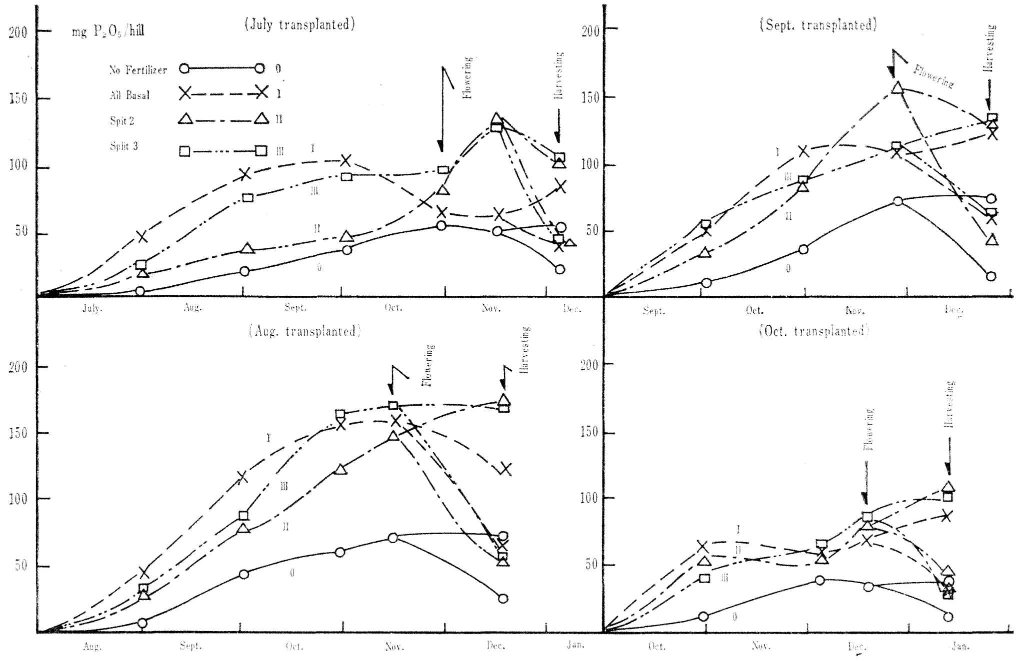


Fig. 9. Pattern of phosphorus uptake

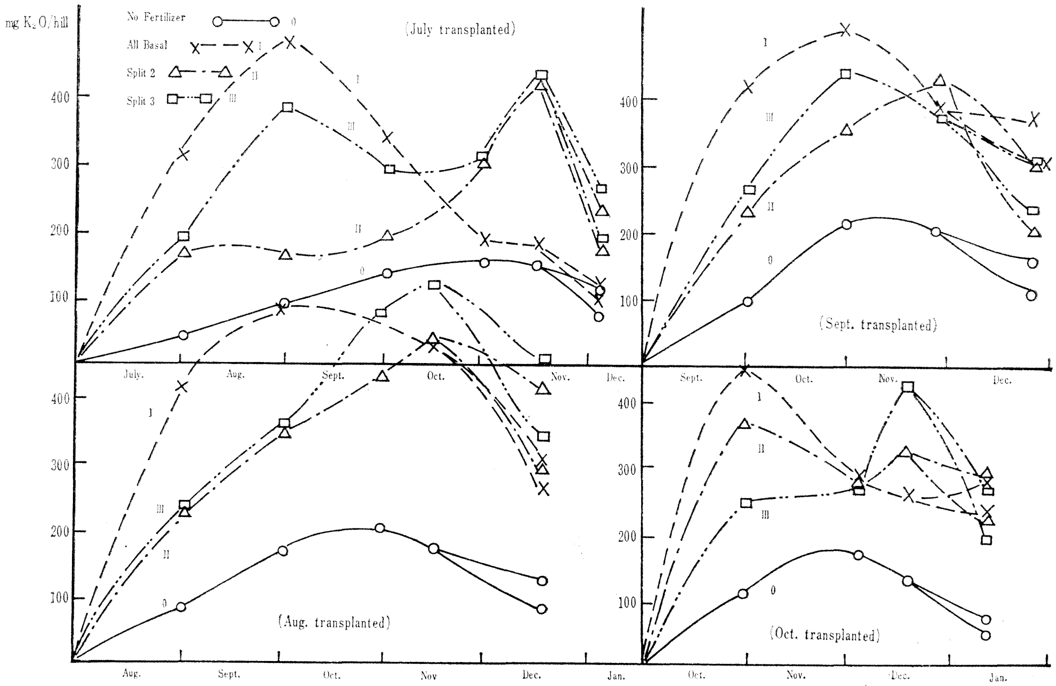


Fig. 10. Pattern of potassium uptake

was made in later season.

b) Phosphorus

As shown in the Fig. 9 phosphorus uptake continued steadily with the maximum uptake at the stage of flowering. Contrary to the nitrogen, the loss or slow down of phosphorus uptake was not observed at the vegetative-lag phase, even though plants were transplanted in the early season.

c) Potassium

Generally speaking, the uptake process of potassium is similar to that of nitrogen. The loss or slow down of potassium uptake was also observed at the vegetative-lag phase as shown in the Fig. 10.

C) The recovery rate of fertilizer

Figure 11 indicates that the recovery rate of fertilizer was very low when all the nitrogen was applied as basal dressing, but, split applications increased remarkably the rate. The experimental data revealed that when plants were transplanted in June and all the nitrogen fertilizer was dressed basically, only 13% of the dressed nitrogen could actually be utilized by the plants. On the other hand, the split application of the same amount of nitrogen (1/3 applied basic, 1/3 at one month after transplanted, and 1/3 at I.P.P. stage) could make the recovery rate as high as 32%.

The recovery rate of fertilizer varied not only with the method of dressing as mentioned above, but also with the time of transplanting.

Early transplanting (*e.g.* June or July planting) as well as late transplanting (October or November planting) resulted in low rate of recovery, with an intermediate planting (August or September) giving the highest rate.

Thus, there is a maximum point in respect to the fertilizer utilization. The data indicate that this point falls on August.

The recovery rate of fertilizer is found to be closely correlated to the grain yield as shown in Table 2. High yield is alway associated with high recovery rate of fertilizer. An improvement in recovery rate of fertilizer directly leads an increased yield.

Table 2. Yield of paddy (t/ha)

Treatment		Rep. I	Rep. II	Rep. III	Total	Mean
July transplanted	All basic	1.35	1.91	1.75	5.01	1.67
	Split-2	3.57	2.56	3.28	9.41	3.14
	Split-3	2.53	2.00	3.79	8.32	2.77
	Control	0.59	0.95	1.54	3.08	1.03
Aug. transplanted	All basic	1.94	2.00	3.42	7.36	2.45
	Split-2	3.76	3.59	3.86	11.21	3.74
	Split-3	3.97	4.11	3.74	11.82	3.94
	Control	1.78	1.89	1.58	5.25	1.75
Sept. transplanted	All basic	1.81	2.86	2.32	6.99	2.33
	Split-2	2.61	2.74	2.90	8.52	2.75
	Split-3	2.88	2.68	2.66	8.22	2.74
	Control	1.51	1.35	1.25	4.11	1.37
Oct. transplanted	All basic	1.25	1.44	1.26	3.95	1.32
	Split-2	1.54	1.75	1.81	5.10	1.70
	Split-3	2.00	1.44	1.71	5.15	1.72
	Control	1.22	1.05	0.99	3.26	1.09

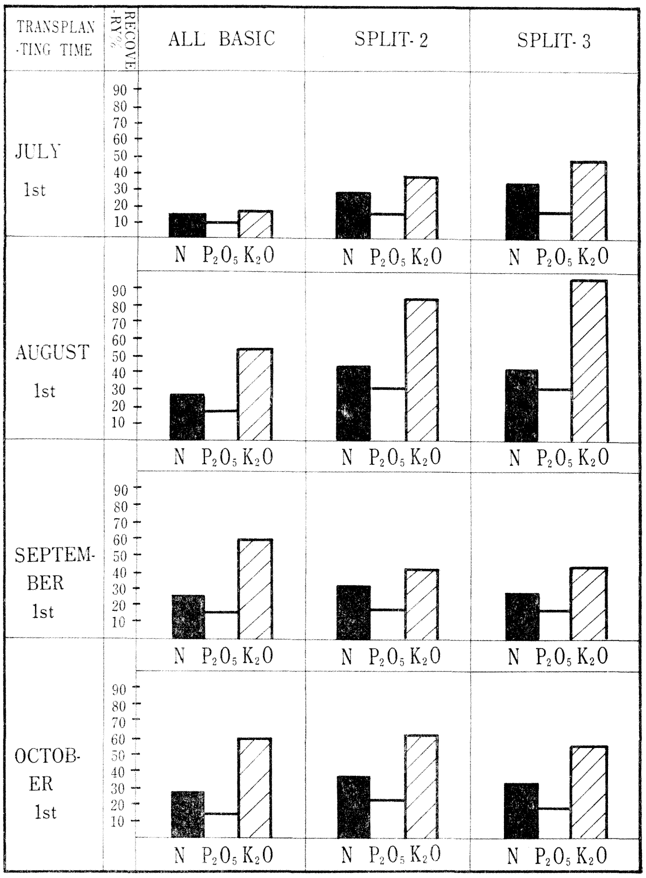


Fig. 11. Plant recovery rate of fertilizer

II. Varietal Difference in Growth Response to Changing Time of Transplanting

To know the varietal characteristics is indispensable to improve rice cultivation. One recommendable method of cultivation established on a variety could not always be successfully applicable to other varieties. The varietal differences of Indica rice plant are very wide indeed. Thus, to know the varietal characteristics is naturally important. From this point of view, the authors examined the response of 10 recommended local rice varieties in Thailand to the change of transplanting time.

METHOD

1) Location of experiment:

This experiment was carried out in the paddy field of Bangkhen Rice Experiment Station in Thailand.

2) Treatment:

Varietal comparison in response to six different transplanting time was carried out using 10 recommended local varieties shown in Table 3.

Table 3. Design of Experiment

a) Amount of fertilizer dressing.

Elements and methods	Basic-dressing	1st Top-dressing	2nd Top-dressing
N(kg/ha)	25	25	25
P_2O_5 (kg/ha)	75	—	—
K_2O (kg/ha)	75	—	—
Method of dressing	Deep placement	Top-dressing	Top-dressing
Time of dressing	Before transplanting	1 month later after transplanting	I.P.P. stage of growth

b) Time of transplanting

Name of plot	Time of transplanting	Name of plot	Time of transplanting
V A	JUN. 15th	V D	SEPT. 15th
V B	JUL. 15th	V E	OCT. 15th
V C	AUG. 15th	V F	NOV. 15th

c) Variety

No.	Variety name	No.	Variety name
1	GOW RUANG-88	6	BAI LOD-104
2	GAM PAI-41	7	NAHNG MON-S4
3	KHAO PAHK MAW-17	8	LEUANG TONG-82
4	MUEY NAWNG-62M	9	PUANG NAHK-16
5	DAWK MALI-3	10	LEUANG PRATEW-123

3) **Spacing:** 20 cm × 20 cm
4) **Number of seedlings:** three per hill
5) **Area of one plot:** 25 m^2 (5 m × 5 m)
6) **Plant protection:** Proper spraying were conducted to protect the crop against pests.
7) **Replication:** Three replications
8) **Sampling:**

Plant samples were taken at the tillering stage, one month after transplanting, at intermediate stage, at flowering stage, and at harvesting time. At least 20 hills were taken for a sample.

9) **Chemical analysis:**

All the plant samples were subjected to chemical analysis. Method of analysis was as follows:

Nitrogen: determined by semi-micro Kjeldahl distillation method.
Phosphorus: determined by Ammonium Vanado Molybdate method.
Potassium: determined by Dr. Lange's flamephotometer, at the wave length of 768 mμ.
Silica: determined by gravemetric method.

10) **Measurement of plant shape:**

Plants were cut into successive strata from the top to the base of the plants at 10 cm interval. All green leaf blades were taken from stems with each of the strata, and their weight was measured after drying. Weight of leaf blade of each stratum was illustrated so as to represent the spacial distribution of leaf blades within the plant community.

RESULTS

A) Response of plant growth

1) Plant height

As shown in Fig. 12, plant height varied remarkably depending upon the transplanting time. It is evident that the later the transplanting time, the lower the plant height. In other words, the plant height is closely correlated to the length of growth duration, within a range not exceeding 170 days. The June transplanting showed a lower plant height than that of July planting. With such a long growth duration exceeding 170 days resulted from June transplanting, nutrient supply might be insufficient even though 75 kg/ha of N, P_2O_5, and K_2O were applied by a split method at three times.

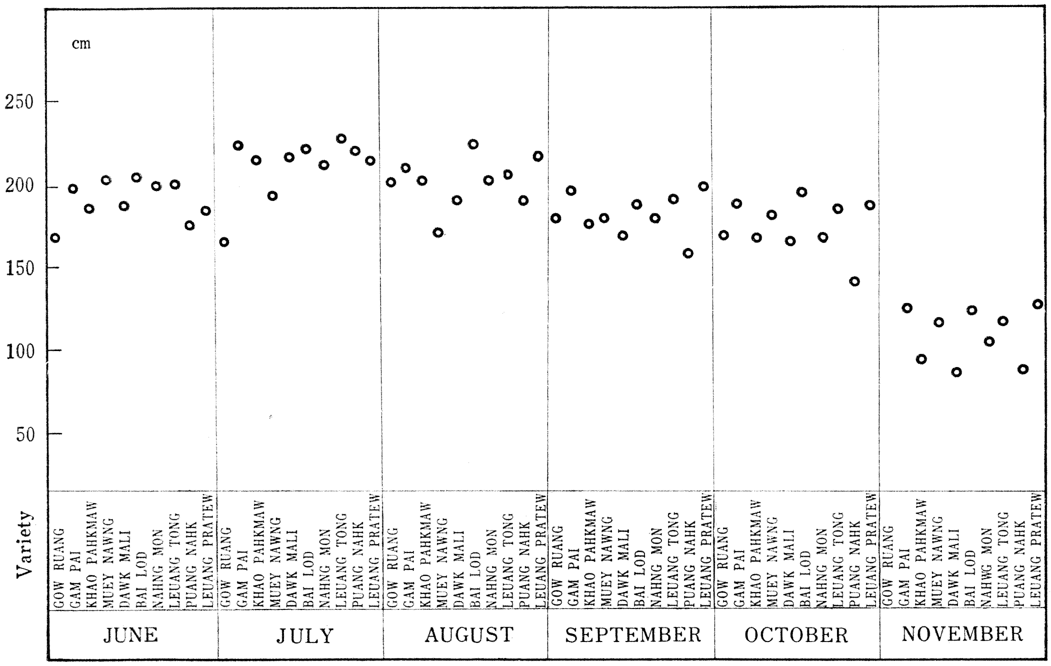
2) Number of tillers

A gradual increase in number of tillers with the delay of transplanting time was observed as shown in Fig. 13. Concerning the varietal difference in tiller number, it was found that a variety Dawk Mali 3 showed higher tillering ability than other varieties, except in the case of later transplanting. At later transplanting, Puang Nahk 16, and Leuang Pratew 123 showed good tillering. It is interesting that the both varieties belong to the late maturing group.

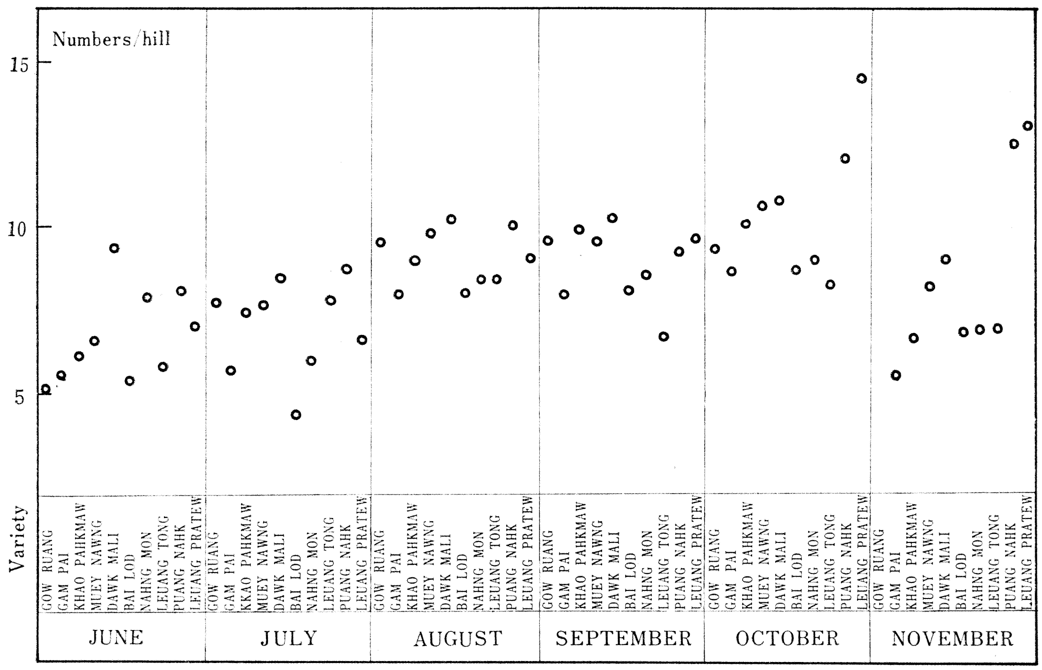
3) Weight of dry matter

General tendency of the plant response in dry matter to the change of transplanting time is quite similar to that of the plant height.

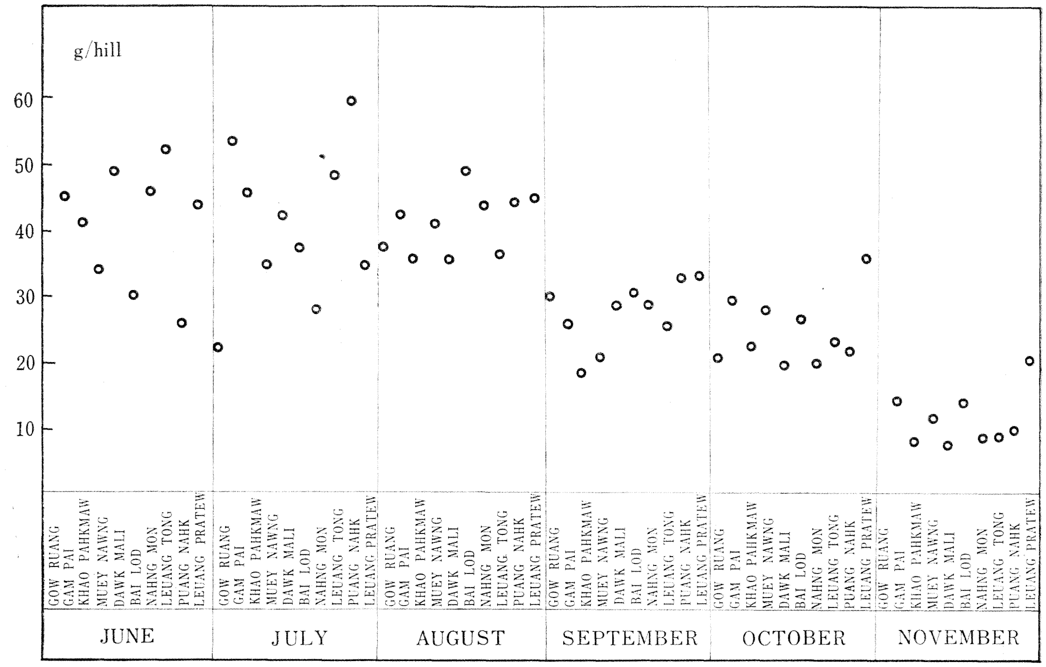
Figure 14 indicates that the weight of dry matter at the time of maturity is closely related to the length of growth duration;



Transplanting time
Fig. 12. Plant height

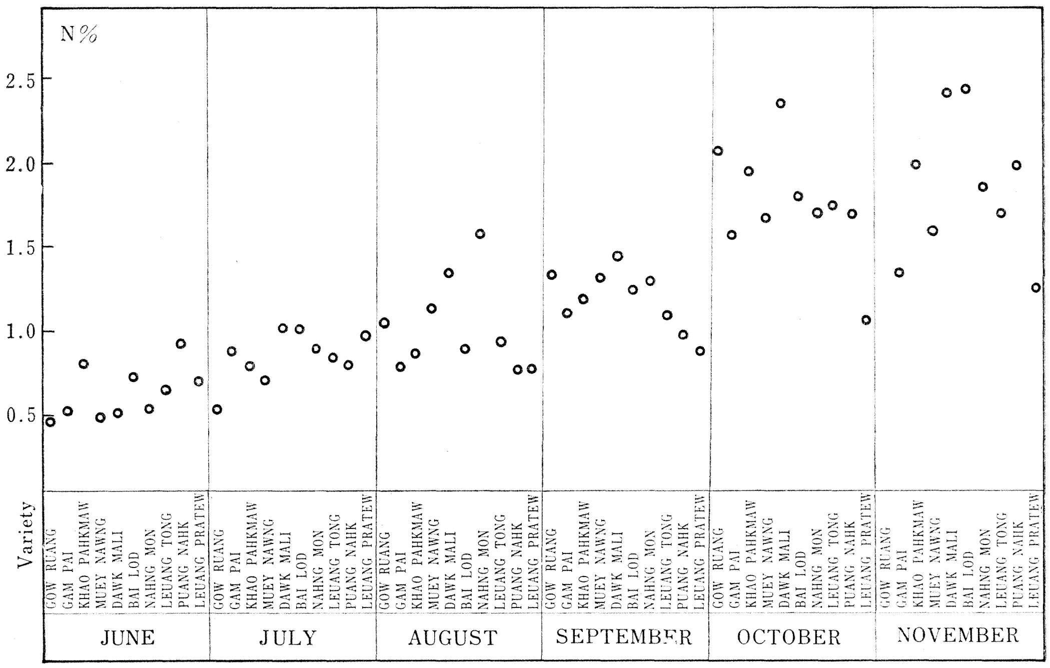


Transplanting time
Fig. 13. Number of tillers



Transplanting time

Fig. 14. Weight of dry matter



Transplanting time

Fig. 15. Nitrogen content

However, this tendency was more or less disturbed by insect damage, disease, lodging and malnutrition, when the growth duration became very long.

Thus, the dry matter of early-transplanted materials showed a wide range of variation.

With respect to varietal difference, no distinct varietal difference among tested 10 varieties was observed.

B) Response of nutrient content

1) Nitrogen

Nitrogen content in plants increased remarkably with the delay of transplanting time. This trend coincides with the result of Chapter-I as shown in Fig. 15. Thus the nitrogen content of plants is reversely correlated to the weight of dry matter.

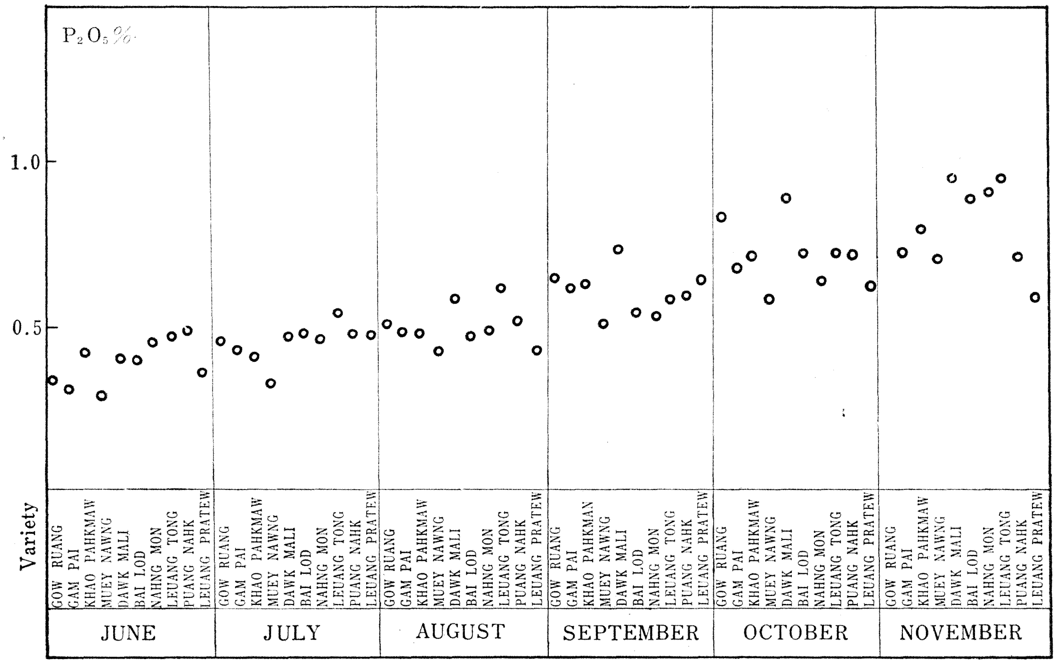
However, no difference in the ratio of water-soluble N to total N in the straw at the flowering stage was found irrespective of the different time of transplanting, suggesting that the efficiency of protein synthesis of late-palnted crops might be same as the early-planted crops.

No appreciable varietal difference was found in the total nitrogen content as well as in the ratio of soluble nitrogen to total, as shown in Table 4.

Table 4. Total nitrogen and water soluble nitrogen content of 10 varieties transplanted in different seasons

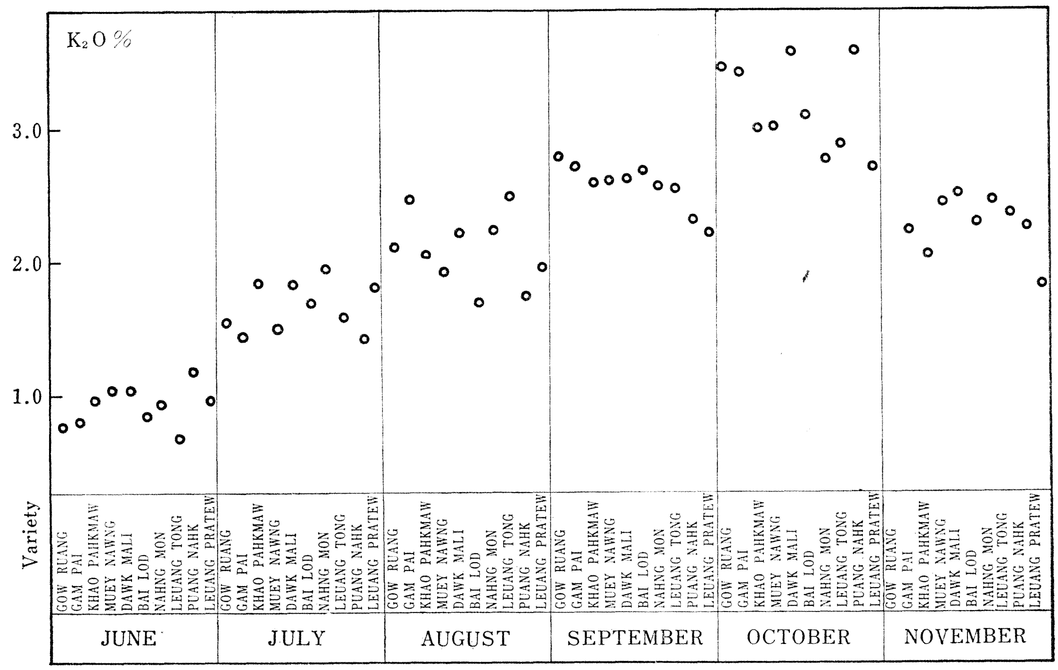
Transplanting time	Variety	T-N	W-Soluble-N	W-None Soluble-N	Soluble-N / T-N
		%	%	%	
July. 15	GOW RUANG-88	0.52	0.15	0.37	0.29
	GAM PAI-41	0.85	0.18	0.67	0.21
	KHAO PAHKMAW-17	0.77	0.22	0.55	0.29
	MUEY NAWNG-62M	0.69	0.21	0.48	0.30
	DAWK MALI-3	1.03	0.23	0.80	0.22
	BAI LOD-104	1.03	0.27	0.76	0.25
	NAHNG MON-S4	0.89	0.33	0.56	0.37
	LEUNG TONG-82	0.83	0.17	0.66	0.20
	PUANG NAHK-16	0.79	0.14	0.65	0.18
	LEUANG PRATEW-123	0.96	0.29	0.67	0.30
Sept. 15	GOW RUANG-88	1.31	0.21	1.11	0.16
	GAM PAI-41	1.09	0.29	0.80	0.26
	KHAO PAHKMAW-17	1.17	0.36	0.81	0.31
	MUEY NAWNG-62M	1.30	0.39	0.91	0.30
	DAWK MALI-3	1.43	0.18	1.25	0.13
	BAI LOD-104	1.23	0.34	0.89	0.28
	NAHNG MON-S4	1.28	0.37	0.91	0.29
	LEUNG TONG-82	1.07	0.19	0.88	0.18
	PUANG NAHK-16	0.96	0.25	0.71	0.26
	LEUANG PRATEW-123	0.87	0.22	0.65	0.25
Nov. 15	GOW RUANG-88	—	—	—	—
	GAM PAI-41	1.32	0.33	0.99	0.25
	KHAO PAHKMAW-17	1.96	0.57	1.39	0.29
	MUEY NAWNG-62M	1.57	0.32	1.25	0.20
	DAWK MALI-3	2.40	0.57	1.83	0.24
	BAI LOD-104	2.41	0.34	2.07	0.14
	NAHNG MON-S4	1.82	0.45	1.37	0.25
	LEUNG TONG-82	1.68	0.37	1.31	0.22
	PUANG NAHK-16	1.96	0.48	1.48	0.25
	LEUANG PRATEW-123	1.21	0.26	0.95	0.22

Remarks: Analytical samples were taken at flowering time.



Transplanting time

Fig. 16. Phosphorus content



Transplanting time

Fig. 17. Potassium content

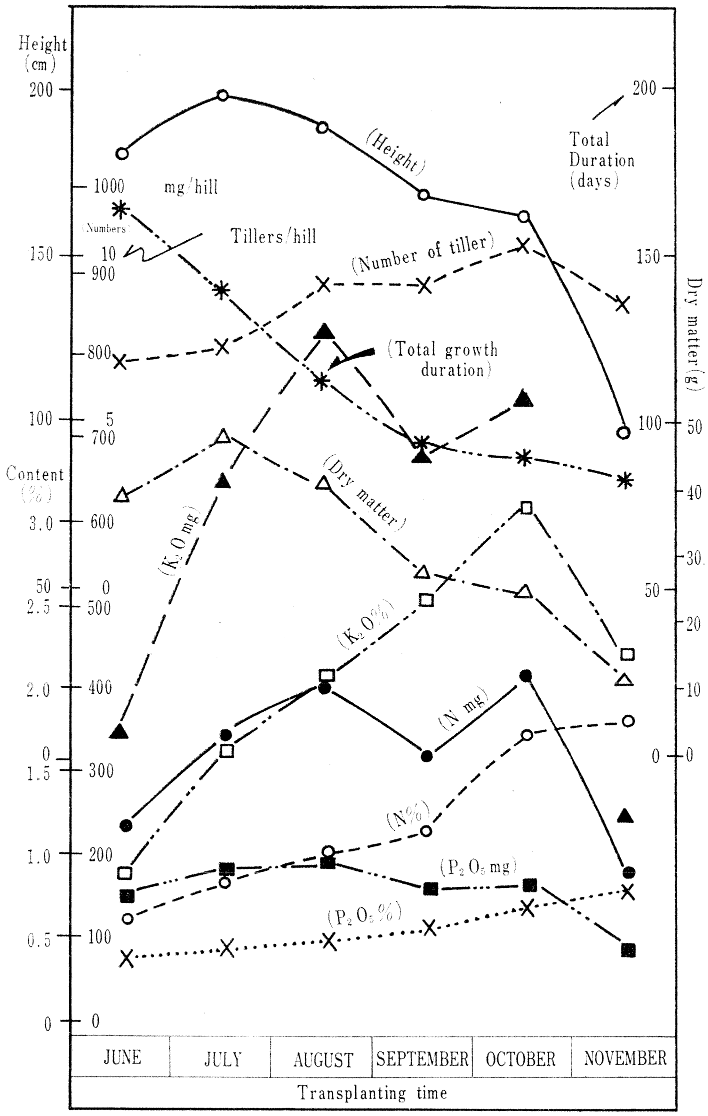


Fig. 18. Growth and nutrient content of plants at flowering time

2) Phosphorus

Change in phosphorus content caused by delayed transplanting time is same as that of nitrogen.

As shown in Fig. 16, the phosphorus content increased with delaying transplanting time. Plants transplanted in November showed phosphorus content almost twice that of June transplanted one.

The data also showed that Muey Nawng 62M has peculiarly low content of phosphorus, while Dawk Mali 3 has high content comparing with other varieties.

3) Potassium

Change in potassium content in relation to the transplanting time is also quite similar to that of nitrogen and phosphorus.

However, it was found that November transplanting gave lower potassium content as shown in Fig. 17.

Growth and nutrient content of plants at the stage of flowering and maturity are illustrated in Figs. 18, 19, and 20. It is shown clearly here again that the early transplanting gave very low nutrient content, and the content increased with the delay of transplanting time.

From the physiological viewpoint, the level of nutrient content of the early-transplanted plants seems to be insufficient at the flowering stage, while that of the later-transplanted one seems to be optimal.

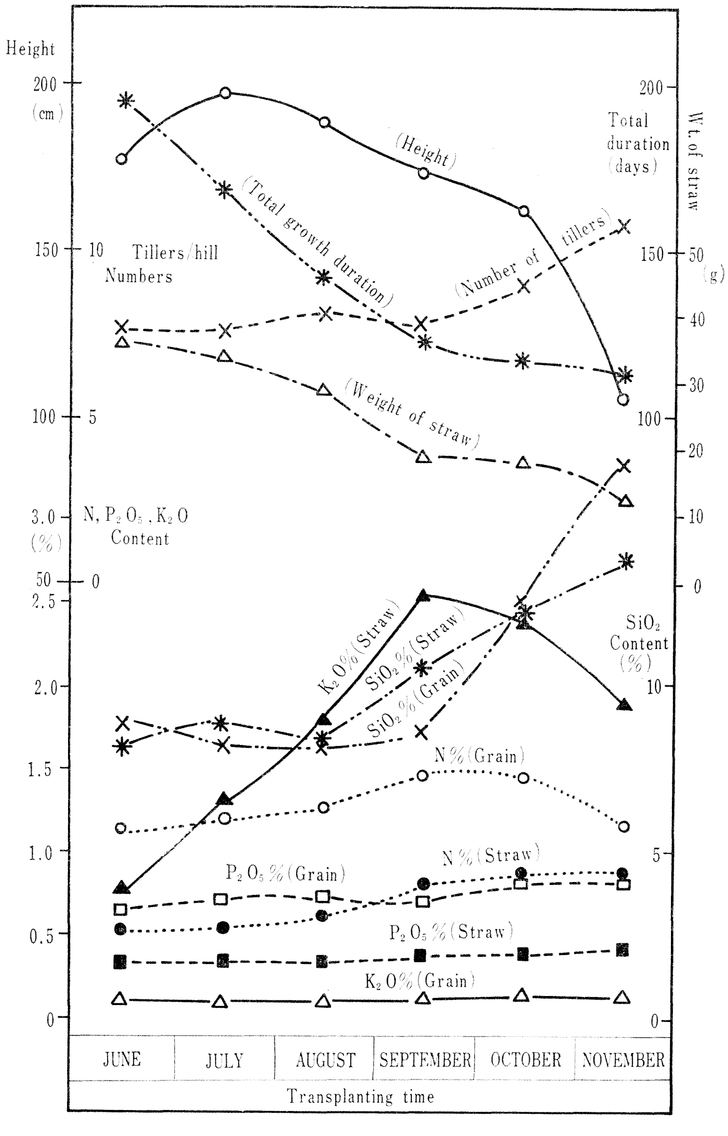


Fig. 19. Growth and nutrient content of plants at harvesting time

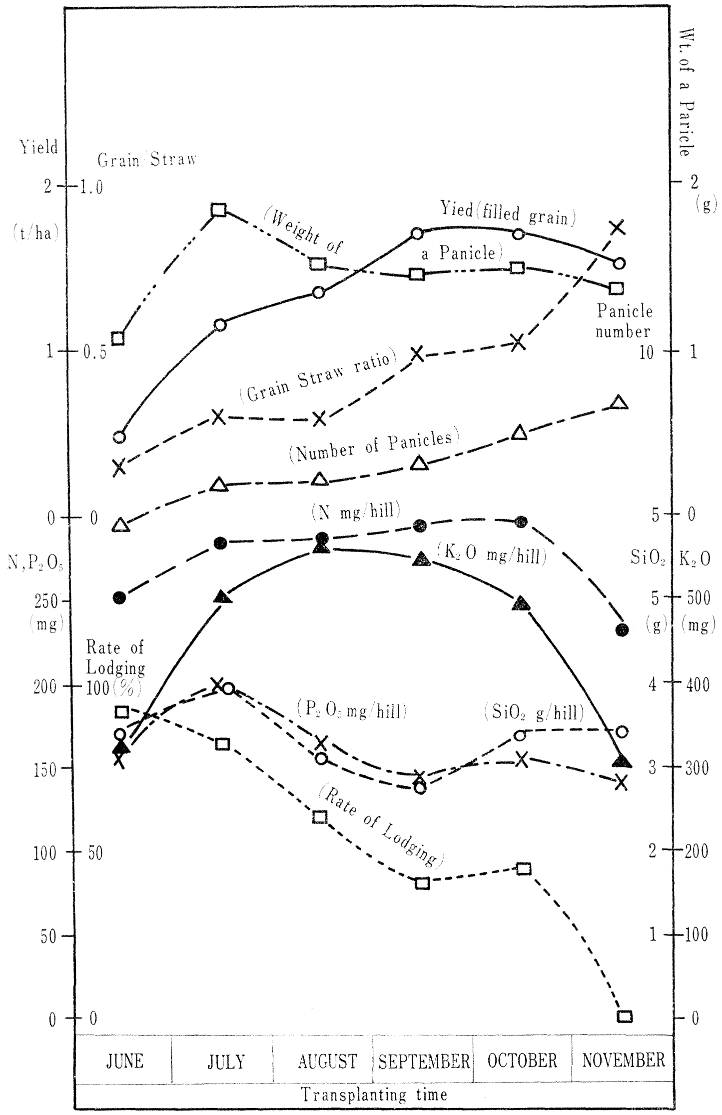


Fig. 20. Yield and nutrient absorption by plants at harvesting time

C) Rate of lodging

Delaying the transplanting time of photoperiod-sensitive variety shortened the plant height and consequently decreased the rate of lodging (Table 5). As lodging is inconsistent with high yield, decreased lodging is regarded as one of the advantages of later transplantation. Among tested 10 varieties Puang Nahk 16 showed high resistance to lodging.

D) Plant shape

Among 10 local varieties used, "Puang Nahk 16" developed a very good plant shape suitable for receiving sunlight most effectively as shown in Figs. 21-a~21-e. This variety has high resistance to lodging, good response to fertilizer application and high-grain yield as

Table 5. Rate of lodging at harvesting time

No.	Variety	Ttransplanting time					
		June 15	July 15	Aug. 15	Sept. 15	Oct. 15	Nov. 15
1	Gow Ruang-88	+++	+++	+++	+++	++	—
2	Gam Pai-41	+++	+++	++	++	++	—
3	Khao Pahk Maw-17	+++	+++	++	++	++	—
4	Muey Nawung-62M	+++	++	++	++	++	—
5	Dawk Mali-3	+++	++	++	+	+	—
6	Bai Lod-104	+++	+++	++	+	++	—
7	Nahng Mon-S4	+++	++	+	—	—	—
8	Leuang Tong-82	+++	+++	++	+	+	—
9	Puang Nahk-16	+	+	—	—	—	—
10	Leuang Pratew-123	+++	+++	++	+	++	—

Remarks: — No lodging + Slight lodgeing ++ Medium lodping +++ Heavy lodging

proved by TAKAHASHI (19). One of the reason for such superior performance of the variety can be attributed to its good plant shape.

E) Grain yield

Grain yield can be expressed as a product of two yield components; number of panicles and average weight of a panicle. Relationships between yield and yield-components are illustrated in Fig. 22.

It is clearly shown in Fig. 22 that the early transplanting caused a decrease in panicle number and a resulted increase in an average weight of panicle, while the late transplanting was effective in increasing number of panicles with a resulted decrease in average weight of panicle. In other words, higher yields obtained by late transplanting depend primarily on an increased number of panicles, though an average weight of a panicle was decreased. The nitrogen application was found effective in increasing both of number of panicles and average weight of panicle. However, when plants were transplanted early, the yield increase due to nitrogen dressing owed mainly to the increased average weight of panicle. On the other hand, when plants were transplanted lately, the yield increase owed mainly to the increased number of panicles.

F) Relationship between nutrient content and plant size

From the viewpoint of plant nutrition, the late-transplanting gives higher nutrient content of plants than that of early-transplanting as shown in Fig. 23. Therefore, the late-transplanting combined with nitrogen supply mainly as top-dressing will produce rice plants of small size but with high nutrient content. On the contrary, the early-transplanting combined with nitrogen supply mainly as basal-dressing will result in big plants with low nutrient contents. Big plants are usually characterized by either tall plant height, which is a main cause of lodging or heavy mutual shading of leaves, and liable to lower grain yields.

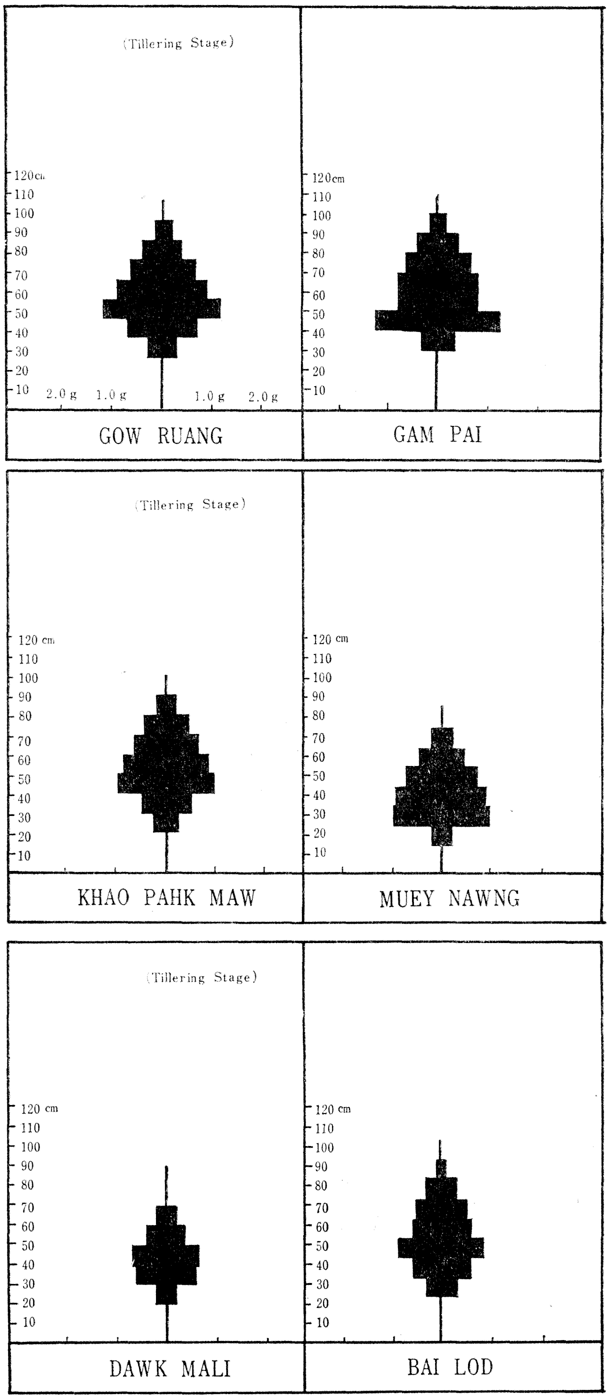


Fig. 21-a. Plant shape (at tillering stage)

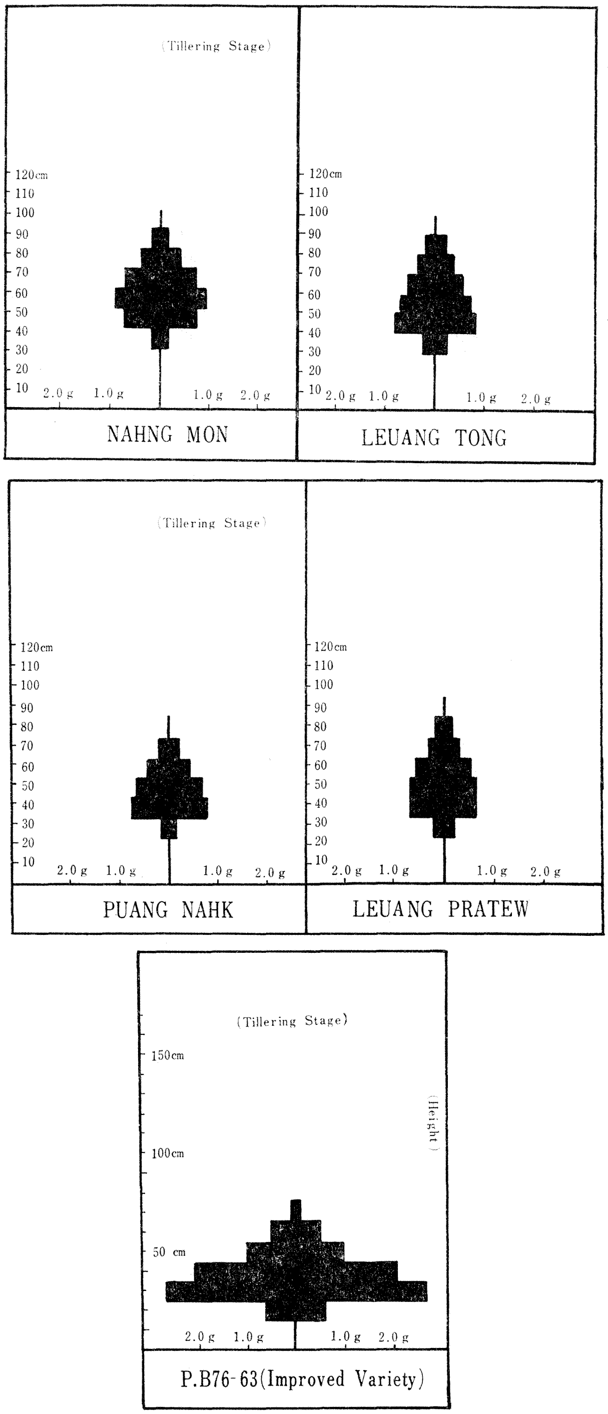


Fig. 21-b. Plant shape (at tillering stage)

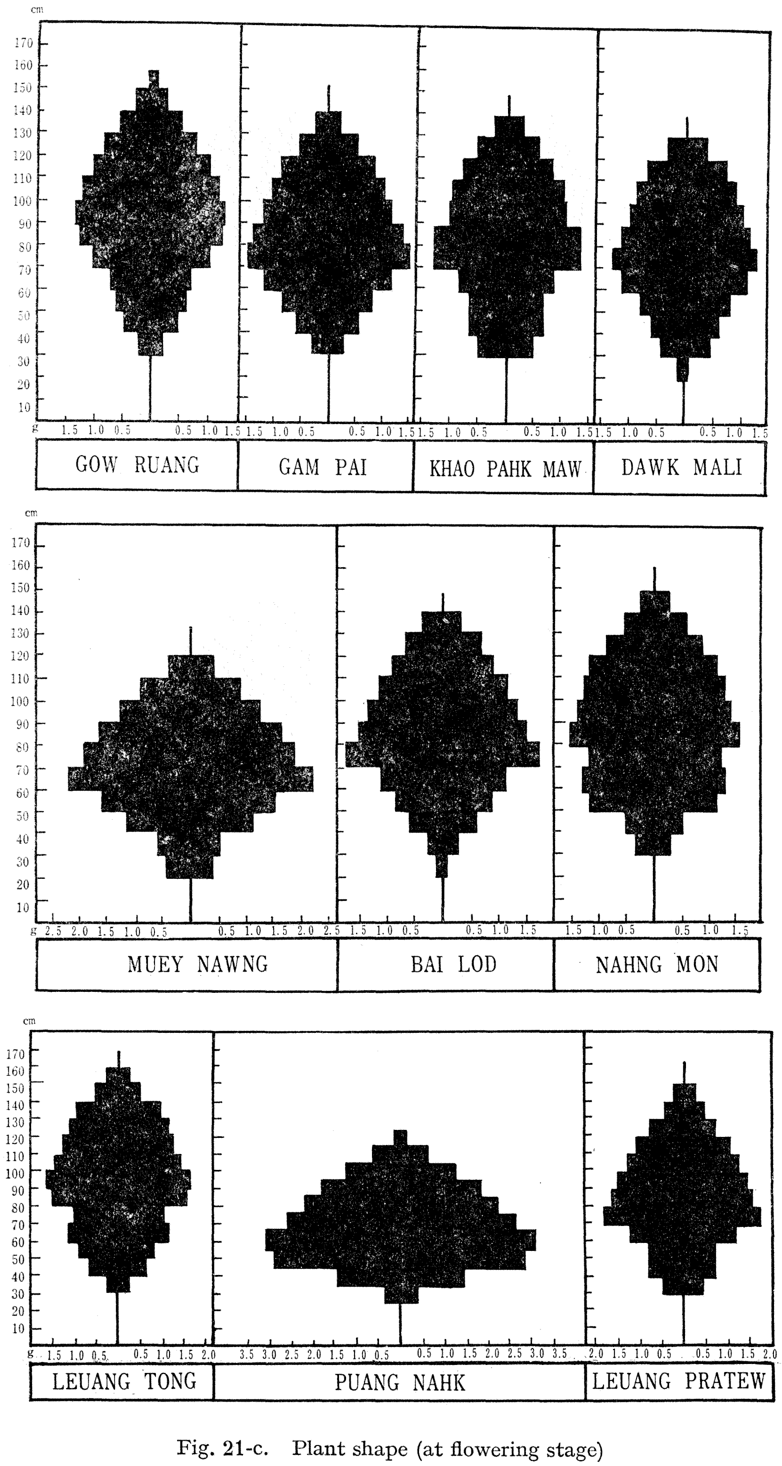


Fig. 21-c. Plant shape (at flowering stage)

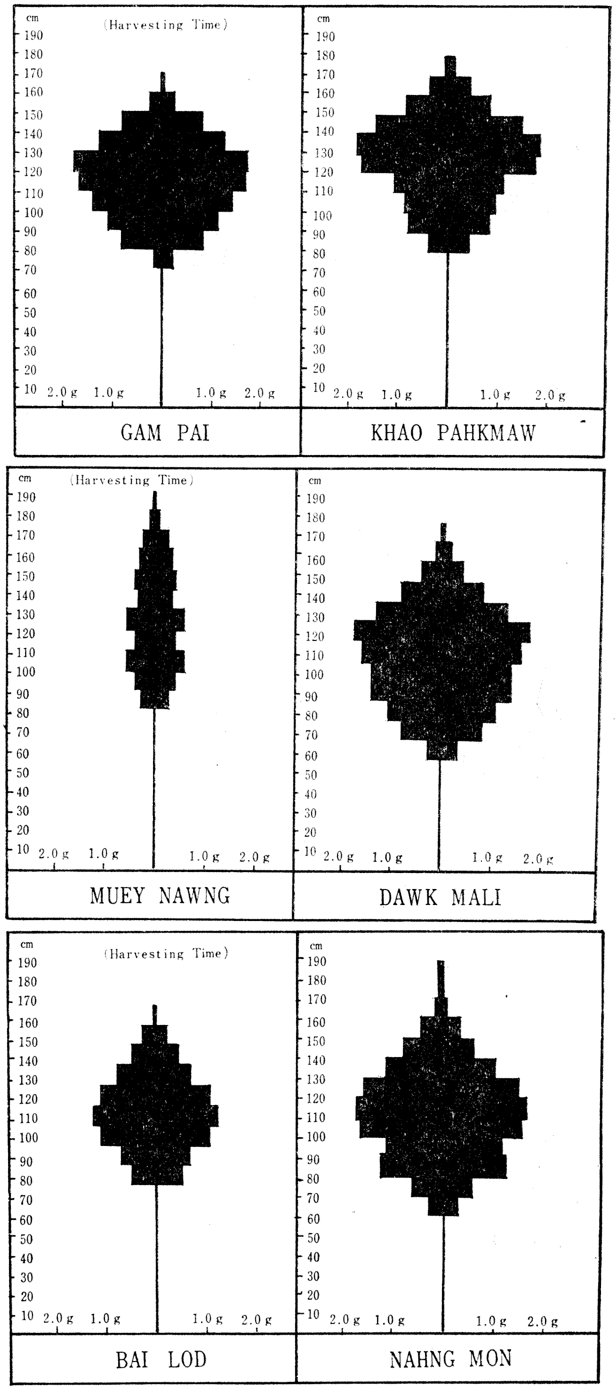


Fig. 21-d. Plant sharpe (at harvesting)

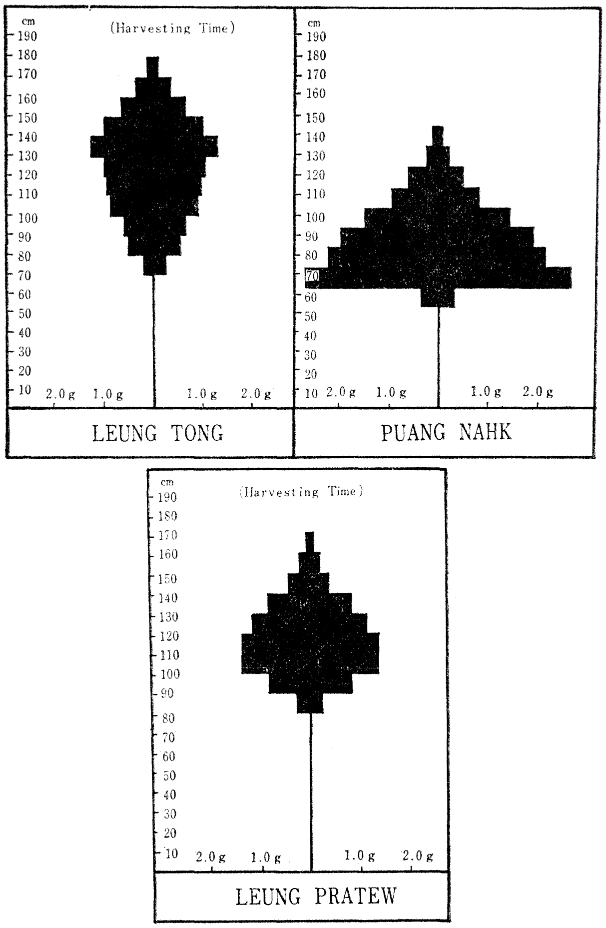


Fig. 21-e. Plant shape (at harvesting)

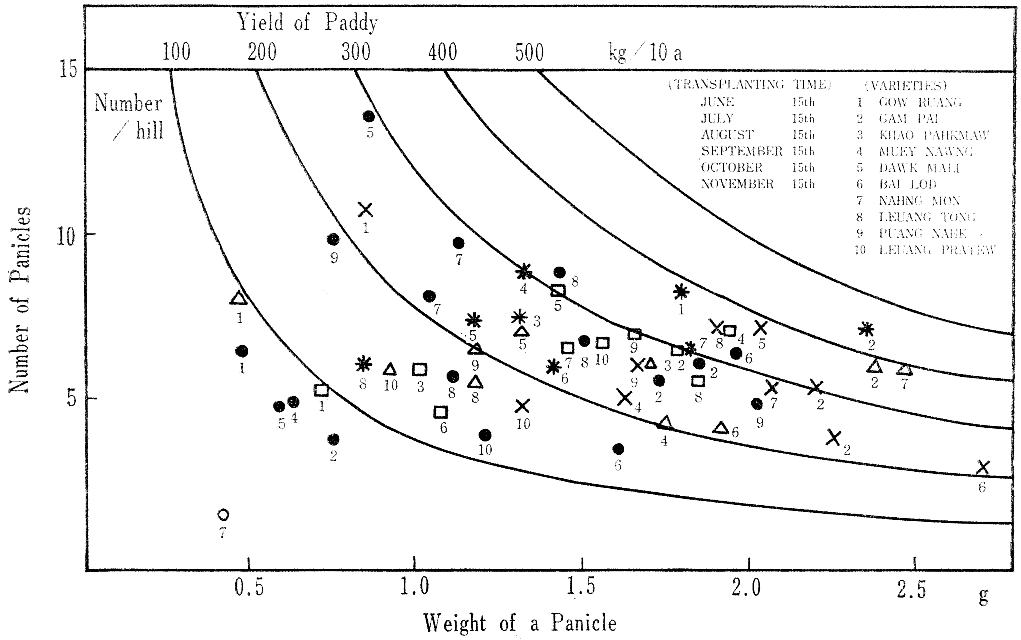


Fig. 22. Relationship among yield of paddy, number of panicles and weight of panicle

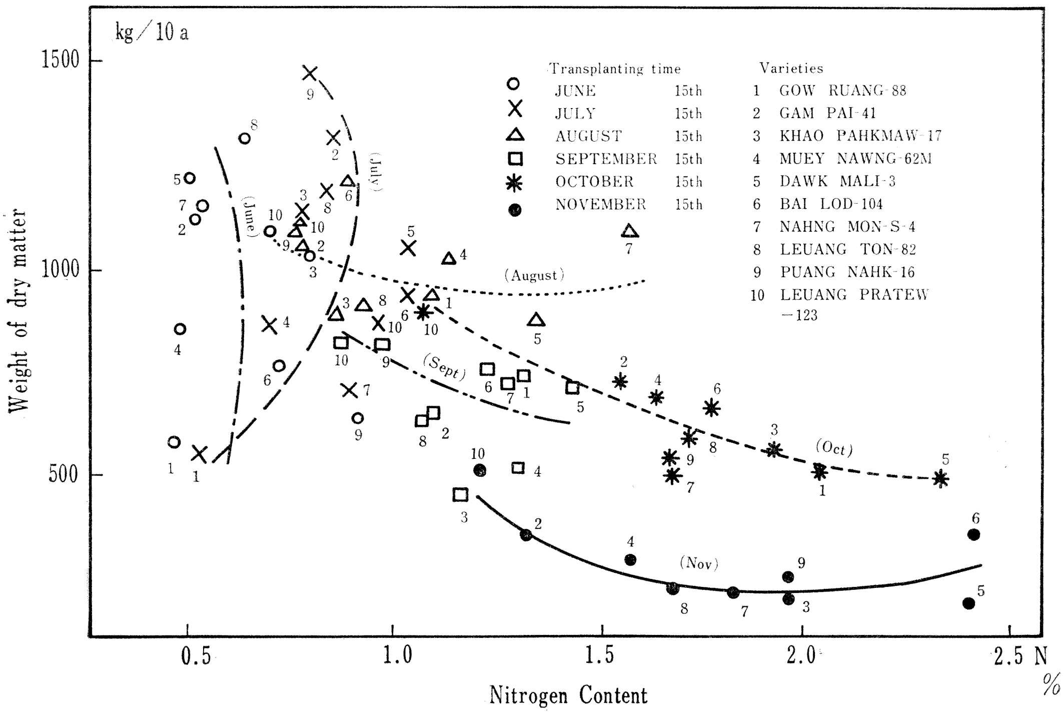


Fig. 23. Relationship between nitrogen content and weight of dry matter

GENERAL DISCUSSION

It has been reported by many authors that the heavy application of nitrogen under the tropical condition is very liable to induce heavy lodging and luxuriant vegetative growth.

From the result of this experiment, it was realized that the following three points are most important to improve the rice culture under a fertilized condition in the tropical region; 1) to secure an adequate number of panicles, 2) to prevent the plants from lodging and luxuriant growth, 3) to supply adequate nutrients at the middle and later stage of plant growth, in order to maintain appropriate nutrient contents at the later stage of growth.

MORIYA[5] and FUKUI[6] pointed out that the grain yield is primarily correlated to the number of panicles produced, and a shortage of number of panicles is a main cause of low yield in the tropical rice culture. The failure of getting sufficient number of panicles is not due to the poor tillering ability of plant itself, but mainly due to the die-back of late developed tillers caused by unfavorable conditions such as the shortage of sunlight, nutrient supply and so on, as indicated by low percentage of effective tillers to the total number of tillers. Because the long growth duration induces a marked decrease in percentage of effective tillers, the growth duration should be shortened to avoid such disadvantage.

Secondly, as MURAYAMA[7] proposed, the physiological conditions of rice plants at the flowering stage determines yield components and consequently the yield. Taking the number of grains for instance, SHIMIZU[8] found that there is a close relationship between the number of grains per unit area and the amount of nitrogen absorbed by rice plants up to the flowering stage.

The results of the present study indicate that the nutritional conditions of plants at the flowering stage can be improved by delaying the transplanting time. Thus, it can be concluded that the practice of late-transplanting can meet the three requirements, mentioned above, for obtaining high grain yield; (1) sufficient number of panicles, (2) no lodging and no luxuriant vegetative growth, and (3) good nutritional conditions of plants at the later stage of growth.

MURAYAMA clarified that rice plants grown in northern Japan have generally higher percentage of nitrogen with less straw weight than those grown in southern Japan. This fact implies that rice plants in northern regions can produce an equal number of grains with less straw weight as compared with those of southern regions. In other words, the rice plants in the northern regions have higher efficiency of productivity in terms of garin numbers produced per unit straw weight.

A number of difference in growth pattern observed between early-transplanting and late-transplanting is quite similar to the difference in growth pattern between southern and northern regions of Japan.

As pointed out by TAKAHASHI *et al.*, the shortening of growth duration caused by the late-transplanting with photoperiod-sensitive indica rice is induced almost exclusively by the shortening of the period from maximum-tiller-stage to the panicle-primordia-initiation stage whereas the period from transplanting to maximum tiller stage and from panicle primordia initiation stage to the maturity remain almost unchanged irrespective of the length of a whole growth duration.

The period from the maximum-tiller-stage to the primordia-initiation stage is known as a vegetative-lag stage, and during this period the number of tillers decreases, plants continue to grow taller, and nutrient contents continue to decrease, as observed in the present study.

Therefore as far as the length of this period is concerned, it is desirable to minimize it.

However, if the growth duration becomes too short to develop sufficient leaf area, to produce enough dry matter, and to absorb sufficient amount of nutrients, high yield can not be expected.

Importance of the length of growth duration in rice cultivation practice has already been pointed out by many workers (YAMAKAWA, VERGARA,[9] TAKAHASHI,[10] and TANAKA,[11] *etc.*). The result of the present study furnished a clear analysis of physiological significance of growth duration.

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