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Takeo KOYAMA, Chittana CHAMMEK and Natee NIAMSRICHAND

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ABSTRACT

To improve the growth and yield of rice crop, the behavior of nitrogen element in the soil-plant system should be clarified. Therefore, the tracer technique using ^{15}N was adopted to study the behavior of nitrogen in field experiments by distinguishing the supply of nitrogen from the soil nitrogen from that of fertilizer.

With the standard fertilizer application practice, *i.e.*, 37.5 kg N/ha for basal dressing at the time of planting and 37.5 kg N/ha for top-dressing at the panicle primordia initiation stage, an improved variety P.B. 76-63, absorbed 82 N kg/ha, 36% of which was derived from the fertilizer while the balance, 64% was from the soil nitrogen. It was also made clear that of the total quantity of nitrogen (30 kg N/ha) absorbed by plants from fertilizer N, about 1/3 of it was from the basal dressing and 2/3 from the top-dressing.

As the same amount of nitrogen was applied for both basal- and top-dressing, it can be said that the recovery rate of top-dressing nitrogen is just twice that of the basal dressing. The rate for the former was 54%, and that of the latter was only 27%. Some trials were carried out in order to improve, such a low recovery rate of the basal dressing nitrogen, and it was found that whole layer application method (fertilizer is mixed with top soil to the depth of 10 cm) gave a rate twice of that of top layer application method and the mixture of nitrification inhibitor raised the recovery rate of basal dressing by about 50%.

In the light of the high effectiveness of top-dressing in increasing yields a study have been made on the timing of top-dressing. The top-dressing applied at 25~30 days prior to the flowering was particularly effective for improved photoperiod non-sensitive varieties. The effectiveness was largely influenced by the length of growth duration. Namely, when the growth duration was prolonged by an early planting the earlier application than that indicated above gave the best result, whereas when the growth duration was around 130 days, same as that of improved photoperiod non-sensitive varieties, the proper application time of top-dressing came around 25~30 days prior to flowering just like improved varieties. Therefore, the proper time of top-dressing must be determined by considering the growth duration of plants, but it can be concluded that with improved varieties the proper time is around 25~30 days prior to flowering.

A study was made to know what is the reason for such high effectiveness of top-dressing observed in Bangkhen, and it was found that soil nitrogen was mineralized mainly during the period of early stage of plant growth: the percentage distribution of the mineralized soil nitrogen absorbed by plants was 60% during the period up to the end of tillering, 36% during the panicle formation stage, and 4% during the ripening period.

Compared with the percentage distribution of 45:27:28% observed with high-yielding Nagano soils in Japan, it is clear that the release of soil nitrogen during the late period is very low in the Bangkhen soil, and this can be a major reason for the high effectiveness of top-dressing of nitrogen on the Bangkhen fields.

The total amount of soil nitrogen mineralized during the growth duration of rice was 131 kg N/ha in the Bangkhen soil as compared to 249 kg N/ha in the Nagano paddy field. It can be said that nitrogenous soil fertility of the Bangkhen soil, which is regarded rather fertile, is not sufficient.

Another important finding obtained by the authors is that an application of fertilizer nitrogen promotes mineralization of soil nitrogen, and as the result uptake of soil nitrogen by plants is increased.

An application of basal dressing of nitrogen caused an increase in absorption of soil nitrogen by 7.7 kg N/ha and top-dressing resulted in an additional uptake of soil nitrogen of about 7.1 kg N/ha on the Bangkhen paddy soils. The total amount of soil nitrogen, absorbed additionally by plants as the effect of fertilizer application, constituted 18% of the total nitrogen absorbed by plants during a whole growth duration.

Accordingly, it is necessary to enhance nitrogenous soil fertility in order to raise further the yield level at Bangkhen field. The facts that nearly two thirds of the total nitrogen absorbed by plants grown in Bangkhen was derived from soil nitrogen and that the grain yields showed a very high correlation of $\gamma=0.90$ to the soil nitrogen absorbed up to the flowering time furnish a good evidence for that concept.

It is also import to know to what extent the soil nitrogen will be consumed by adopting double-cropping of rice in a rainy season. The authors' result indicated the consumption as much as 16%. Although the percentage may be lower than 16% with soils of higher fertility, yet this problem must not be neglected in practicing the double-cropping of rice.

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INTRODUCTION

Of many factors contributing towards the yield increase of rice, the fertilizer application is of great importance. Marked increase in rice yields that has been achieved so far throughout the world could be attributed to several major factors including the fertilizer application.

Of the commonly used fertilizer elements, nitrogen is the most important one, being an element required by crops in a substantial quantity in spite of a limited natural supply and directly responsible for plant growth and grain development.

In rice production researches, therefore, much emphasis has been placed on problems of nitrogen nutrition of plants and techniques of nitrogenous fertilizer application, such as optimum levels of nitrogen supply, time and methods of application including placement of application, *etc*.

Since a technique of nitrogen application varies with different environmental and cultural conditions, the proper technique has to be established in relation to a given local condition, although efforts for generalization are equally important at the same time.

As to the problems of nitrogen nutrition of rice plants and technique of nitrogenous fertilizer application in the tropical region much remains to be solved. Therefore, the authors carried out a series of field experiments by using the ^{15}N tracer technique in order to establish the rational nitrogen application technology for tropical rice in Thailand.

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I. Effect of the Nitrogenous Soil Fertility and its Liberation upon the Nitrogen Utilization by Rice Plants in Bangkhen Paddy Soil.

The lowland rice depends comparatively more on the nitrogen supply from soil resources than any other upland crop does. Usually, lowland rice plants utilize much more natural soil nitrogen than the applied fertilizer nitrogen.[1-3]

From the stand point of crop production, nitrogen element has a most important and unique place among the nutrient elements in soils. Accordingly, the fertility of paddy soils is, in its narrow sense, regarded as a nitrogen supplying potential of soil. Many studies[4,5] on soil fertility problems have been focused on the availability and the recovery by crops of soil organic nitrogen, because the grain yield of rice is primarily determined by the liberation of this organic nitrogen.

Suzuki, S., Sakai, H., and Dei, Y.,[6] reviewed this subject recently and they stated that the nitrogen liberated from paddy soils during the rice growing period played the most important and crucial role, because in Japan rice plants absorbed 75 kg/ha of natural soil nitrogen in average, and this constituted 77% of total nitrogen in the plant at the harvesting time.

The authors carried out a series of investigation to clarify the effect of soil nitrogen and its liberation in Bangkhen paddy soil upon the nitrogen utilization of rice plants.

In order to distinguish the nitrogen originated from the soil from the nitrogen supplied by fertilizer, ^{15}N, a heavy nitrogen was used. With the hope that the results to be obtained can be applied directly to cultural practice, the research was carried out by a field experiment. Moreover the experimental results were described in comparison with the case of Japan.

METHOD

1) Location of experiment:

The experiment was conducted in the paddy field of Bangkhen Rice Experiment Station in Thailand.

2) Characteristics and properties of the soil:

The soil of this experimental field belongs to the series of Bangkhen Dark Heavy Clay, profiles of which are not well developed and clay contents are extremely high. Content of total nitrogen, total carbon, and available phosphorus and pH are low. Field trials indicate that this soil shows good response to nitrogen and phosphorus application as shown in Table 1.

3) Treatment:

The design of fertilizer treatment is as follows. In every treatments same amount of phosphorus and potassium was applied as basal dressing, but nitrogen was applied by the following three different methods:

Table 1. Chemical Properties of Bangkhen soil

Layer (Depth)		I (0～8 cm)	II (8～25 cm)	III (25～38 cm)	IV (38～80 cm)
pH (H_2O)		5.0	4.9	5.0	5.7
Organic matter %		2.45	—	—	—
CEC me		28.1	—	—	—
Texture	Sand %	12.7	—	—	—
	Silt %	16.6	—	—	—
	Clay %	70.7	—	—	—
Total-N %		0.13	0.08	0.05	0.02
Fractination of Organic-N*	Fraction-I %	8.2	—	—	—
	Fraction-II %	39.7	—	—	—
	Residual %	52.1	—	—	—
KCL exch. NH_3-N mg/100 g D.S.		1.26	—	—	—
Ammoniacal N** in anaerobic incubation mg/100 g D.S.		6.8	—	—	—
Total-P (PPM)		284	261	174	284
Available-P (PPM)***		3.9	1.3	1.3	0.4
Available-K (PPM)		130	—	—	—
Nitrogen absorption coefficient N mg/100 g D.S.		564	524	525	537
Phosphorus absorption coefficient P_2O_5 mg/100 g D.S.		998	1260	1260	1180
Exch. Ca me/100 g D.S.		7.6	—	—	—
Exch. Mg me/100 g D. S.		13.3	—	—	—
Exch. K me/100 g D.S.		0.91	—	—	—

* Stewart method.[23]
** Air-dried soils were anaerobically incubated at room temperature for four weeks.
*** Bray & Kurz No. 2

a) Basal application—Two levels of dosage, 37.5 kg and 75 kg/ha of nitrogen, were used. The application was made one day before transplanting as basal dressing.

b) Split application—A full dosage of 75 kg/ha of nitrogen was split into 37.5 kg of basal application and 37.5 kg of top-dressing. The top-dressing was applied at the panicle primordia initiation stage of rice plants, *i.e.*, about 30 days before flowering. All the basal dressings were applied by deep placement and top-dressing was done as surface application.

c) No application—No nitrogen applied.

In this experiment nitrogen fertilizer was labelled by 5.1% excess ^{15}N isotope.

4) Replications:

Three replications for each treatment.

5) Area of plot:

The area of each plot was 25 m^2 (5 m×5 m) in which a small sub-plot surrounded by galvanized iron sheet was set.

^{15}N enriched ammonium sulphate was applied in this small sub-plot of 0.8 M^2 (0.8 M×1.0 M).

6) Variety:

P.B. 76-63 (non photoperiod-sensitive improved rice variety).

7) Transplanting date: July 1.

8) Spacing: 20×20 cm.

9) **Number of seedlings**: three per hill.

10) **Chemical analysis**:

Nitrogen was determined by Kjeldahl distillation method.

The samples labelled by ^{15}N were condensed to 2~3 ml after distillation, then subjected to isotope-ratio measurement.

A-value was calculated from the following equation.[7]

$$A = \frac{M(100-C)}{C}$$

where

A= Amount of available nitrogen in the soil except fertilized nitrogen (A-value)

B= Amount of fertilizer ^{15}N applied

C= Proportion of nitrogen in the plant derived from fertilizer ^{15}N.

11) **Nagano paddy soil**:

a) Characteristics and properties:

The soil belongs to the Ogata soil series, which is known for its high productivity. It has a very fine texture and the presence of manganese concretion can be seen in the sub-soil.

Clay mineral consists of monmolline, and both the nitrogen and phosphorus fertility are very high. Loss of applied nitrogen and phosphorus is also small.

b) Treatment:

82.5 kg N as ammonium sulfate, 56.3 kg P_2O_5 as superphosphate and 56.3 kg K_2O as potassium sulfate per hactare were applied as basal dressing, according to the conventional practice in this district.

All fertilizers were spread on the soil surface and then mixed into furrow slice.

c) Replication:

Three replications were used.

d) Area of one plot:

The area of each plot was 10.3 m^2, containing one internal plot of 0.735 m^2, in which $(^{15}NH_4)_2SO_4$ was applied.

e) Variety: Norin No. 17

f) Transplanting: July 2

g) Spacing: 15×30 cm

h) Number of seedlings: three per hill

i) Harvesting: October 21

12) **Saitama paddy soil**:

a) Characteristics and properties:

The soil belongs to the Ageo soil series, and it consists of a volcanic ash horizon, grey or greyish brown horizon having a medium texture.

Based on the nature of allophanic clay, much humus is accumulated in this soil and the whole furrow-slice becomes a severely reduced condition. The soil is very low in phosphorus fertility.

b) Treatment:

According to the conventional practice, 60 kg N, 112.5 kg P_2O_5 and 112.5 kg K_2O were applied basally per hectare.

All basal fertilizers were spread on the soil surface and mixed with furrow slice.

In addition, 15 kg of nitrogen were applied as top-dressing at the panicle primordia initiation stage.

c) Replication:

Three replications were used.

d) Area of one plot:

The area of a plot was 13.8 m^2, containing one internal plot of 0.735 m^2, in which $(^{15}NH_4)_2$-SO_4 was applied.

e) Variety: Norin No. 25

f) Transplanting date: June 22

g) Spacing: 15×30 cm

h) Number of seedlings: Three per hill

i) Harvesting date: October 31

RESULTS

A) Fate of nitrogen in the Bangkhen paddy soil.

Recovery of fertilizer nitrogen and soil nitrogen in rice plants was determined and presented in Table 2. In the plot of split application of nitrogenous fertilizer at the Bangkhen paddy field, soil received 75 kg/ha of fertilizer nitrogen, of which 29.8 kg/ha were utilized by the rice plants. Since the rice plants absorbed a total of 81.7 kg/ha of nitrogen, the balance of 51.9 kg/ha must have been originated from the mineralized soil nitrogen.

Table 2. The fate of nitrogen in paddy soils

	BANGKHEN (Thailand)				NAGANO	SAITAMA
	37.5 kg/ha N all basal	75 kg/ha N all basal	75 kg/ha N split 2 times	Non-N	82.5 kg/ha N all basal	75.0 kg/ha N split 2 times
Applied-^{15}N	37.5	75.0	75.0	0	82.5	75.0
Soil-^{14}N in rice plants	44.8	58.1	51.9	37.1	77.9	65.5
Applied-^{15}N in rice plants	6.2	14.0	29.8	0	25.8	32.0
$^{14}N+^{15}N$ in rice plants	51.0	72.1	81.7	37.1	103.7	97.5
Immobilization and lost-^{15}N from soil-plant system	31.3	61.0	45.2	0	56.7	43.0

In the case of the basal application at the Bangkhen field, soil received 75 kg/ha of fertilizer nitrogen, of which only 14.0 kg/ha N were utilized by plants. On the other hand, in the experiment at Nagano,[8] soil received 82.5 kg/ha of fertilizer nitrogen, of which 25.8 kg/ha were utilized by rice plants, whereas the plants utilized as much as 77.9 kg/ha of native soil nitrogen. Utilization of soil nitrogen in the Nagano soil is apparently much more than those of the Bangkhen soil.

In the case of Saitama paddy soil,[9] rice plants utilized 97.5 kg/ha of nitrogen of which 32 kg/ha were derived from applied fertilizer nitrogen, and the balance of 65.5 kg/ha were originated from native soil nitrogen.

The difference between recovered ^{15}N and applied ^{15}N indicates the sum of the amount of immobilized ^{15}N and of the loss of fertilized ^{15}N from the soil and plant system. However, it is difficult to distinguish the immobilized ^{15}N from the loss of fertilizer ^{15}N.

Results of several tracer studies[10] so far reported indicated that about 25 to 60% of applied nitrogen remained immobilized in soil. The amount of immobilized nitrogen increases with the increase in amount applied[11] and decreased with the increase in nitrogen-suppling capacity of soils.[12] However, results of the experiment conducted in parallel indicated that, the recovery rate of fertilizer ^{15}N applied by the deep placement method (fertilizer was mixed into the top soil up to 10 cm depth) was twice that of ^{15}N applied by the surface application method, and the mixture of nitrification inhibitor (2-amino-4-chloro-

6-methyl pyrimidine) increased the recovery rate by about 50% in the Bangkhen field as shown in Table 3.

The loss of fertilizer ^{15}N through denitrification would be a main cause of low recovery of fertilizer-^{15}N in rice plants observed with the Bangkhen paddy soil under submerged condition.

In Japan, the losses ranging from 30% to more than 50% were reported[13] as a result of surface application. In India, ABICHANDANI and PATNAIK[14] evaluated the losses due to denitrification to be about 20 to 40%.

Table 3. Utilization of ^{15}N in plants by different methods of basically dressed ^{15}N (N g/m^2)

Treatment	$^{15}N+^{14}N$ in plants	^{15}N in plants	Plant recovery of ^{15}N (%)
Deep placement	3.94	1.31	17.5
Surface application	2.06	0.61	8.2
Nitrification-inhibitor added*	3.70	0.88	11.7

Remarks: Plant samples were taken 33 days after transplanting.
* 2-amino-4-chloro-6-methyl pyrimidine

B) Effect of nitrogenous soil fertility upon the nitrogen utilization by plants.

To evaluate the effect of applied fertilizer nitrogen, it is necessary to clarify the effect of the native soil-nitrogen.

T. KOYAMA derived following equation by the theory of isotope dilution.

$$N = Nf + Ns$$

$$Nf = \frac{R \cdot M}{100} = \frac{C \cdot N}{100}$$

$$C = \frac{R \cdot M}{N}$$

$$A = \frac{M(100-C)}{C}$$

$$N = \frac{R \cdot M}{C} = \frac{R}{100}(A+M)$$

where

N =Amount of the nitrogen utilized by plants
Nf =Amount of the nitrogen in plant derived from the fertilizer ^{15}N
Ns =Amount of the nitrogen in plant derived from the soil
R =Plant recovery rate of the fertilizer ^{15}N
M =Amount of the fertilizer ^{15}N applied
A =Amount of the available nitrogen in the soil (A-value)
C =Proportion of fertilizer ^{15}N by total nitrogen in the plant

According to this theoretical formula, amount of nitrogen utilized by plants is as a function of the plant recovery rate of fertilizer ^{15}N, the amount of available nitrogen in the soil (A-value) and the amount of fertilizer ^{15}N applied in the soil.

As shown in Table 4, within the range of standard dose of fertilizer application, the A-value of the soil is about 2 to 7 times the amount of fertilizer nitrogen applied. Thus it is clear that the nitrogen utilization by plants is largely affected by the nitrogenous soil fertility of paddy fields.

Table 4. Nitrogen utilization in rice plants as affected by applied-^{15}N, plant recovery rate of ^{15}N, contribution of ^{15}N, dilution factor and A-value in different paddy soils.

Location	Applied-^{15}N (N kg/ha) (M)	$^{14}N+^{15}N$ in plants (N kg/ha) (N)	Recovery % (R)	Contribution-^{15}N % (C)	Dilution factor (D)	A-value (N kg/ha) (A)
BANGKHEN	75.0*	81.7	39.7	36.5	1.74	131
	37.5	51.0	16.5	12.2	7.23	271
	75.0**	72.1	18.7	19.4	4.15	311
SAITAMA	75.0	97.5	42.7	32.8	3.05	153
NAGANO	82.5	103.7	31.3	24.9	4.02	249

* Split-2-time
** All basal

C) Effect of fertilizer nitrogen on the increase in soil nitrogen uptake.

An interesting fact that the plant uptake of soil nitrogen is increased by the addition of fertilizer nitrogen is clearly observed; The increased soil nitrogen uptake of plants was obtained by the difference between the soil nitrogen removed by the plants from control plot (no-nitrogen) and that removed from fertilized plot. In the plot with split application of fertilizer, it was found that the plant uptake of soil nitrogen was increased by about 7.7 kg/ha due to the addition of basal-nitrogen, and it was also observed that an increase in uptake of soil nitrogen of about 7.1 kg/ha was caused by the addition of nitrogen as top-dressing in the Bangkhen paddy soil.

When all the 75 kg/ha of fertilizer nitrogen were dressed as basal, an increase in uptake of soil nitrogen as much as 21 kg/ha was induced, as shown in Table 4.

Several investigators[15–17] have observed that, with an increase in the amount of mineral fertilizer nitrogen applied to soils under green-house conditions, there was usually an increase in the amount of soil nitrogen recovered in the harvested crop, and also an increase in the immobilization of added nitrogen in the soil. This occurs with both ammonia and nitrate sources of nitrogen.

It is not known whether such an increase in soil nitrogen uptake caused by an addition of fertilizer nitrogen is a result of so-called "priming effect" defined by Broadbent[18–20]

Table 5. The composition of nitrogen in rice plants originated from different nitrogen sources (Bangkhen paddy soil)

Nitrogen sources	37.5 kg/ha ^{15}N all basal		75 kg/ha ^{15}N all basal		75 kg/ha ^{15}N split 2 times		No nitrogen	
	N kg/ha	Index %	N kg/ha	Index %	N kg/ha	Index %	N kg/ha	Index %
Total N in plants	51.0	100	72.1	100	81.7	100	37.1	100
Fertilizer ^{15}N in plants	6.2	12	14.0	20	29.8	36	0	0
1) Derived from basal dressing-^{15}N	6.2	12	14.0	20	9.8	12	0	0
2) Derived from top dressing-^{15}N	0	0	0	0	20.0	24	0	0
Soil ^{14}N in plants	44.8	88	58.1	80	51.9	64	37.1	100
1) Soil ^{14}N in plants with no addition of fertilizer-^{15}N	37.1	73	37.1	51	37.1	46	37.1	100
2) Increased plant uptake of soil-^{14}N by addition of fertilizer-^{15}N	7.7	15	21.0	29	14.8	18	0	0

et al., *i.e.*, a stimulating effect of inorganic fertilizer nitrogen on the mineralization of soil organic nitrogen, or a result of root growth promotion by an added fertilizer nitrogen.

Whatever the mechanism may be, the increments of soil nitrogen uptake induced by the addition of fertilizer nitrogen in the Bangkhen soil constituted as much as 15~29% of the total nitrogen contained in plants as shown in Table 5.

D) Contribution of fertilizer nitrogen to the plant nitrogen at different stages of growth.

At Bangkhen, nitrogen which came from the fertilizer shared 33% of the total plant nitrogen at the tillering stage, when 37.5 kg/ha of nitrogen were applied as basal-dressing, but the share decreased to as low as 12% at the harvesting time, when the additional nitrogen was not applied. However, the top-dressing of additional 35 kg/ha of nitrogen applied at the panicle primordia initiation stage resulted in a remarkable increase of the share. As shown in Table 6, the share in this case was 37%. Basal dressing of 75 kg/ha of nitrogen without top-dressing resulted in the share of fertilizer nitrogen as low as 20%.

Table 6. Contribution percentages of fertilizer nitrogen at the different stages of growth

Growth stage	BANGKHEN (Thailand) (Heavy clay soil)			NAGANO (Clay laom soil)	SAITAMA (Volcanic ash soil)
	37.5 kg/ha ^{15}N all basal	75 kg/ha ^{15}N all basal	75 kg/ha ^{15}N split 2 times	82.5 kg/ha ^{15}N all basal	75 kg/ha ^{14}N split 2 times
Tillering[1)]	33%	58%	33%	44%	55%
I.P.P.[2)]	22	34	48	44	49
Flowering	12	23	39	31	42
Harvesting	12	20	37	25	33

1) At 30-day-later transplanting.
2) At panicle primordia initiation (30-day-before flowering)

Thus, it is made clear with the Bangkhen soil that the share of nitrogen derived from fertilizer to the total plant nitrogen becomes very low, when no additional nitrogen was supplied as a top-dressing. This fact indicates that the utilization of basally applied fertilizer nitrogen is very low in this soil at the later stages of plant growth.

On the other hand, in the Nagano and Saitama soils, the percentage contribution of fertilizer nitrogen to the plant nitrogen is definitely higher than that of the Bangkhen soil, in spite of the fact that these two soils release a large amount of soil nitrogen during the later stages of plant growth.

It is concluded, therfore, that the application of top-dressing of nitrogen is essential to increase grain yield, and that the yield-increasing effect of top-dressing is remarkable with the Bangkhen soil.

E) Amount of soil nitrogen utilized by plants at different stages of growth.

In Bangkhen soil, rice plants in the split application plot observed 42.5 kg/ha of nitrogen during the vegetative growth phase of which 33.0 kg/ha were native soil nitrogen, as shown in Table 7.

The uptake of nitrogen during the reproductive growth phase was 39.7 kg/ha, of which 17.3 kg/ha were derived from soil nitrogen, but during the ripening growth phase the balance-sheet of nitrogen in plants showed a little negative value, and the plants utilized as little as 1.6 kg/ha of soil nitrogen.

On the other hand, when nitrogen top-dressing was not applied, a stagnancy of nitrogen utilization took place as early as reproductive phase.

On the contrary, in the Nagano and Saitama soils, rice plants well utilized soil nitrogen

Table 7. **The amount of soil-^{14}N and fertilizer-^{15}N utilized by the plant during each growth stage** (N kg/ha)

Growth stage	BANGKHEN (heavy clay soil) 37.5 kg/ha N all basal			BANGKHEN 75 kg/ha N all basal			BANGKHEN 75 kg/ha N split 2 times		
	$^{15}N+^{14}N$ in plants	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$ in plants	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$ in plants	^{15}N from fertilizer	^{14}N from soil
Vegetative[1)]	42.5	9.5	33.0	47.2	15.8	31.4	42.5	9.5	33.0
Reproductive[2)]	4.7	−3.9	8.6	30.3	1.9	28.4	39.7	22.4	17.3
Ripening[3)]	3.8	0.6	3.2	−5.4	−3.7	−1.7	−0.5	−2.1	1.6

Growth stage	BANGKHEN (heavy clay soil) No-N			NAGANO (Clay loam soil) 82.5 kg/ha N all basal			SAITAMA (Volcanic ash soil) 60 kg/ha N basal+ 15 kg/ha N top-dressing		
	$^{15}N+^{14}N$ in plants	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$ in plants	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$ in plants	^{15}N from fertilizer	^{14}N from soil
Vegetative[1)]	28.8	—	28.8	62.7	27.6	35.1	54.3	26.8	27.5
Reproductive[2)]	3.9	—	3.9	18.2	−2.9	21.1	23.2	5.6	17.6
Ripening[3)]	4.4	—	4.4	22.8	1.1	21.7	20.0	−0.4	20.4

1) From transplanting to initiation of panicle primordia.
2) From initiation of panicle primordia to flowering.
3) From flowering to harvesting.

throughout their whole growth period.

Thus, the ^{15}N tracer field experiment demonstrated clearly a remarkable difference in the utilization of soil nitrogen by rice plants during the reproductive growth phase between the Bangkhen soil and soils of Nagano and Saitama.

Although there was no distinct difference in the utilization of soil nitrogen and fertilizer nitrogen between these soils during the vegetative growth phase, a marked difference was observed during the later stages of growth after panicle primordia initiation; almost no utilization of soil nitrogen with the Bangkhen soil in contrast to other soils which released a large amount of soil nitrogen (Table 8).

Table 8. **Translocation of nitrogen in the plants from the flowering stage to harvesting time** (N kg/ha)

Growth stage	BANGKHEN (37.5 kg/ha N applied as basal) (37.5 kg/ha N applied at I.P.P. stage) N in straw			N in grains		
	^{15}N from basal-^{15}N	^{15}N from top dressing-^{15}N	^{14}N from soil	^{15}N from basal-^{15}N	^{15}N from top dressing-^{15}N	^{14}N from soil
Flowering	8.5	19.9	42.7	1.1	2.8	7.6
Harvesting	3.1	6.8	17.5	6.7	13.2	34.4
Difference	−5.4	−13.1	−25.2	5.6	10.4	26.8
Balance			(−0.9)			

Growth stage	SAITAMA (60 kg/ha N applied as basal) (15 kg/ha N applied at I.P.P. stage) N in straw			N in grains		
	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$
Flowering	26.6	36.0	62.6	5.9	9.3	15.2
Harvesting	12.2	25.2	37.4	20.0	40.5	60.5
Difference	−14.4	−10.8	−25.2	14.1	31.6	45.3
Balance			(+20.1)			

Growth stage	NAGANO (82.5 kg/ha N applied as basal) N in straw			N in grains		
	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$	^{15}N from fertilizer	^{14}N from soil	$^{15}N+^{14}N$
Flowering	20.7	47.3	68.0	4.0	8.9	12.9
Harvesting	11.1	32.9	44.0	14.7	45.8	60.5
Difference	−9.6	−14.4	−24.0	10.7	36.9	47.6
Balance			(+23.6)			

This difference can be attributed to the fact that the Bangkhen soil releases soil nitrogen mainly in an early stage, while the soils of Nagano and Saitama are able to release nitrogen continuously up to the end of plant growth. This nature of the Bangkhen soil is observed evidently in the no-fertilizer plot where rice plants absorbed 28.8 kg/ha of soil nitrogen during the vegetative phase, but only 3.9 kg/ha during the reproductive phase, and 4.4 kg/ha during the ripening phase.

There is a question on the possibility that the ability of plant roots to absorb soil nitrogen might have been reduced by some damage to roots, so that plants can not utilize soil nitrogen, even when the soil itself continues to release soil nitrogen. However, this is not the case, because, as shown in Table 9, plants showed a continued utilization of fertilizer nitrogen during the later stages of growth.

Table 9. Plant recovery of applied ^{15}N for 10 days after dressing

Time of application	Applied-^{15}N (kg/ha)	Utilized-^{15}N in plants (kg/ha)	Plant recovery rates of ^{15}N (%)
40 days before flowering	37.5	17.0	45.3
30 days before flowering	37.5	24.9	66.4
20 days before flowering	37.5	21.1	56.3
10 days before flowering	37.5	26.3	70.1
Flowering time	37.5	28.9	77.1
10 days after flowering	37.5	24.5	65.3

Consequently, it is clear now that a very few utilization of soil nitrogen by plants during the later stages of plant growth with the Bangkhen soil is not caused by a lowering of root ability to absorb nitrogen, but due to the very limited availability of soil nitrogen.

Numerous experimental data with Japanese paddy soils indicated that the mineralization of soil nitrogen is largely affected by the temperature of soils. The higher is the soil temperature after flooding, the faster the mineralization of soil nitrogen to ammonia;[21] the mineralization increases remarkably at soil temperature exceeding 20 °C.

In the northeast district of Japan, soil temperature is relatively low at an early stage of plant growth as compared with other districts. Accordingly, plants usually, at an early half of their growing period, absorb about 20~30% of the total soil nitrogen to be utilized by plants up to the harvest time. On the contrary, in the southeast district of Japan where soil temperature is rather high, plants absorb during an early half of growth over 50% of the total soil nitrogen to be utilized by plants.

Thus, regional differences in soil nitrogen mineralization occur mostly owing to the difference in soil temperature of each region. It is therefore easily understood that tropical soils like the Bangkhen soil are characterized by an early release of soil nitrogen followed by the exhausted availability of it, particularly when the soil organic matter content is low.

Table 10. The release of soil nitrogen at several growth phase

<table>
<tr><th rowspan="2">Growth phase</th><th colspan="2">JAPAN</th><th colspan="4">THAILAND (Bangkhen)</th><th rowspan="2">Optimum release of soil nitrogen</th></tr>
<tr><th>Northeast district</th><th>Southwest district</th><th>37.5 kg/ha all basal</th><th>75 kg/ha all basal</th><th>75 kg/ha split 2 times</th><th>No-N</th></tr>
<tr><td>Active vegetative phase[1)]</td><td>6</td><td>15</td><td>21</td><td rowspan="2">31</td><td>21</td><td>17</td><td>5~6</td></tr>
<tr><td>Vegetative lag phase[2)]</td><td>11</td><td>15</td><td>12</td><td>12</td><td>12</td><td>11~14</td></tr>
<tr><td>Reproductive phase[3)]</td><td>26</td><td>17</td><td>9</td><td>28</td><td>17</td><td>4</td><td>24~31</td></tr>
<tr><td>Ripening phase[4)]</td><td>22</td><td>9</td><td>3</td><td>−2</td><td>2</td><td>4</td><td>7~10</td></tr>
</table>

1) During one month after transplanting.
2) From one month to the initiation of panicle primordia.
3) From the initiation of panicle primordia to the flowering.
4) From the flowering to the harvesting.

When the soil nitrogen release pattern of the Bangkhen soil is compared with the optimum one that was summarized in Japan,[22] it is apparent that the liberation of soil nitrogen is substantially scarce in the Bangkhen soil at the later stage of growth, as shown in Table 10.

SUMMARY

Using ^{15}N as a tracer, a field experiment was conducted at Bangkhen paddy field with different methods of nitrogenous fertilizer application to know the effect of nitrogenous soil fertility and its liberation on the nitrogen utilization by rice plants.

It was made clear that soil nitrogen release during the rice growing period played the most important and crucial role in rice production.

Nitrogen derived from the soil nitrogen constituted as much as 63~88% of the total plant nitrogen at the harvesting time. However that amount of soil-derived nitrogen in plants was absorbed mostly during the early half of growth, because the Bangkhen soil is characterized by an early release of soil nitrogen followed by the exhausted availability of it. This pattern of soil nitrogen release is most probably attributable to the high soil temperature under the tropical climate.

II. Effect of Double-Cropping of Rice Practiced in a Rainy Season upon the Nitrogenous Soil Fertility of Bangkhen Paddy Field

Among many measures to increase rice production per unit area, multiple cropping of rice is considered to be one of the most effective method under the tropical climate. In Thailand temperature and sunlight are sufficient for practicing multiple cropping of rice in a year. However, under the present condition of rice growing,[24] the area of rice cropping in the dry season is extremely restricted because of the limited availability of irrigation water, and the mono-cropping of photoperiod-sensitive local rice varieties in the rainy season is generally prevalent.[25] The authors consider that, the double-cropping of non-phtoperiod-sensitive rice varieties in the wet season could be the most practical method of increasing production because it can get rid of the problem of water supply.

Tropical paddy soils are, in general, characterized by the low soil fertility and rice culture has been practiced with meager fertilizers for centuries. When a system of the successive double-cropping of rice in the rainy season is introduced into farmer's practice, the problem of soil fertility maintenance will definitely become most serious. This experiment was carried out to look into the effect of double-cropping of rice in the rainy season on the nitrogeneous soil fertility.

METHOD

1) Location of experiment:

The experiment was conducted in the paddy field of Bangkhen Rice Experiment Station in Thailand.

2) Characteristics and properties of the soil:

Same as already described in the chapter 1.

3) Variety:

P.B. 76-63 Improved non-photoperiod-sensitive non-glutinous rice variety.

4) Spacing: 20×20 cm

5) Number of seedling: three per hill

6) Design of fertilizer application:

Three different treatments were given. The first one was the no-nitrogen plot, which received potassium and phosphate, but not nitrogenous fertilizer. The other two plots received 37.5 kg/ha of N as a basal dressing and another 37.5 kg/ha of N as top-dressing, but in one plot the basal dressing was labelled with ^{15}N, while top-dressing was labelled with ^{15}N in the other, as shown in Table 11. For this purpose, ammonium sulphate was labelled by 10% excess ^{15}N and was applied in the small intraplot area surrounded by galvanized iron sheet.[26] The area of this sub-plot was 0.8 M^2 ($0.8\ M \times 1.0\ M$).

The no-nitrogen plots in the first cropping were used successively as no-nitrogen plots in the second cropping.

Table 11. Design of fertilizer application (kg/ha)

Plot	Basal dressing N	Basal dressing P_2O_5	Basal dressing K_2O	Top-dressing N
^{15}N labelled N was applied as basal dressing	(37.5)*	75	75	37.5
^{15}N labelled N was applied as top dressing	37.5	75	75	(37.5)*
Control (no-nitrogen)	0	75	75	0
Chemical form	Ammonium sulphate	Super-phosphate	Potassium sulphate	Ammonium sulphate
Method of application		Deep placement		Top-dressing

* Bracket indicate ^{15}N labelled ammonium sulphate.

7) Transplanting time:

The first crop was transplanted on 1st of July, Immediately after the harvest, the field was plowed and the second crop was transplanted on 22th of October.

8) Plant protection:

Necessary sprayings to safe guard the crop against insects pests and animals were conducted.

9) Replication:

Area of one plot was 25 m^2 (5 m$\times$5 m) and number of replication was three.

10) Sampling:

Plant samples were taken at 30 days after transplanting, panicle primordia initiation stage, and harvesting stage respectively. At least 10 hills were taken for one sampling.

11) Measurement of plant growth:

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

12) Chemical analysis:

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

Nitrogen: Nitrogen was determined by semimicro Kjeldahl distillation method. After back titration, the sample solution was condensed to 2~3 ml, and then subjected to massspectrometry.[27]

Phosphorus: Phosphorus was determined by Ammonium Vanado-Molybdate method.

Potassium: Potassium was determined by Dr. Lange flame photometer at the wave length of 768 mμ.

RESULTS

A) Plant growth.

1) Plant height.

In plots with nitrogen application, no significant difference in plant height was found during the vegetative growth period between the first and the second crop, but during the reproductive growth stage plants of the first crop continued to increase their height until the harvesting time, whereas plants of the second crop failed to increase their height. As a result, the first crop was taller than the second crop by 30 cm. Similarly, in no-nitrogen plots too, plant height of the first crop was 20 cm taller than that of the second crop, as shown in Table 12.

2) Number of tillers.

A marked difference in the tillering process was observed between the first and the second crop in fertilized plots. The first crop developed a large number of tillers, showing no distinct peak tillering, but after the tillering stage (32 days after transplanting) the number of tillers decreased and only 60% of the tillers remained at the harvesting time. The second crop showed a peak tillering at the panicle primordia initiation stage. Interesting enough is that the final number of tillers is almost the same with the first and second crop. In no-nitrogen, plots the number of tillers of the first crop was always more than that of the second crop as shown in Table 12.

Table 12. Plant growth, yield components under the double-cropping in the rainy season

Plot	Growth stage	Plant height (cm)	Number of tiller	Weight of ry matter (t/hill)	Yield of paddy (t/ha)	Yield cpomonents			
						Number of panicles/hill	Number of spikeletes per panicle	Percentage of ripened grains (%)	Weight of 1000 grains (g)
First crop									
N.P.K.	Tillering*	53.1	19.8	6.6	—	—	—	—	—
	I.P.P.**	67.8	18.6	18.9	—	—	—	—	—
	Flowering	101.7	16.9	33.8	—	—	—	—	—
	Harvesting	119.7	12.0	39.2	4.86	10.3±0.9	99.8±2.1	77.5±1.9	24.4±0.4
P.K. (-N)	Tillering	45.8	13.5	3.6	—	—	—	—	—
	I.P.P.	57.4	17.8	12.0	—	—	—	—	—
	Flowering	86.0	13.2	20.8	—	—	—	—	—
	Harvesting	94.5	10.6	23.5	3.16	9.8±0.1	73.9±1.8	80.5±0.1	21.7±0.3
Second crop									
N.P.K.	Tillering	58.0	13.8	3.9	—	—	—	—	—
	I.P.P.	78.9	18.0	12.8	—	—	—	—	—
	Flowering	85.7	11.5	18.0	—	—	—	—	—
	Harvesting	86.6	11.5	25.0	3.19	10.8±0.6	86.1±5.3	60.7±2.1	22.6±0.3
P.K. (-N)	Tillering	50.8	10.9	2.7	—	—	—	—	—
	I.P.P.	53.0	11.3	6.6	—	—	—	—	—
	Flowering	75.0	10.9	11.3	—	—	—	—	—
	Harvesting	73.1	8.8	13.0	1.47	7.9±0.3	57.1±7.4	61.6±1.6	21.1±0.2

Remarks: * Tillering: one month after transplanting.
** Initiation of panicle primordia (I.P.P.)

3) Weight of dry matters.

In all plots, with or without nitrogen application, weight of dry matter of the first crop was markedly greater than that of second crop at the time of maturity, though there was no significant difference in dry weight during the vegetative growth period. Dry weight of the first crop was almost 50% greater than the second crop in fertilized plots.

4) Yield, and yield components.

Grain yield of the second crop was lower than that of the first crop by about 1 ton/ha, when nitrogen fertilizer was applied as shown in Table 12. Without fertilizer, yield of the second crop was almost a half that of the first crop.

Considering the climatic condition which is more favourable to the second crop than for the first crop, a reason for reduced yield of the second crop seems to be found in the degradation of nitrogenous soil fertility. Yield component analysis indicates that decreased number of spikeletes per panicle, low percentage of ripened grain and decreased weight of 1000 grains are responsible for low yields of the second crop in plots with nitrogen application, while in case without nitrogen application, the decrease in number of panicles per hill, number of spikeletes per panicle and in ripening percentage are responsible for yield decrease of the second crop, as shown in Table 12.

B) Effect of double-cropping in the rainy season upon the nitrogenous soil fertility.

1) The behaviour of the fertilizer nitrogen in a practice of double-cropping. As shown in Table 13, the first crop absorbed 85 kg/ha of nitrogen, of which 10 kg/ha were derived from the basal dressing, and 23 kg/ha from the top-dressing of nitrogen. The balance of 52 kg/ha was originated from mineralized soil nitrogen. This amount constitutes 61% of total nitrogen in the plants at the harvesting time.

The second crop absorbed 10 kg/ha of N from the basal dressing and 22 kg/ha from the top-dressing as shown in Table 13.

Thus, the utilization of fertilizer nitrogen by the second crop is identical with that of the first crop. However the second crop utilized only 43 kg/ha of soil nitrogen, 17% less than that of the first crop.

In no-nitrogen plots too, the first crop absorbed much more soil nitrogen than the second crop, the difference being about 10 kg/ha of nitrogen. This value is in good accordance with the difference observed with fertilized crops, *i.e.*, $52-43=9$ kg/ha.

Table 13. Uptake of nitrogen, soil A-value and residual effect of fertilizer nitrogen to successive second crop.

Plot	Growth stage	N in plants (%)	N Uptake (N kg/ha): Soil ^{14}N	Fertilizer ^{15}N: Basal ^{15}N	Fertilizer ^{15}N: Top-dressing ^{15}N	Total N	A-value (N kg/ha)	Residual ^{15}N (N kg/ha) derived from: Basal ^{15}N	Top dressing ^{15}N
First crop									
N.P.K.	Tillering	1.89	20.8	10.1	0	30.9	—	—	—
	I.P.P.	0.91	33.0	9.5	0	42.5	—	—	—
	Flowering	1.01	48.2	9.3	23.2	80.7	—	—	—
	Harvesting	0.85	52.1	10.3	22.8	85.2	118.2	—	—
P.K.(-N)	Tillering	1.88	16.6	0	0	16.6	—	—	—
	I.P.P.	0.96	28.8	0	0	28.8	—	—	—
	Flowering	0.63	32.7	0	0	32.7	—	—	—
	Harvesting	0.62	37.1	0	0	37.1	—	—	—
Second crop									
N.P.K.	Tillering	2.49	15.7	8.9	0	24.6	—	—	—
	I.P.P.	1.50	36.8	11.1	0	47.9	—	1.4	0.7
	Flowering	1.31	36.1	9.3	22.4	67.8	—	—	—
	Harvesting	1.10	43.3	9.8	22.1	75.2	100.8	1.7	0.9
P.K.(-N)	Tillering	2.22	14.2	0	0	14.2	—	—	—
	I.P.P.	1.18	19.5	0	0	19.5	—	—	—
	Flowering	0.94	26.6	0	0	26.6	—	—	—
	Harvesting	0.82	26.8	0	0	26.8	—	—	—

Residual effects of fertilizer nitrogen applied for the first crop are shown in Table 13. The second crop utilized only 2.6 kg/ha of residual fertilizer nitrogen, of which 1.7 kg/ha came from basal-dressing and 0.9 kg/ha from the top-dressing, both applied for the previous crop.

The amount of 2.6 kg/ha of residual fertilizer nitrogen utilized by the succeeding crop is only 3.5% of fertilizer nitrogen applied to the first crop. As BROADBENT *et al.*[28,29] pointed out, when mineral nitrogen is once immobilized, its release is very slow.

They studied the residual value of nitrogen immobilized in Sacramento clay in rice culture. Tagged fertilizer ^{15}N was applied before planting rice, and after the crop of rice was harvested more than half the initial tagged fertilizer was still present in the soil organic fraction. The following crop of sudan grass was able to utilize only a very small proportion of the immobilized nitrogen.

It is apparent that very little of the tagged fertilizer ^{15}N was utilized by the sudan grass after the second cutting, indicating that it was mineralized at a very slow rate.

The balance between detected ^{15}N and added ^{15}N indicated the amount of immobilization plus loss of fertilized ^{15}N from the soil and plant system.

Schematic diagram showing the behaviour of nitrogen under the double-cropping system in the rainy season is given in Fig. 1.

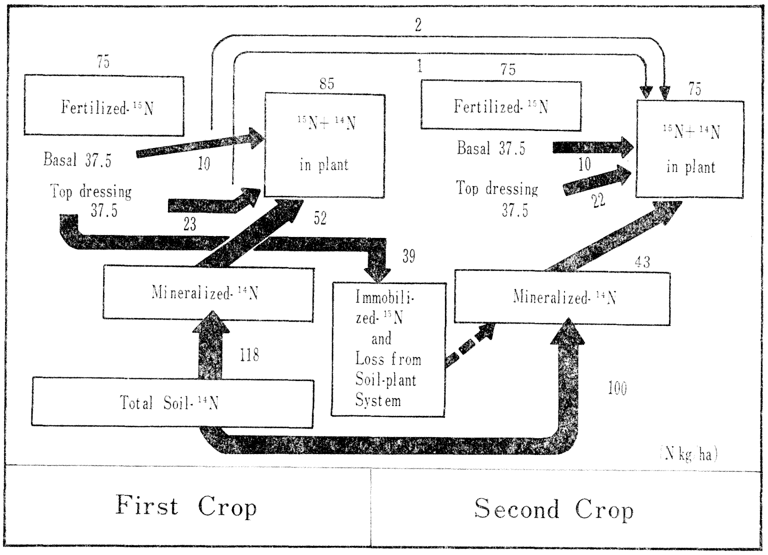

Fig. 1. Shematic diagram showing the behavioures of the nitrogen under double cropping in a rainy season.

2) Changes of nitrogenous soil fertility. As mentioned earlier in this paper, the problem of maintaining soil fertility is highly important for the practice of intensive double-cropping.

The fertilizer application can prevent the degradation of chemical soil fertility to some exten., but not full extent.

Though many trials to evaluate the nitrogenous soil fertility or availability of soil nitrogen have been made, a tracer technique using ^{15}N offers a good tool for the evaluation.

FRIED[30] assumed that a plant confronted with two sources of a nutrient would take them up in direct proportion to the availability of each.

The proposed method for measuring the quantity of available nutrient in soil involves the addition of a tagged standard source of the nutrient under test to a soil and determing the percentage of the nutrient in plants that is derived from the standard nutrient source. The amount of available nutrient in the soil can then be calculated in terms of the standard source. From this theory, amount of available nitrogen in soils can be calculated from A-values of soil. Data obtained in this experiment furnish the following calculation. During the first crop period 118.2 kg/ha of soil nitrogen were presumably mineralized, while in the second crop period 100.8 kg/ha were mineralized, and hence, the extent of degradation of nitrogenous soil fertility was estimated to be 17.4 kg/ha, which amounted to 14.7% of the initial soil fertility available.

As mentioned above, the first crop and the second crop utilized the same amount of fertilizer nitrogen, but the second crop utilized 17% less soil nitrogen than the first crop did. This difference is most likely caused by the degradation of soil fertility.

However, before giving such a conclusion a problem of the seasonal variation in the release of mineralized soil nitrogen must be considered as pointed out by Obata.[31] If the soil nitrogen mineralization takes place much more in the earlier season than the later season, it should be natural that the first crop utilized much more soil nitrogen than the second crop did.

But, the rice plants transplanted in July utilized less mineralized soil nitrogen than the September transplanted ones as shown in Table 14. Therefore, it is clear now that the difference in the soil nitrogen utilization between two croppings was not attributed to the seasonal variation in soil nitrogen mineralization between these two seasons.

Thus, the soil fertility degradation was found to be as much as 17%. It is assumed that this percentage might increase with the lowering of soil fertility, therefore, the problem deserves serious attention in the practice of double-cropping.

Table 14. Uptake of nitrogen and soil A-value by the different transplanting time

Plot	Growth stage	N in plants (%)	N uptake (N kg/ha)				A-value (N kg/ha)
			Soil ^{14}N	Fertilizer ^{15}N		Total N	
				Basal ^{15}N	Top-dressing ^{15}N		
July transplanted	Tillering	1.84	24.4	11.3	0	35.7	—
	I.P.P.	0.97	44.6	5.6	0	50.2	—
	Flowering	1.01	41.7	6.0	18.8	66.5	—
	Harvesting	0.90	39.9	3.8	13.9	57.4	169.1
September transplanted	Tillering	2.15	49.9	11.3	0	61.2	—
	I.P.P.	1.40	59.5	8.1	0	67.6	—
	Flowering	1.39	74.3	7.2	27.0	74.3	—
	Harvesting	0.85	63.3	5.9	17.6	86.8	202.0

Remarks: Variety; Puang Nahk (photoperiod-sensitive local variety): Rate of nitrogen application; 75 N kg/ha split two times (basal 37.5, I.P.P. growth stage 37.5)

C) Balance-sheet of the fertilized element between the first and the second croppings.

The balance-sheet of the fertilized element in double-cropping is highly important from the viewpoint of soil conservation.

Table 15. Balance sheet of the nutritional element between first and second croppings.

Element	Part	First crop		Second crop		Balance sheet kg/ha
		Applied	Utilized	Applied	Utilized	
N	Straw		26.7		27.3	
	Panicle	75	58.5	75	47.9	−10.4
	Total		85.2		75.2	
P_2O_5	Straw		12.2		8.4	
	Panicle	75	32.5	75	27.8	+69.1
	Total		44.7		36.2	
K_2O	Straw		102.6		83.2	
	Panicle	75	14.0	75	15.0	−64.7
	Total		116.6		98.1	

As shown in Table 15, the soil received 150 kg/ha of nitrogen, but plants absorbed 160.4 kg/ha of nitrogen resulting in a balance sheet of −10.4N kg/ha. Therefore, more nitrogen fertilizer should be applied for the second crop. As to the phosphate, the soil received 150 kg/ha of phosphate, but only 80.9 kg/ha were utilized by the plant, the balance of 69.1 kg/ha of phosphate might remain in the soil.

On the other hand, a great negative balance was calculated with potassium, but this deficit will never happen under the natural condition because of plenty supply of potassium by irrigation water.[32]

SUMMARY

Effect of double-cropping of rice in the rainy season upon the plant growth and nitrogenous soil fertility was studies. It was found that grain yield of the second crop was lower than that of the first crop by almost 1 ton/ha. Considering the climatic condition which is more favourable to the second crop than for the first crop, a reason for that reduced yield of the second crop was found in the degradation of nitrogenous soil fertility.

Field tracer experiment using ^{15}N isotope demonstrated that the first and the second crops were almost identical in the utilization of fertilized nitrogen, but a marked difference was found in the absorption of soil nitrogen, the second crop absorbed 17% less soil nitrogen than the first crop did. The experimental results also showed that during the first crop period 118.2 kg/ha of soil nitrogen were presumably mineralized from the soil whereas 100.8 kg/ha were mineralized during the second crop period. Thus, the degree of degradation of nitrogenous soil fertility was estimated to be 17.4 kg/ha, equivalent to as much as 14.7% of the initial nitrogenous soil fertility available.

This percentage may increase with soils of low fertility. Therefore the problem how to maintain the soil fertility in the practice of double-cropping of rice should deserve a serious attention.

III. Method to Improve Productive Efficiency of Basically Applied Nitrogen

As reported by SHIOIRI and AOMINE,[4] a considerable portion of the fertilizer nitrogen may be lost through denitrification under the strong reductive conditions of flooded rice soils.

From the results of the previous experiments, it was found that recovery rates of nitrogen applied as basal dressing were unexpectedly low. The data showed that only 27% of dressed nitrogen was recovered by rice plants. Many field experiments in Japan indicated that almost 30~40% of basal nitrogen were usually recovered by rice plants.[13]

The efficiency of applied nitrogen in flooded soils could sometimes be considerably improved if the nitrogen is placed in the reduced layer. By the use of ^{15}N labelled fertilizer nitrogen, it is possible to measure the efficiency of applied nitrogen with reasonable accuracy, so that the study was carried out to clarify the behaviours of basally dressed nitrogen and to find out methods of improving it's recovery.

METHOD

1) Location of experiment:

Paddy field of Bangkhen Rice Experiment Station in Thailand.

2) Treatment:

Design of the experiment is shown in Table 16.

3) Fertilizers:

75 kg/ha each of N, P_2O_5 and K_2O were applied. P_2O_5 and K_2O were applied as basal dressing and N was applied by the following methods:

A) Short term experiment:

a) Surface application: One-half of N was applied on the surface of soil, immediately after transplanting.

Another half was applied at the panicle primordia initiation stage.

b) A. M. added: One-half of N was mixed well with A. M. and then applied on the surface of soil. Another half was applied at the panicle primordia initiation stage.

c) Deep placement: One-half of N was incorporated into soil up to the depth of 10 cm of plow layer. Another half was applied at the panicle primordia initiation stage.

B) Long term experiment:

a) Standard: One-half of N was incorporated into soil up to the depth of 5 cm of plow layer. Another half was applied at the panicle primordia initiation stage.

b) A. M. added: One-half of N was mixed well with A. M., and then incorporated into soil up to about 5 cm of plow layer. Another half was applied at the panicle primordia initiation stage.

c) Delayed basal-N application: One-half of N was applied on 20 days after transplanting. The rest was applied at the panicle primordia initiation stage.

4) Chemical form of fertilizers:

Nitrogen was applied as ammonium sulphate, phosphorus as superphosphate, and potassium as potassium sulphate.

Table 16.

(Short term experiment)

Method of nitrogen application	Rates of application (kg/ha)			
	N	P_2O_5	K_2O	A.M.**
Surface application	75*	75	75	0
A.M.** added	75*	75	75	10
Deep placement	75*	75	75	0

(Long term experiment)

Method of nitrogen application	N (kg/ha)			P_2O_5 (kg/ha)	K_2O (kg/ha)	A.M.** (kg/ha)
	Basal	20 days after transplanting	30 days before flowering			
Standard	37.5*	0	37.5	75	75	0
A.M. added	37.5*	0	37.5	75	75	10
Delayed basal-^{15}N application	0	37.5*	37.5	75	75	0

N.B.: * ^{15}N labelled ammonium sulphate

** Nitrification inhibitor: 2-amino-4-chloro-6-methylpyrimidine

5% excess ^{15}N ammonium sulphate was applied in the small subplot surrounded by the galvanized iron sheet. The area of this sub-plot was 0.8 M^2 (0.8 M × 1.0 M).

5) **Variety:** P.B. 76—63
6) **Transplanting time:** June 27
7) **Spacing:** 20×20cm
8) **Area of a plot:** 0.8 m^2 (Short term experiment) 25 m^2 (Long term experiment)
9) **Replication:** 2 (Short term experiment) 3 (Long term experiment)

RESULTS

A) Short term experiment

1) Amounts of fertilizer nitrogen utilized by plants.

At the stage 30 days after transplanting, it was found that when nitrogen was applied as deep placement, almost twice as much as nitrogen were utilized by plants compared with the surface application as shown in Figs. 2 and 3. Addition of A. M. (nitrification inhibitor) gave the value intermediate between them. However, at the stage of 47 days after transplanting, there was no significant difference between the surface application and the A.M., but only the deep placement was showing still higher utilization of nitrogen.

2) Weight of dry matter and number of tillers.

Weight of dry matter and number of tillers were closely correlated with the extent of nitrogen utilization by plants. The deep placement was apparently effective to boost tillering, and to increase dry matters as shown in Table 17.

3) Conclusion

It is shown that nitrogen fertilizer to be applied as a basal dressing of ammonium form should be mixed thoroughly with soil of furrow slice or more preferably should be placed deeply in furrow slice in order to avoid the loss of nitrogen as free gas.

Table 17. Nitrogen taken up by different methods of basically dressed nitrogen N (g/m^2)

(Short term experiment)

Date of Sampling	Treatment	Plant height cm	Number of tillers/hill	Weight of dry matter g/m^2	N %	T-N	Proportion % Fertilizer-^{15}N	Proportion % Soil-^{14}N	Fertilizer nitrogen taken up by plant	Soil nitrogen taken up by plant	A-value	Recovery %
27/June	Seedling	28.0	3.0	2.33	1.52	0.035	0	100	0	0.035	—	—
7/July	Surface application	33.6	3.3	6.25	3.50	0.219	52.5	47.6	0.115	0.104	6.78	1.5
	Deep placement	35.4	3.9	6.75	3.84	0.259	59.8	40.2	0.155	0.104	5.03	2.1
	AM added	34.8	3.3	7.75	3.85	0.289	59.3	40.7	0.177	0.121	5.13	2.4
17/July	Surface application	41.4	7.1	25.5	3.21	0.820	36.7	63.3	0.298	0.522	13.14	4.0
	Deep placement	43.7	9.5	41.5	3.16	1.313	35.3	64.7	0.464	0.849	13.72	6.2
	AM added	42.1	7.5	34.3	3.41	1.168	34.1	65.9	0.398	0.770	14.51	5.3
30/July	Surface application	51.3	17.1	129.3	1.60	2.064	30.5	69.5	0.612	1.452	17.79	8.2
	Deep placement	53.9	24.2	191.5	2.06	3.940	33.0	67.0	1.309	2.631	15.07	17.5
	AM added	52.4	19.8	143.5	2.58	3.699	23.7	76.3	0.877	2.822	24.13	11.7
13/Aug.	Surface application	59.5	16.3	230.3	1.33	3.073	15.6	84.4	0.478	2.595	40.72	6.4
	Deep placement	62.8	18.9	297.8	1.20	3.585	25.3	74.7	0.906	2.679	22.18	12.1
	AM added	58.5	16.7	221.2	1.60	3.536	13.8	86.2	0.487	3.049	46.96	6.5

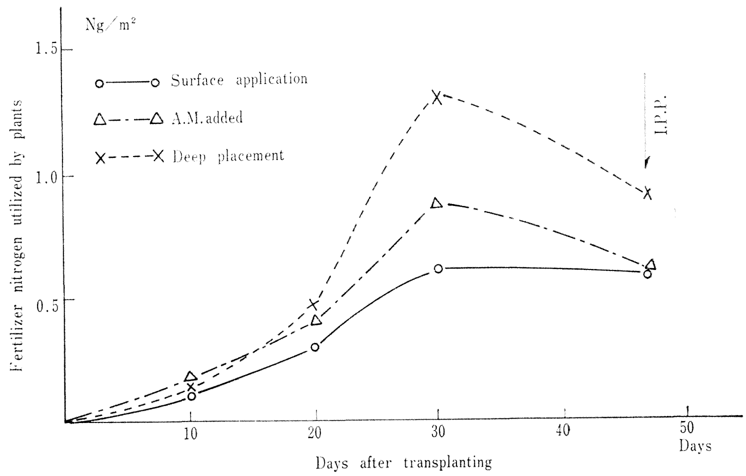

Fig. 2. Amount of fertilizer nitrogen utilized by plants by different methods of nitrogen application

B) Long term experiment

1) Amounts of fertilizer nitrogen utilized by plants.

Addition of A. M. caused a significantly higher utility of basal-^{15}N than the standard application method until the flowering stage of growth. However, there was no significant difference in basal-^{15}N utilization between them at the time of harvest as shown in Table 18.

With respect to the delayed basal-^{15}N application, it was expected that if plant roots have developed well by the time of application, the efficiency of basal nitrogen utilization might be improved, because the active root system already established can absorb nitrogen quickly.

Table 18. Nitrogen uptake

(Long term experiment) (*D.B.: Delayed basal N) N g/10 m^2

Date	Treatment	Part	N%	T-N	Proportion		Fertilizer Nitrogen				Soil Nitrogen
					F-^{15}N%	S-^{14}N%	Basal	D.B.*	I.P.P.	Total	
27/June (0)	Seedling	Total	1.50	0.35	0	100	0	0	0	0	0.35
11/July (14)	Standard	Total	3.19	3.03	—	—	—	—	—	—	—
	Delayed basal-^{15}N application	Total	2.61	1.63	0	100	0	0	0	0	1.63
	A.M. added	Total	3.82	4.49	41.3	58.7	1.85	0	0	1.85	2.64
13/Aug. (47)	Standard	Leaf	2.04	18.87	23.7	76.3	4.47	0	0	4.47	14.41
		Stem	0.92	13.60	22.7	77.3	3.09	0	0	3.09	10.52
		Total	1.35	32.47	23.3	76.7	7.56	0	0	7.56	24.93
	Delayed basal-^{15}N application	Leaf	2.23	16.68	25.4	74.6	0	4.24	0	4.24	12.44
		Stem	1.07	11.40	23.3	76.7	0	2.66	0	2.66	8.74
		Total	1.55	28.08	24.6	75.4	0	6.90	0	6.90	21.18
	A.M. added	Leaf	2.07	24.18	20.1	79.9	4.86	0	0	4.86	19.32
		Stem	0.96	16.81	19.3	80.7	3.24	0	0	3.24	13.57
		Total	1.41	40.99	19.8	80.2	8.10	0	0	8.10	32.89
11/Sept. (76)	Standard	Leaf	1.89	29.63	39.0	61.0	2.36	0	9.20	11.56	18.07
		Stem	0.55	18.44	34.5	65.5	1.52	0	4.85	6.37	12.07
		Panicle	1.22	13.21	32.9	67.1	0.86	0	3.49	4.35	8.86
		Total	1.02	61.28	36.4	63.6	4.74	0	17.54	22.28	39.00
	Delayed basal-^{15}N application	Leaf	1.55	35.96	43.9	56.1	0	4.66	11.11	15.77	20.19
		Stem	0.43	17.80	39.7	60.3	0	2.07	5.00	7.07	10.73
		Panicle	1.25	12.03	38.3	61.7	0	1.43	3.18	4.61	7.42
		Total	0.89	65.79	41.7	58.3	0	8.16	19.29	27.45	38.34
	A.M. added	Leaf	2.06	31.98	40.3	59.7	3.00	0	9.88	12.88	19.10
		Stem	0.56	22.63	37.4	62.6	2.11	0	6.36	8.47	14.16
		Panicle	1.31	15.30	35.5	64.5	1.39	0	4.04	5.43	9.87
		Total	1.03	69.91	38.3	61.7	6.50	0	20.28	26.78	43.13
13/Oct. (108)	Standard	Panicle	0.95	47.68	32.4	67.6	4.54	0	10.91	15.45	32.23
		Stem	0.45	14.05	32.2	67.8	1.27	0	3.26	4.53	9.52
		Total	0.76	61.73	32.4	67.6	5.81	0	14.17	19.98	41.75
	Delayed basal-^{15}N application	Panicle	0.98	53.24	33.3	66.7	0	5.42	12.33	17.75	35.49
		Stem	0.43	15.99	35.9	64.1	0	1.71	4.03	5.74	10.25
		Total	0.76	69.23	33.9	66.1	0	7.13	16.36	23.49	45.74
	A.M. added	Panicle	0.92	51.21	31.7	68.3	4.38	0	11.86	16.24	34.97
		Stem	0.45	17.59	33.1	66.9	1.40	0	4.43	5.83	11.76
		Total	0.73	68.80	32.1	67.9	5.78	0	16.29	22.07	46.73

The experiment using ^{15}N showed that nitrogen of top-dressing lately applied was utilized by plants at a higher rate of recovery than nitrogen of standard application. This trend was apparent during the later growth stages, though during the early stages a reverse relation was observed.

2) Plant growth.

Plant growth was a reflection of nitrogen uptake.

The plot with A. M. showed apparently better growth than another two plots during the early stages, but the differences in plant growth became in significant at the later stages as shown in Table 19.

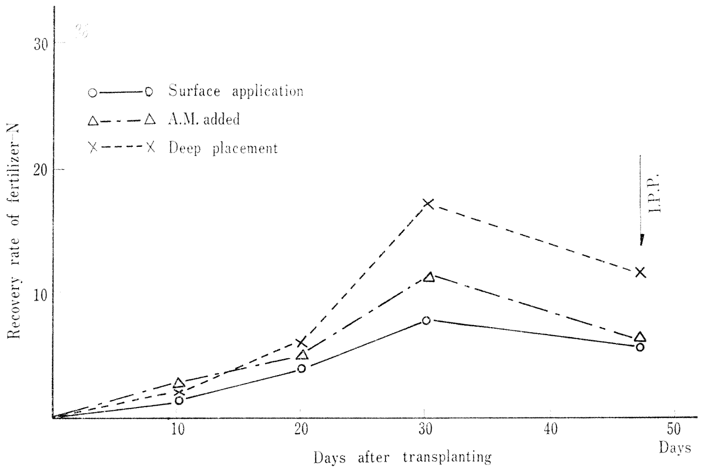

Fig. 3. Recovery rate of fertilizer nitrogen by different method of nitrogen application

Table 19. Plant Growth

(Long term experiment) * Days after transplanting.

Date sampled	Plot	Plant height cm	Number of tillers /hill	Weight of dry matter g/hill			
				Leaf blade	Stem	Panicle	Total
11/July (14)*	Standard	31.5	4.2	0.38	—	—	0.38
	Delayed basal-^{15}N application	33.1	3.1	0.25	—	—	0.25
	A.M. added	36.3	4.6	0.47	—	—	0.47
13/Aug. (47)	Standard	62.1	13.7	3.70	5.94	—	9.64
	Delayed basal-^{15}N application	61.1	13.0	2.99	4.28	—	7.27
	A.M. added	64.4	17.4	4.67	6.98	—	11.65
11/Sept (76)	Standard	108.3	11.5	6.27	13.53	4.33	24.13
	Delayed basal-^{15}N application	92.5	14.6	9.28	16.56	3.85	29.69
	A.M. added	112.6	11.0	6.21	16.16	4.67	27.04
13/Oct. (108)	Standard	100.7	11.4	12.47	—	20.06	32.53
	Delayed basal-^{15}N application	100.9	11.7	14.70	—	21.66	36.36
	A.M. added	104.9	12.0	15.52	—	22.18	37.70

3) Yield

As shown in the Table 20, there was no significant difference in grain yield between three plots, inspite of the differences in nitrogen utilization.

Therefore, it can be concluded that the nitrogen utilization was significantly increased by either addition of A. M. or delaying the basal application, but the increase in nitrogen absorption was not sufficient to increase the yield.

Table 20. Paddy yield

(Long term experiment)

Plot	Number of panicles	Length of panicle cm	Number of spikelets	Percentage of ripened grains %	Weight of 1,000 grains g	Yield g/m^2
Standard	10. 3±0. 8	21. 7±0. 3	116. 2±3. 4	67. 6±3. 5	22. 3±0. 3	452. 9±47. 0
Delayed basal-^{15}N application	10. 0±0. 7	20. 7±0. 6	111. 6±6. 2	70. 5±0. 6	23. 3±0. 8	454. 3±38. 8
A.M. added	10. 4±0. 1	22. 1±0. 4	118. 8±1. 5	64. 0±1. 4	23. 0±1. 7	455. 0±36. 3

IV. Studies on the Split Application of Nitrogen at Different Nitrogen Levels

Many research works have been so far conducted to know the efficient utilization of nitrogen by rice plants, because the nitrogen utilization is one of the most important factors for increasing rice yields.

It is very difficult to assess accurately nitrogen requirements at different stages of growth in the field experiment, because many factors related to the soil such as soil nitrogen availability are involved in the experiment. The present study was carried out by the use of ^{15}N isotope to approach to this problem. It is generally recognized that there are four appropriate times for the application of nitrogenous fertilizer during the rice growth period, namely,[33] 1) immediately before planting (basal dressing) 2) tillering stage (top-dressing at the tillering stage) 3) panicle primordia initiation stage or primordia developing stage, and 4) early stage of ripening.

This experiment was designed to know appropriate time and dosage of nitrogen application with special reference to yield components.

METHOD

1) **Location of experiment:**

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

2) **Treatment:**

Experimental treatments were consisted of the combination of four different times of application and five levels of dosage, as shown in Table 21.

3) **Replications:** Three
4) **Number of plots:** 39 in total Area of one plot is 25 m² (5 m×5 m)
5) **Variety:** P. B. 76-63
6) **Transplanting date:** June 25
7) **Spacing:** 20×20 cm
8) **Number of seedlings:** three per hill
9) **Measurement made:**
   - A) **Chemical analysis**
     - a) Nitrogen determination
     - b) Isotopic ratio measurement
   - B) **Analysis of yield components**
     - a) Panicle numbers per unit area
     - b) Number of spikelets per panicle
     - c) Percentage of ripened grains
     - d) Weight of 1000 grains

Table 21. Design of fertilizer application

Plot	N kg/ha					P_2O_5	K_2O
	Basic	I.M.*	I.P.P.**	F***	Total		
A	(56. 2)	0	0	0	56. 2	112. 5	112. 5
B	(37. 5)	0	(37. 5)	0	75. 0	112. 5	112. 5
C	(18. 7)	(18. 7)	37. 5	0	75. 0	112. 5	112. 5
D	18. 7	18. 7	37. 5	(18. 7)	93. 7	112. 5	112. 5
E	18. 7	18. 7	(56. 2)	0	93. 7	112. 5	112. 5
F	(56. 2)	0	(37. 5)	0	93. 7	112. 5	112. 5
G	(37. 5)	(18. 7)	37. 5	0	93. 7	112. 5	112. 5
H	37. 5	18. 7	(37. 5)	(18. 7)	112. 5	112. 5	112. 5
I	37. 5	18. 7	(56. 2)	0	112. 5	112. 5	112. 5
J	(75. 0)	0	(37. 5)	0	112. 5	112. 5	112. 5
K	(56. 2)	(18. 7)	37. 5	0	112. 5	112. 5	112. 5
L	56. 2	18. 7	(37. 5)	(18. 7)	131. 2	112. 5	112. 5
M	56. 2	18. 7	(56. 2)	0	131. 2	112. 5	112. 5

N.B. * I.M. 20 days after transplanting
** I.P.P. 30 days before flowering
*** F Flowering stage
Remarks: Figures in bracket indicate using heavy nitrogen (^{15}N-isotope)

RESULTS

A) Plant growth

Plant height: Plant height was increased with increasing doses of nitrogen irrespective of the number of splitting, but it was leveled off over the dose of 93 kg/ha as shown in Table 22.

Number of tillers: In an early stages of growth. there was apparently a close relation between number of tillers and doses of nitrogen, but the effect of doses was not clearly observed in the later stages of growth.

Weight of dry matter: Weight of dry matter increased in accordance with increasing doses of nitrogen. However, it showed variations depending on the time of nitrogen application even when the total doses of application are same. Nitrogen applied during the vegetative stages of growth was more effective in increasing dry matter than that applied in the reproductive stage. Effect of number of split application on dry matter was not significant.

Nitrogen content in plants: Nitrogen content in plants at the harvesting time showed an increase consistently with increasing doses of nitrogen. Time of application also gave variations in plant nitrogen content, especially when nitrogen was applied at the flowering stage as shown in Fig. 4.

B) Uptake of nitrogen by plants at different levels of nitrogen application

The total quantity of nitrogen utilized by plants increased consistently with increasing doses of nitrogen, as shown in Tables 22 and 23.

This increase is mainly caused by the increased utilization of fertilizer nitrogen. How-

Table 22. Plant growth, grain yield and uptake of nitrogen at several levels of nitrogen application (1)

Level of nitrogen (kg/ha)	Time of nitrogen application				Plant height cm	Nitrogen content in plant %	Nitrogen utilized by plant (kg/ha)			Contribution of fertilizer ^{15}N in plant %
	B	I.M.	I.P.P.	F			Total N	^{15}N. from fertilizer	^{14}N from soil	
0	0	0	0	0	86.8	0.69	32.0	0	32.0	0
37.5	37.5	0	0	0	92.3	0.70	43.3	5.4	37.8	12.5
56.2	56.5	0	0	0	83.6	0.72	41.7	8.9	32.8	21.4
75.0	37.5	0	37.5	0	100.7	0.76	61.7	20.0	41.7	32.4
75.0	37.5(AM)*	0	37.5	0	104.9	0.73	68.8	22.1	46.7	32.1
75.0	18.7	18.7	37.5	0	97.4	0.77	57.3	18.1	39.2	31.6
75.0	0	37.5	37.5	0	100.9	0.76	69.2	23.5	45.7	34.0
93.7	18.7	18.7	37.5	18.7	95.7	0.83	71.1	32.6	38.5	45.9
93.7	18.7	18.7	56.2	0	108.3	0.79	64.1	28.5	35.6	44.5
98.7	56.2	0	37.5	0	103.0	0.78	67.8	25.5	42.3	37.6
93.7	37.5	18.7	37.5	0	106.9	0.82	76.0	23.8	52.2	31.3
112.5	37.5	18.7	37.5	18.7	100.7	0.87	75.2	32.3	42.9	43.0
112.5	37.5	18.7	56.2	0	107.8	0.84	73.3	34.7	38.6	47.3
112.5	75.0	0	37.5	0	104.6	0.76	72.1	29.7	42.4	41.2
112.5	56.2	18.7	37.5	0	110.9	0.79	68.8	25.4	43.4	36.9
131.2	56.2	18.7	37.5	18.7	106.4	0.91	89.3	44.7	44.6	50.1
131.2	56.2	18.7	56.2	0	106.9	0.82	63.8	30.7	33.1	48.1

* Nitrogen fertilizer is mixed with AM (2-amino-4-chloro-6-methyl pyrimidine)

Table 22. Plant growth, grain yield and uptake of nitrogen at several levels of nitrogen application (2) (Continued)

Recovery rate of fertilizer %	Yield Component				Yield of paddy (t/ha)	Weight of straw (t/ha)	Total number of spikelets per m²
	Number of panicles	Number of spikelets	Percentage of ripened grains %	Weight of 1000 grains			
0	8.9	65.5	71.1	21.4	2.32	2.34	14570
14.4	9.4	84.4	72.4	21.7	3.20	2.93	19834
15.8	9.6	94.3	77.8	23.7	4.18	2.57	22680
26.7	10.3	116.2	67.6	22.3	4.53	3.12	29922
29.5	10.4	118.8	64.0	23.0	4.55	3.88	30888
24.1	9.8	111.9	69.6	22.4	4.23	3.09	27416
31.3	10.0	111.6	70.5	23.3	4.54	3.67	27900
34.8	10.0	122.5	74.2	22.6	5.14	3.29	30625
30.4	10.5	126.6	67.1	24.0	5.33	3.46	33233
27.2	10.3	125.6	70.3	23.3	5.29	3.46	32342
25.4	10.6	123.0	69.1	22.8	5.13	4.15	32595
28.7	10.6	112.9	71.9	22.5	4.86	3.55	29919
30.8	10.9	119.4	69.7	22.8	5.18	3.56	32537
26.4	10.9	125.5	68.8	23.6	5.53	3.93	34199
22.6	10.9	119.3	70.5	23.6	5.39	3.78	32509
34.1	10.5	123.5	69.8	23.0	5.15	4.33	32419
23.4	10.8	125.4	68.1	22.6	5.19	3.37	33858

Table 23. Relationship between dressing amounts of nitrogen and utilized amounts of them by the plants.

Plot	Dressing amount of nitrogen (kg/ha)					Fertilizer nitrogen utilized by plant (kg/ha)				
	B	IM	IPP	F	Total	B	IM	IPP	F	Total
A	56.2	0	0	0	0	8.9	0	0	0	8.9
B	37.5	0	37.5	0	75.0	5.8	0	14.2	0	20.0
C	18.7	18.7	37.5	0	75.0	2.5	3.3	12.3	0	18.1
D	18.7	18.7	37.5	18.8	93.7	3.2	4.0	15.2	10.2	32.6
E	18.7	18.7	56.2	0	93.7	2.9	3.6	22.0	0	28.5
F	56.2	0	37.5	0	93.7	10.5	0	15.0	0	25.5
G	37.5	18.7	37.5	0	93.7	7.6	3.6	12.6	0	23.8
H	37.5	18.7	37.5	18.7	112.5	7.6	3.6	11.4	9.7	32.3
I	37.5	18.7	56.2	0	112.5	7.5	3.5	23.7	0	34.7
J	75.0	0	37.5	0	112.5	14.0	0	15.7	0	29.7
K	56.2	18.7	37.5	0	112.5	9.8	4.8	10.8	0	25.4
L	56.2	18.7	37.5	18.7	131.2	12.1	6.1	15.7	10.8	44.7
M	56.2	18.7	56.2	0	131.2	8.7	4.3	17.7	0	30.7

N.B.: B Basal-dressed nitrogen
IM Top-dressing at 20 days after transplanting
IPP Top-dressing at 30 days before flowering
F Top-dressing at flowering time

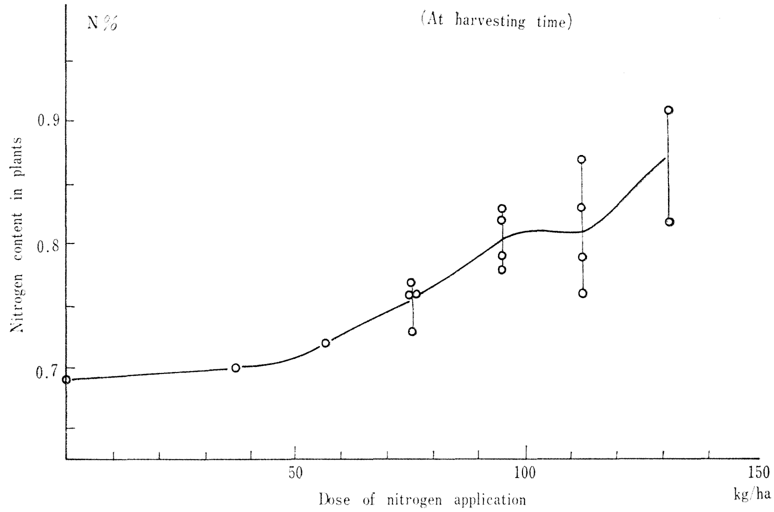

Fig. 4. Nitrogen content in plants at different levels of nitrogen application

ever, no appreciable increase took place at the nitrogen level beyond 93 kg/ha, as shown in Fig. 5. Consequently, the recovery rates of fertilizer nitrogen were also levelled off beyond this dose, as shown in Fig. 6.

The contribution of fertilizer nitrogen to the total nitrogen in plants showed a consistent increase with the increase of nitrogen dose. As shown in Fig. 7, the fertilizer nitrogen constituted 50% of the total nitrogen in plants, when 131 kg/ha of nitrogen were applied by splitting into four times of application.

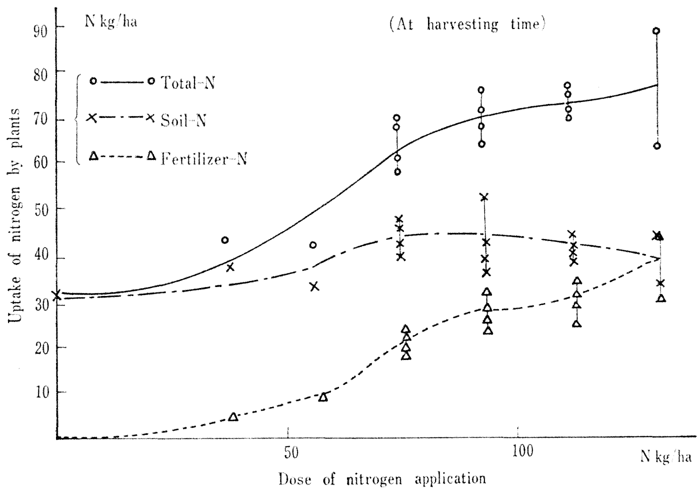

Fig. 5. Uptake of nitrogen by plants at different levels of nitrogen application

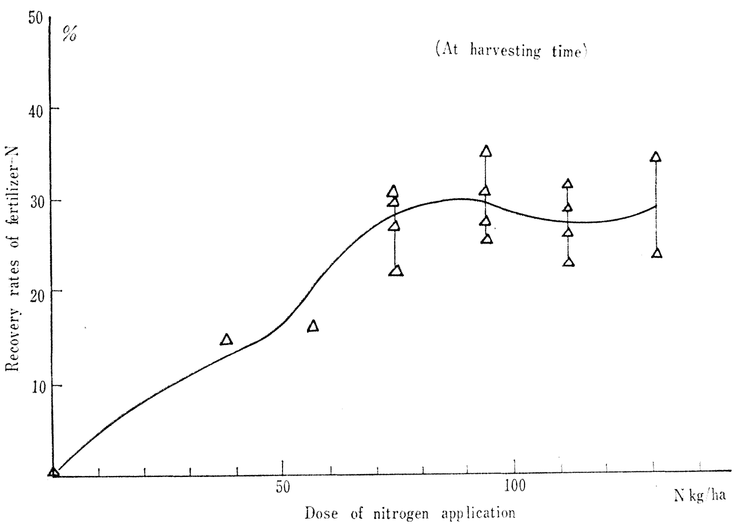

Fig. 6. The recovery rates of fertilizer nitrogen at different levels of application

C) Yield components

Number of panicles per hill was increased with increasing dose of nitrogen up to 112 kg/ha, and no more increase beyond that level of nitrogen, as shown in Fig. 8.

Number of spikeletes per panicle was increased remarkably with increasing dose of nitrogen application up to 94 kg/ha as shown in Fig. 9. Therefore the total number of spikelets per unit area was apparently increased with the increasing dose of nitrogen up to 93 kg/ha, and no increase occurred at nitrogen levels beyond that dose, as shown in Fig. 10.

No close relation was found between percentage of ripened grains and nitrogen doses, but the percentage seems to show a more or less decreasing trend with the increase of nitrogen, as shown in Fig. 11.

Weight of 1000 grains did not vary with the change in nitrogen doses as shown in Fig. 12.

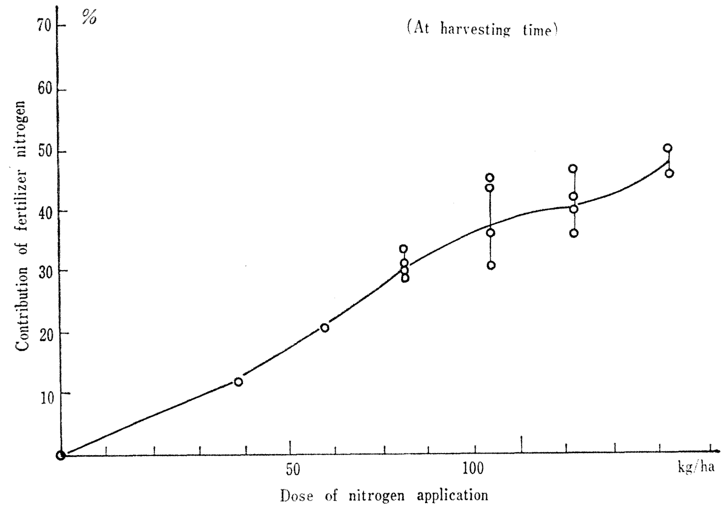

Fig. 7. **The contribution of fertilizer nitrogen to the total plant nitrogen**

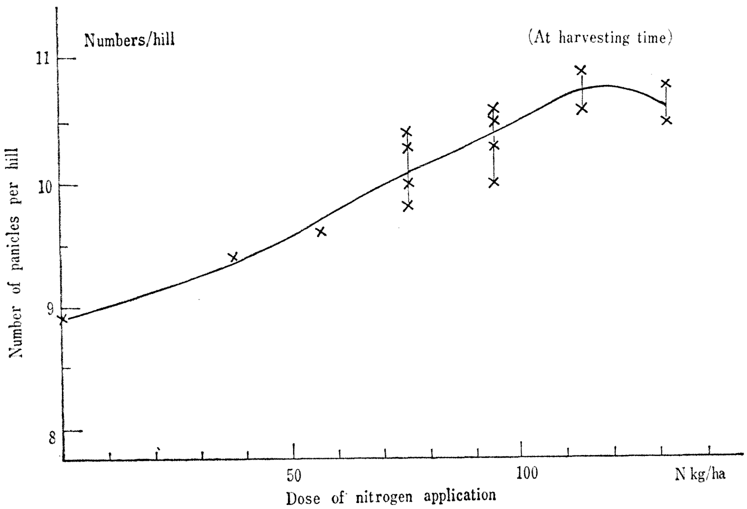

Fig. 8. Number of panicles at different levels of nitrogen application

D) Grain yield

The yield of paddy increased with increasing dose of nitrogen, reaching to the maximum yield at the level of 93 kg/ha of nitrogen as shown in Fig. 13.

This yield increase was obtained by the increased number of spikelets per unit area. A close correlation was found between paddy yields and the amount of fertilizer nitrogen absorbed by plants.

The coefficient of correlation was 0.78 as shown in the Fig. 14.

E) Yield-increasing effect of a basal dressing and top-dressing of nitrogen:

a) Basal dressing: The basal application of nitrogen was found to be very effective in increasing yield. The yield increase of about 1 ton/ha was obtained by an application of basal dressing of 37.5 kgN/ha, as indicated in a comparison with the plot without basal nitrogen.

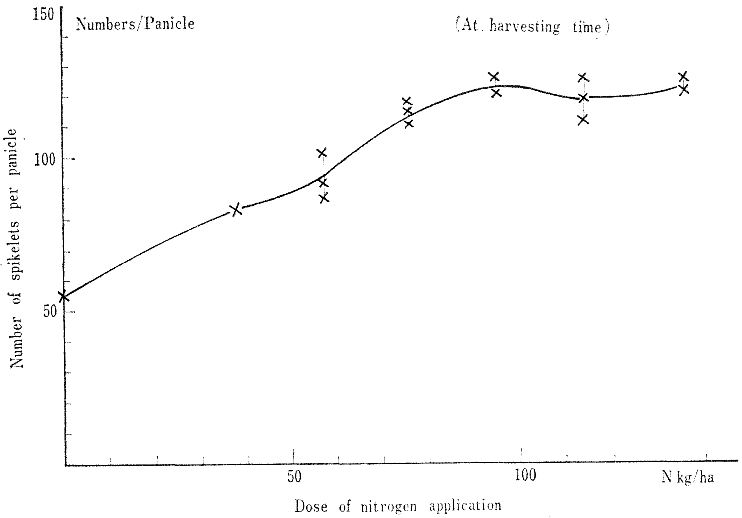

Fig. 9. Number of spikelets at different levels of nitrogen application

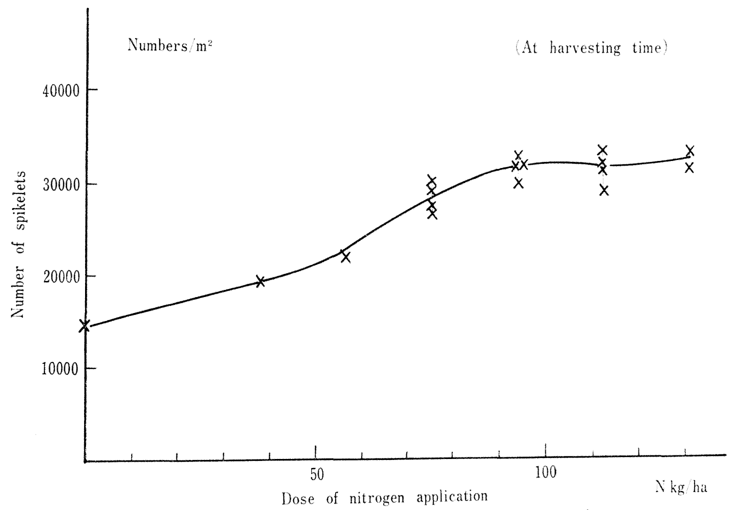

Fig. 10. Number of spikelets per unit area at different levels of nitrogen application

b) Top-dressing: Top-dressing given 20 days after transplanting showed an appreciable yield-increasing effect when a dose of basal dressing was less than 37.5 kg/ha. On the contrary, when an ample amount of basal dressing was applied, the top-dressing at the panicle primordia initiation stage resulted in a marked increase of yield.

So far as the top-dressing at the flowering stage is concerned, a positive effect was obtained, only when the basal nitrogen was rather less, as shown in Table 24.

In order to know whether the quantity of nitrogen fertilizer applied at each stage of plant growth as a basal or top-dressing was sufficient or not, the yield-increasing effect was calculated for an increase of dose of nitrogen applied at each of the different growth stages, as presented in Table 25.

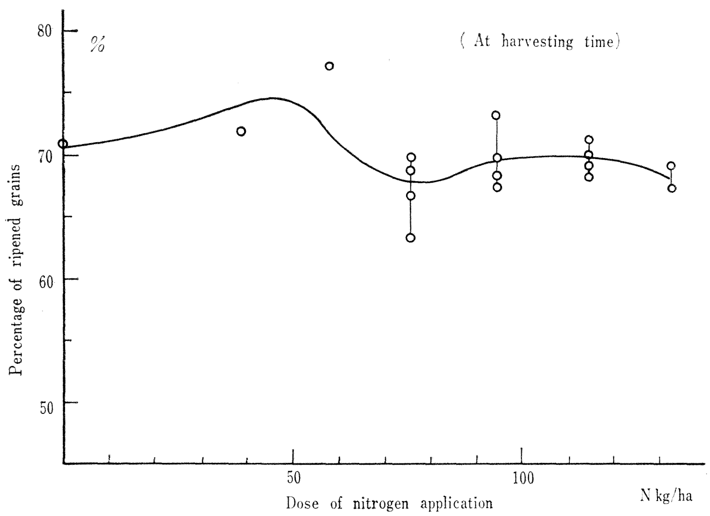

Fig. 11. Percentage of ripened grained at different levels of nitrogen application

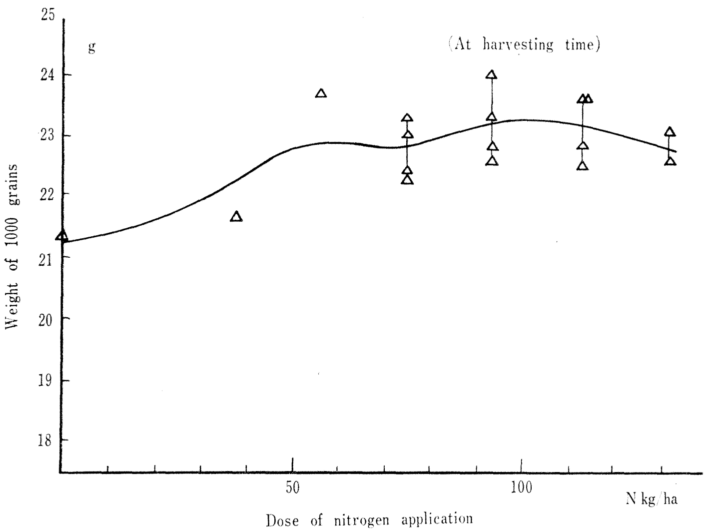

Fig. 12. Weight of 1000 grains at different levels of nitrogen application

It is rather difficult to make this kind of analysis, because number of split application, time and dose of each split application are interrelated in a complicated way, so that effect of dose of nitrogen applied at a given time can not be determined independently from the time and dose of other dressing.

However, based on the calculation presented in Table 25, it was made clear that:

1) When nitrogen was split into two, *i.e.*, a basal dressing and a top-dressing at panicle primordia initiation stage, a marked yield-increase was obtained with a basal dressing increased from 37.5 kg/ha up to 75 kg/ha of nitrogen.

2) In case when nitrogen was split into three, *i.e.*, a basal dressing and top-dressing at 20 days later transplanting and at primordia initiation stage, a marked yield-increase

Table 24. Yield-increasing effect of a basal dressing and top-dressing of nitrogen.

Dressing pattern		Yield excess over check plot (kg/ha)	Fertilizer ^{15}N taken up by plant excess over check plot (kg/ha)	Productive efficiency of fertilizer ^{15}N	Recovery rate of fertilizer (%)
B-^{15}N	1B*	990	6.2	160	16.5
	1.5B*	1020	8.9	115	15.8
M-^{15}N	1B+0.5M*+1P	599	3.6	166	19.3
	1.5B+0.5M*+1P	99	4.8	21	25.7
P-^{15}N	1B+1P*	379	14.2	27	37.9
	1.5B+1P*	1110	15.0	74	40.0
F-^{15}N	0.5B0.5M+1P+0.5F*	908	10.2	89	54.5
	1B+0.5M+1P+0.5F*	−269	9.7	−28	51.9
	1.5B+0.5M+1P+0.5F*	−233	10.8	−22	57.8

N.B.: * ^{15}N Labelled
B-^{15}N Basal dressing-N
M-^{15}N Top-ressing at 20 days after transplanting
P-^{15}N Top-dressing at I.P.P. stage
F-^{15}N Top-dressing at flowering stage
1 Equivalent to 37.5 N kg/ha

Table 25. Yield-increasing effect of the increase of dose of nitrogen applied at each of the different growth stages.

Dressing pattern		Yield excess over check plot (kg/ha)	Fertilizer ^{15}N taken up by plant excess over check plot (kg/ha)	Productive efficiency of fertilizer ^{15}N	Recovery rate of fertilizer (%)
B-^{15}N (Basal nitrogen)					
BP	(1+Δ0.5)B+1P	759	4.7	161	25.1
	(1+Δ1)B+1P	1002	8.2	122	21.9
	(1.5+Δ0.5)B+1P	243	3.5	69	18.7
BMP	(0.5+Δ0.5)B+0.5M+1P	895	5.1	175	27.3
	(0.5+Δ1)B+0.5M+1P	1154	7.3	158	19.5
	(1+Δ0.5)B+0.5M+1P	259	2.2	118	11.8
BMPF	(0.5+Δ0.5)B+0.5M+1P+0.5F	−282	4.4	−64	23.5
	(0.5+Δ1)B+0.5M+1P+0.5F	13	8.9	2	23.7
	(1+Δ0.5)B+0.5M+1P+0.5F	295	4.5	66	24.1
P-^{15}N (Nitrogen at I.P.P. stage)					
BMP	0.5B+0.5M+(1+Δ0.5)P	1099	9.7	113	51.9
	1B+0.5M+(1+Δ0.5)P	55	11.1	5	59.4
	1.5B+0.5M+(1+Δ0.5)P	−201	6.9	−29	36.9

N.B.: Δ indicats increase of dose of nitrogen applied.

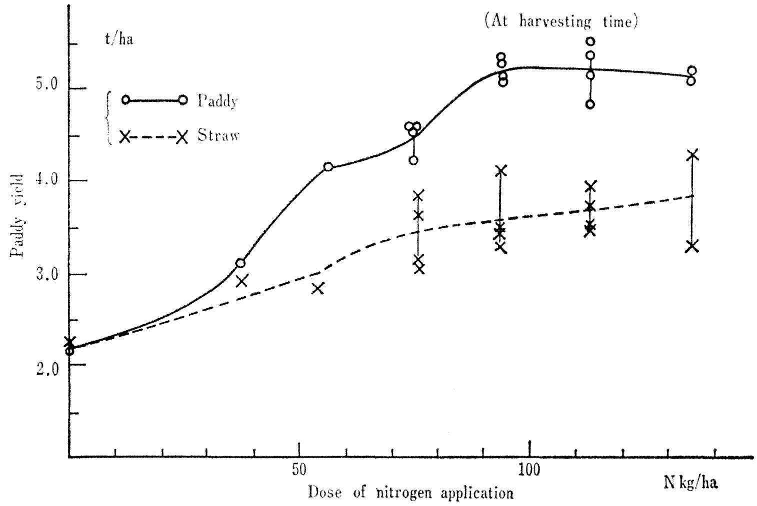

Fig. 13. Paddy yield and weight of straw at different levels of nitrogen application

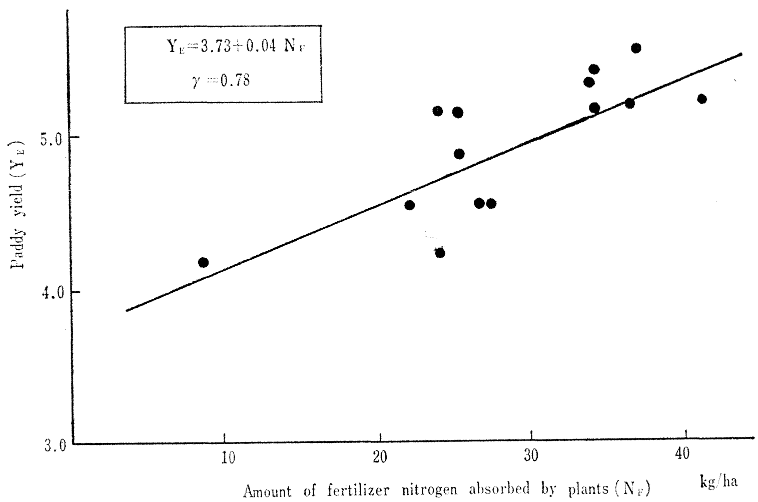

Fig. 14. Rilationship between paddy yield and the amount of fertilizer nitrogen absorbed by plants

was obtained when a basal dressing was increased from 18.8 kg/ha up to 56.2 kg/ha of nitrogen.

3) A remarkable yield-increase was obtained by an increased dose of top-dressing at primordia initiation stage, when less amount of nitrogen was supplied before that stage.

4) High correlation ($\gamma=0.72$) was obtained between increase in grain yield and the amount of nitrogen utilized by plants up to the time of top-dressing.

Plants require more nitrogen in order to get higher yield. However, as the availability of mineralized soil nitrogen was limited, the plants have to depend more and more upon the additional nitrogen supply by fertilizer application. This relationship is illustrated in Fig. 15, in which a close relationship among the total nitrogen utilized by plants, contribu.ion of fertilizer nitrogen to the total plant nitrogen, and the grain yield are shown.

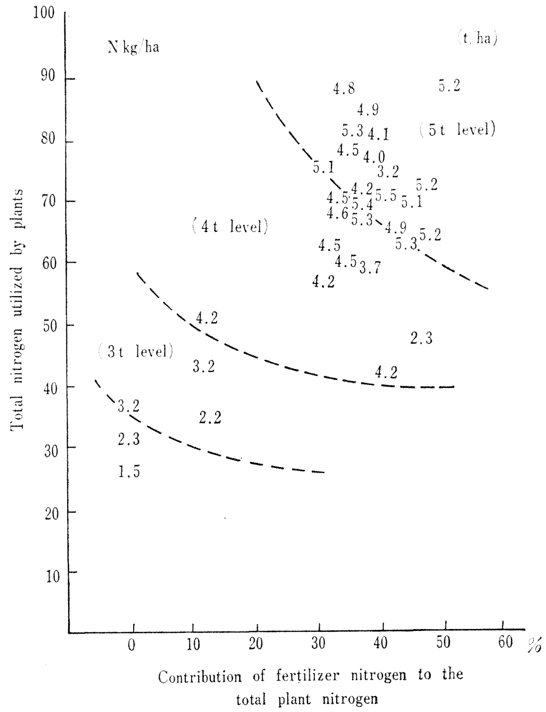

Fig. 15. Relationship among the total nitrogen utilized by plants, contribution of fertilizer nitrogen to the total plant nitrogen and grain yield.

V. Yield Components as Affected by the Timing of Top-dressing of Nitrogen.

A number of factors may be involved in the effect of nitrogen top-dressing applied during the stage of panicle primordia development on yield components of rice plants, such as varietal difference, climate condition, and soil fertility.

It is well known that the top-dressing of nitrogen applied at the panicle primordia development stage give effects on the following three yield components *i.e.*, number of spikelets per panicle, percentage rate of ripened grains and weight of 1000 grains. However, the effect on each yield component varies depending upon the difference in time of application. For example an application at the early stage of panicle primordium development is very effective in increasing the number of spikelets per panicle, but the percentage of ripened grain is usually decreased due to the unbalance between the total volume of spikelets as the acceptor of starch and the amount of starch to be produced by plants. Weight of 1000 grain does not change to an appreciable extent in relation to nitrogen supply if the nitrogen level is high.

Reliable results were reported by S. MATSUSHIMA[34] as to the changes of yield components as affected by the timing of top-dressing of nitrogen with Japonicas. Concerning the Indicas, A. TANAKA[35] studied on the relation between yield components and nitrogen application. He found that varietal difference in nitrogen response plays an important role and that the most prominent difference between low and high nitrogen-response varieties was the difference in the response of panicle number to nitrogen. Low nitrogen-response varieties showed a limited or negligible increase in the panicle number, whereas high response varieties exhibited a big increase in accordance with an increase in nitrogen application.

And the reason for these varietal difference in nitrogen response was found in the mutual shading phenomenon at the maximum tiller number stage.

From the viewpoints of the soil-plant-relationship it must be noted that rice plants utilize not only fertilizer nitrogen, but also soil nitrogen mineralized during their growing periods. NISHIGAKI *et al.*[8,9] clarified that generally rice plants utilized much more soil nitrogen than the fertilized nitrogen, and actually the natural supply of soil nitrogen was so great in amount that it must exhibit a big influence on the effect of timing of top-dressing of nitrogen on yield components.

The present experiment was carried out to clarify the effect of nitrogen to yield components by distinguishing different nitrogen sources, *i.e.*, nitrogen derived from soil and from fertilizer respectively using ^{15}N isotope tracer techniques in two different growing seasons.

METHOD

1) Location of experiment:

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

2) Treatment:

Total amount of nitrogen applied was same for all treatments except no-nitrogen plot and no top-dressing plot, but treatments differed in timing of application as shown in Table 26.

Table 26. The design of the experiment

	Treatment (No.)	Basal dressing (kg/ha)			Top-dressing N	
		N	P_2O_5	K_2O	(kg/ha)	Time of application
First crop	1 D (−20)*	(37.5)	75	75	37.5	20 days before flowering
	2 D (−30)	37.5	75	75	(37.5)	30 days before flowering
	3 D (−20)	37.5	75	75	(37.5)	20 days before flowering
	4 D (−10)	37.5	75	75	(37.5)	10 days before flowering
	5 D (−0)	37.5	75	75	(37.5)	Flowering time
	6 D (+10)	37.5	75	75	(37.5)	10 days after flowering
	7 D (−T)**	37.5	75	75	—	No top-dressing
	8 D (−N)***	—	75	75	—	No nitrogen
	9 D (−40)	37.5	75	75	(37.5)	40 days before flowering
Second crop	1 D S (−20)	(37.5)	75	75	37.5	20 days before flowering
	2 D S (−30)	37.5	75	75	(37.5)	30 dysa before flowering
	3 D S (−20)	37.5	75	75	(37.5)	20 days before flowering
	4 D S (−10)	37.5	75	75	(37.5)	10 days before flowering
	5 D S (−0)	37.5	75	75	(37.5)	Flowering time
	7 D S (−T)	37.5	75	75	—	No top-dressing
	8 D S (−N)	—	75	75	—	No nitrogen
	9 D S (−40)	37.5	75	75	(37.5)	40 days before flowering

N. B. * Days before or later flowering. ** No top-dressing *** No nitrogen

3) **Replications**: Three replications were used.
4) **Number of plots**: 48, area of one plot is 25 m^2 (5 m × 5 m)
5) **Variety**: P. B. 76—63 (none photoperiod-sensitive improved variety)
6) **Transplanting date**: July 1st for first crop September 1st for second crop
7) **Spacing**: 20 × 20 cm
8) **Number of seedlings**: three per hill
9) **Spraying**:

Sevin was sprayed 10 days and 20 days after sowing at the nursery stage, and was sprayed three times at a 10 day interval starting from 10 days after transplanting.

10) **Measurement**:

A) Chemical analysis

Nitrogen was determined by Kjeldahl method and its isotopic ratio was measured by Mass-Spectrometer.

B) Analysis of yield components (a lot of 10 hills was used)

a) panicle numbers per unit area.
b) average number of spikelets per panicle.
c) percentage of fully-ripened grains.
d) 1000 grain weight of paddy.

C) Determination of leaf area index (LAI)

LAI was calculated from the data of Dr. A. OSADA.[36]

RESULTS

A) Plant growth

1) Plant height

Although the nitrogen top-dressing increased plant height, as shown in Figs. 16 and 17, different times of application caused different ways of response. The earlier the time of top-dressing, the more remarkable was the effect. This effect was clearly observed at about 10

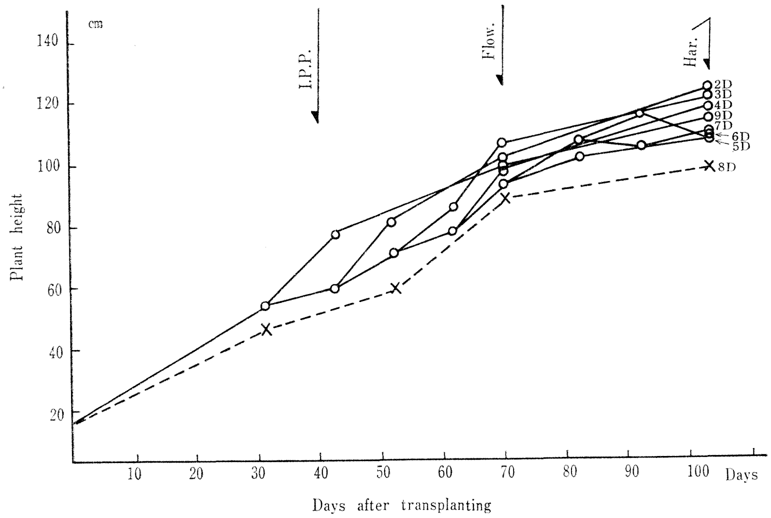

Fig. 16. Plant height (First crop)

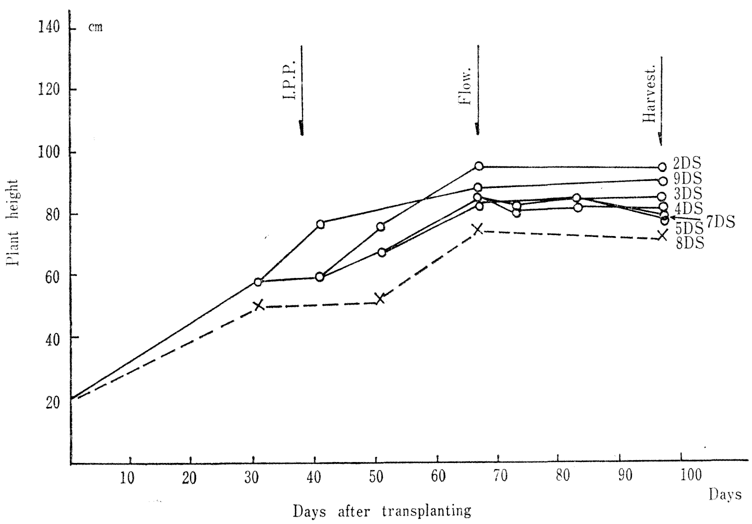

Fig. 17. Plant height (Second crop)

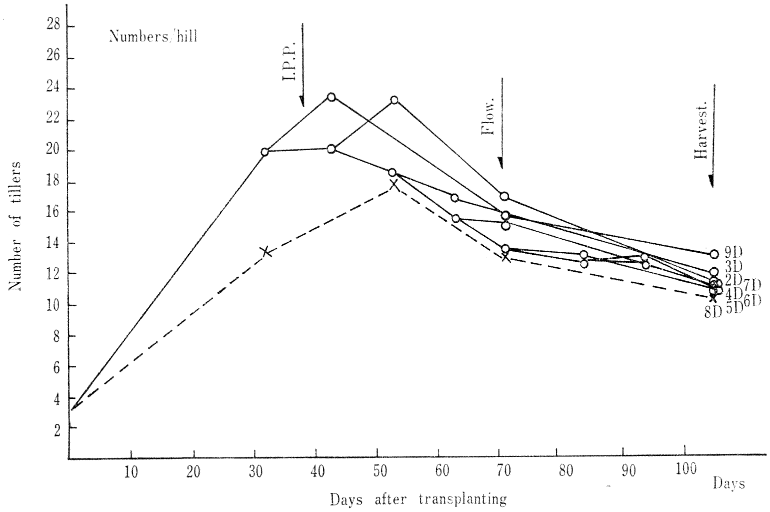

Fig. 18. Number of tillers (First crop)

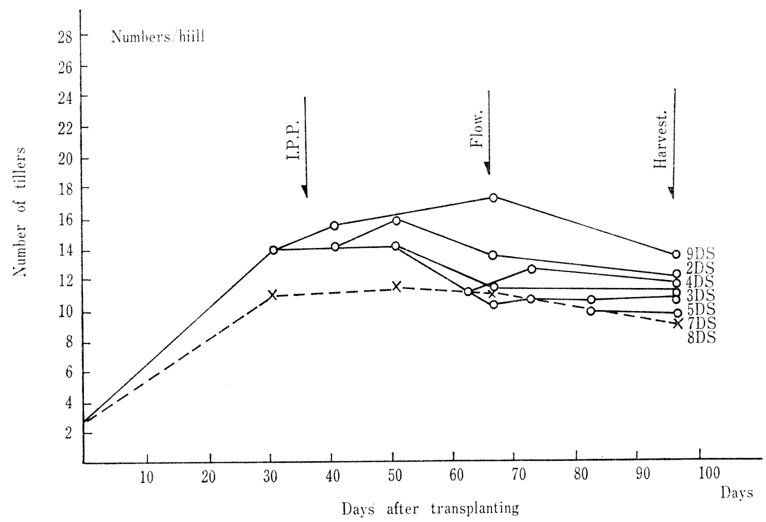

Fig. 19. Number of tillers (Second crop)

days after the treatment of top-dressing. However, the top-dressing applied at an early stage did not always result in higher plants at the time of harvest, because nitrogen shortage occurred at the later stage of growth. On the other hand, top-dressing applied at the later stages exhibited a less effect on plant height. Thus, there exists an optimum time of application which induces the highest plants. The data indicate that the time falls on 30 days before flowering.

2) Number of tillers

Early top-dressing increased remarkably tiller numbers but top-dressing applied after the flowering stage gave no effect, as shown in Figs. 18 and 19. Thus, the earlier the time of

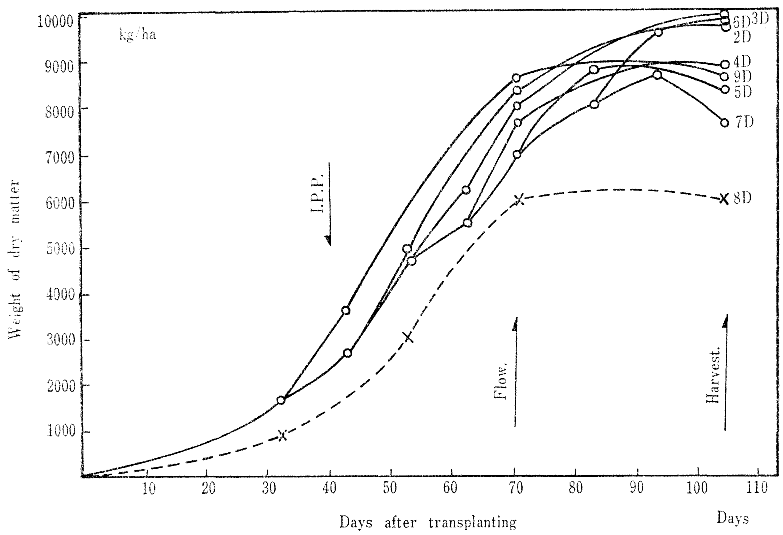

Fig. 20. Weight of dry matter (First crop)

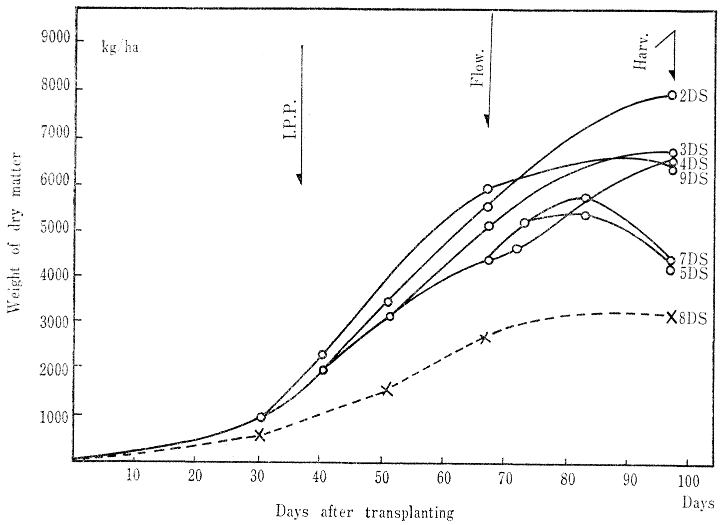

Fig. 21. Weight of dry matter (Second crop)

top-dressing, the more the number of tillers at the harvesting time, and the maximum number of tillers was obtained by the top-dressing at 40 days before flowering.

3) Weight of dry matter

Weight of dry matter was always increased by the top-dressing of nitrogen, but the earlier application caused a greater increase as shown in Figs. 20 and 21.

4) Leaf area index

Nitrogen top-dressing applied at an early stage induced a remarkable increase in LAI, but that applied after flowering stage caused no considerable increase of LAI, as given in Figs. 22 and 23.

5) Leaf length

It has been known by many experiments that leaf length is well effected by the timing of

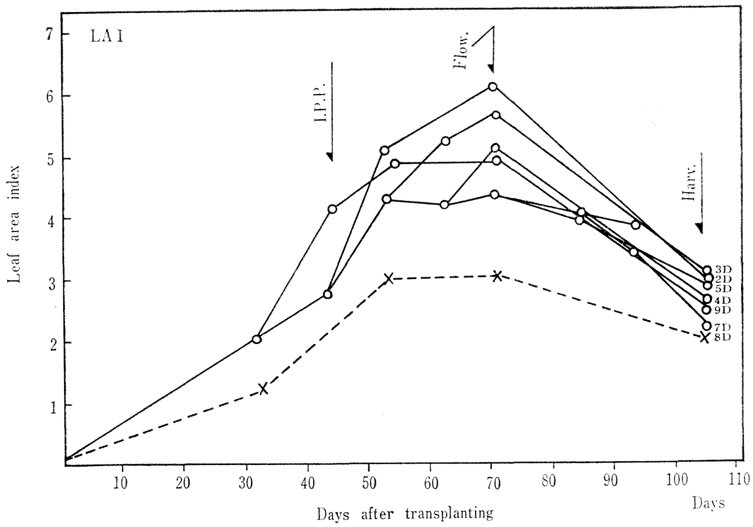

Fig. 22. Leaf area index (First crop)

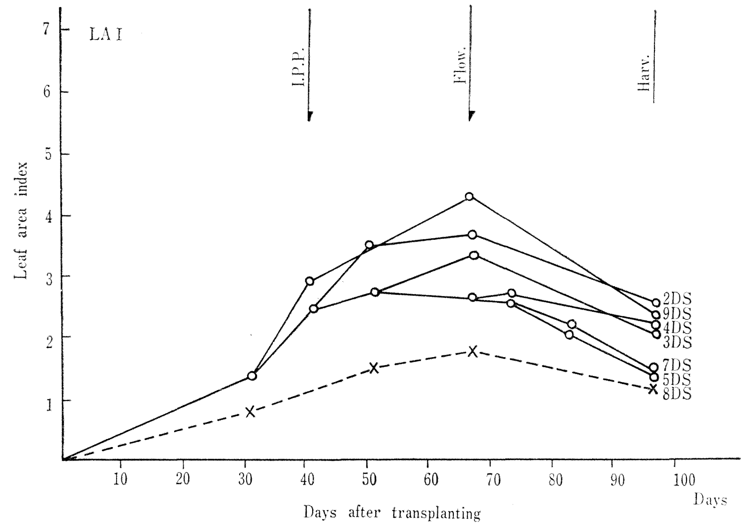

Fig. 23. Leaf area index (Second crop)

top-dressing of nitrogen. The data given in Figs. 24 and 25 indicates that the length of upper leaves was remarkably increased by the nitrogen applied at an early stage prior to 30 days before flowering. Nitrogen applied later than 20 days before flowering, however, gave no significant increase in leaf length.

B) Nitrogen content

As shown in Figs. 26 and 27, nitrogen content of leaf blades was increased by top-dressing of nitrogen. The increment of nitrogen content was 0.5~1.0% N on the basis of leaf blade dry weight when determined 10 days after top-dressing. No considerable difference in nitrogen content was observed between the plants with basal dressing and that without basal dressing when determined at the panicle primordia initiation stage.

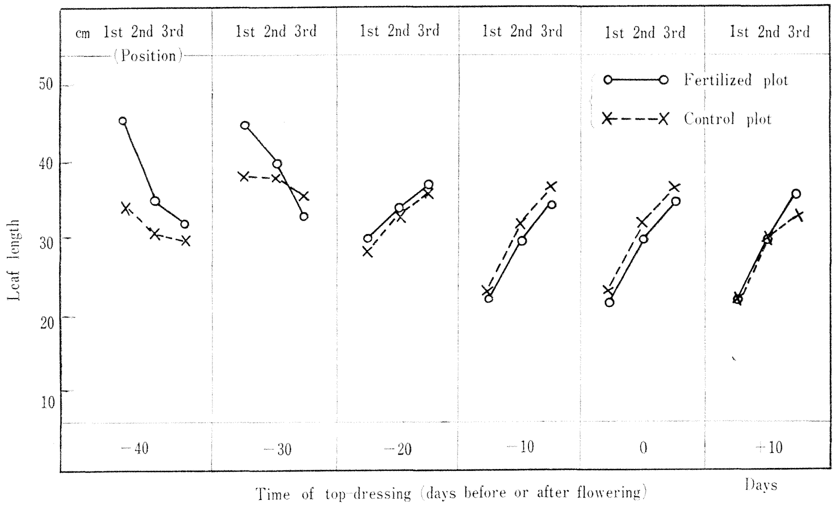

Fig. 24. Leaf length (First crop)

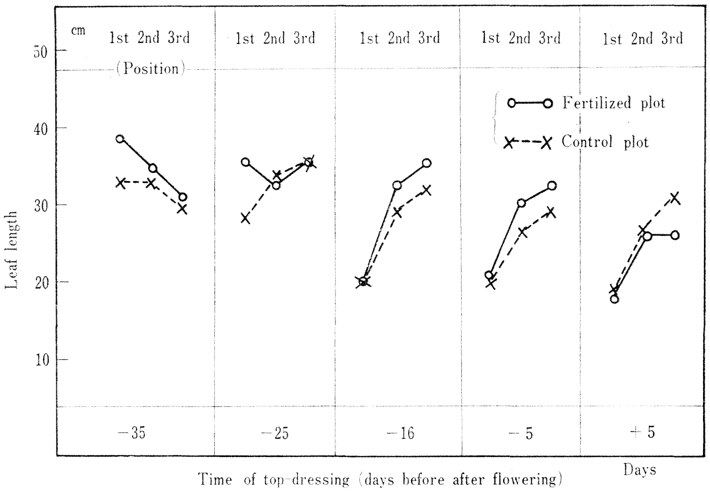

Fig. 25. Leaf length (Second crop)

C) Amounts of fertilizer nitrogen utilized by rice plants

As shown in Figs. 28 and 29, nitrogen applied as top-dressing was well utilized by rice plants; it showed a recovery of 40～70%, and most of it was utilized by plants within 10 day's period after dressing.

Nitrogen applied as basal dressing was recovered in grains and straw at 27%, indicating a very low recovery rate of the basally dressed nitrogen.

Patterns of nitrogen uptake in relation to plant growth was determined. Taking the total nitrogen in rice plants at the time of maturity as 100, 60% of which was derived from soil nitrogen and 40% from the added fertilizer nitrogen, of which one third was derived from basally dressed nitrogen and the rest was derived from the nitrogen of top-dressing.

It was the usual way to evaluate the effects of fertilizer nitrogen on the basis of the quan-

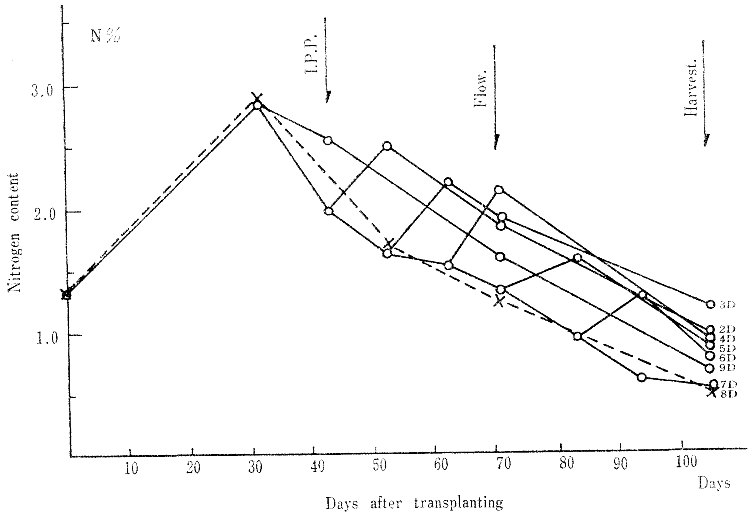

Fig. 26. Nitrogen content in leaf blade (First crop)

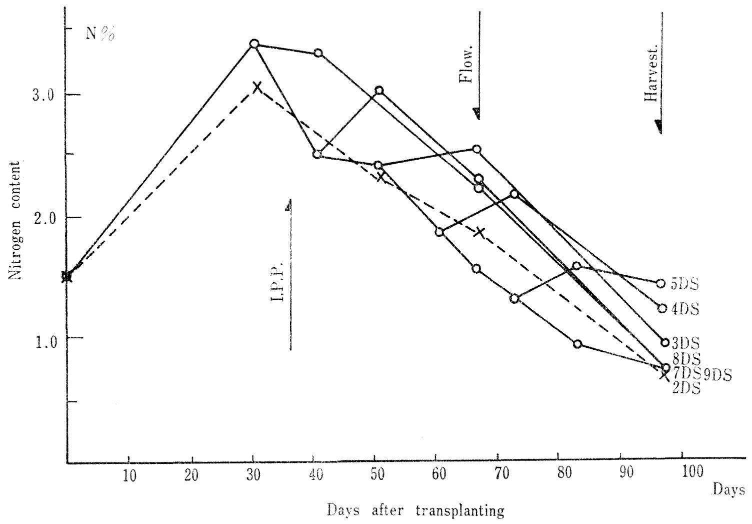

Fig. 27. Nitrogen content in leaf blade (Second crop).

tity absorbed by plants. However, the nitrogen absorbed from fertilizers tells only a part of a whole picture. Not only the nitrogen derived from fertilizers, but also a quantity of nitrogen absorbed from soil nitrogen as well as a ratio of the former to the latter must be taken into consideration. Results of this experiment revealed that at the tillering stage almost 30% of a total plant nitrogen were derived from fertilizer nitrogen applied as a basal dressing but this value was gradually decreased to as low as 20% at the panicle primordia initiation stage. However, at the flowering stage the ratio of fertilizer nitrogen to the total plant nitrogen was increased to about 40% because the top-dressing of nitrogen was applied at the period of panicle formation, and finally the ratio was slightly decreased at the harvesting time.

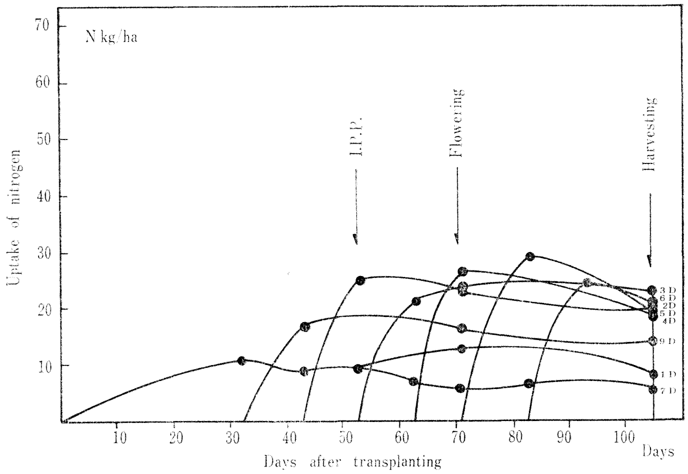

Fig. 28-a. Uptake patter of fertilizer nitrogen (First crop)

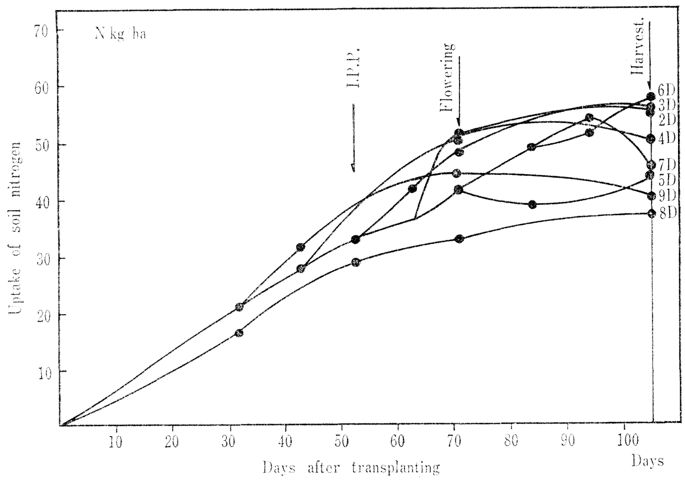

Fig. 28-b. Uptake pattern of soil nitrogen (First crop)

D) Yield components as affected by the timing of top-dressing of nitrogen.

The results are tabulated in Table 27

1) Number of panicles per unit area

As shown in Fig. 30, the response of number of panicles to nitrogen application was almost similar to that of number of tillers. The top-dressing at 30 days before flowering was most effective in increasing panicle number and 15% increase was obtained.

2) Number of spikelets

Of the four components of yield, the number of spikelets responded remarkably to the timing of the top-dressing of nitrogen. The highest number of spikelets was obtained when nitrogen was applied 30 days before flowering, as shown in Fig. 31.

3) Percentage of ripened grains

In contrast to the above-mentioned two yield components, the percentage of ripened grains showed a lowest value when nitrogen was applied 30 days before flowering. The value

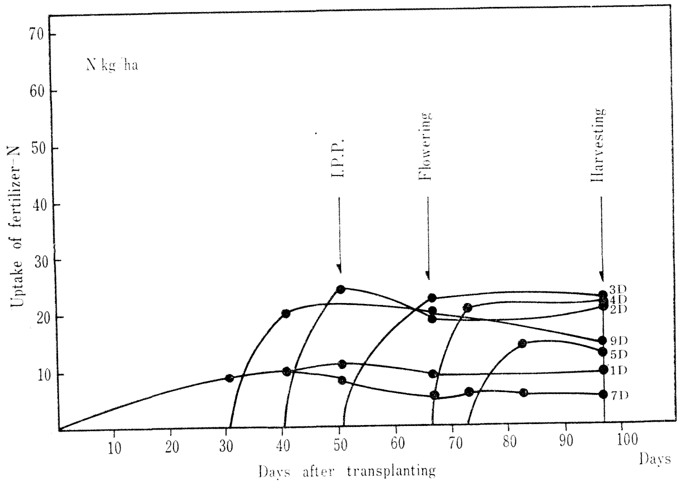

Fig. 29-a. Uptake pattern of fertilizer nitrogen (Second crop)

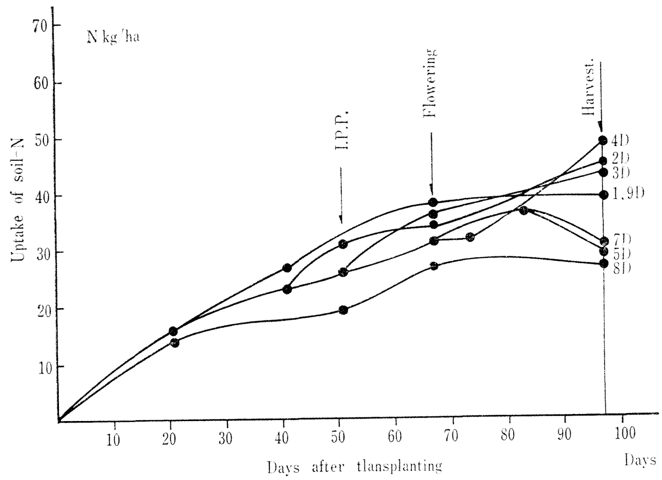

Fig. 29-b. Uptake pattern of soil nitrogen (Second crop)

was about 10% lower than values obtained with other treatment, as shown in Fig. 32.

In general, an increase in the number of spikeletes is accompanied by a decrease in the percentage of ripened grains. This trend was also observed with this experiment.

4) Weight of 1000 grains

As shown in Fig. 33, the weight of 1000 grains was remarkably increased when nitrogen fertilizer was dressed later than 20 days before flowering, a reverse correlation between the number of spikelets and the weight of 1000 grains was observed.

E) Grain yield as affected by the timing of top-dressing of nitrogen

The yield was changed according to the timing of top-dressing of nitrogen.

The best timing of top-dressing of nitrogen was found to fall on the day which is 30 days before flowering.

The analysis of yield components clarified that this was mainly due to the remarkable increase in the number of spikelets or of panicles per hill. Many reports indicated that this timing would be varied with soil fertility, the method of fertilizer application, and the climatic

Table 27. Yield Component (PB 76—63)

Treatment		Number of panicle/hill	Number of spikelets/ panicle	Percentage of ripened grains (%)	Weight of 1000 grains(g)
First crop	7D (No top-dressing)	10. 2	89. 1	81. 2	22. 5
	9D (−40)*	11. 2	89. 6	78. 9	22. 5
	2D (−30)	11. 6	112. 7	71. 2	22. 6
	3D (−20)	10. 3	99. 8	77. 5	24. 4
	4D (−10)	10. 5	90. 1	79. 5	23. 8
	5D (0)	10. 5	81. 5	83. 3	23. 5
	6D (+10)	11. 0	90. 9	84. 3	22. 8
	8D (No nitrogen)	9. 8	73. 9	80. 5	21. 7
Second crop	7D S (No top-dressing)	8. 5	79. 7	63. 5	20. 8
	9D S (−35)	11. 3	93. 0	64. 9	21. 8
	2D S (−25)	10. 9	102. 3	64. 6	22. 2
	3D S (−16)	10. 8	86. 1	60. 7	22. 6
	4D S (− 5)	9. 4	88. 9	67. 6	21. 9
	5D S (+ 5)	8. 3	77. 7	64. 7	21. 6
	8D S (No nitrogen)	7. 9	57. 1	61. 6	21. 1

N. B. * Days before or later flowering.

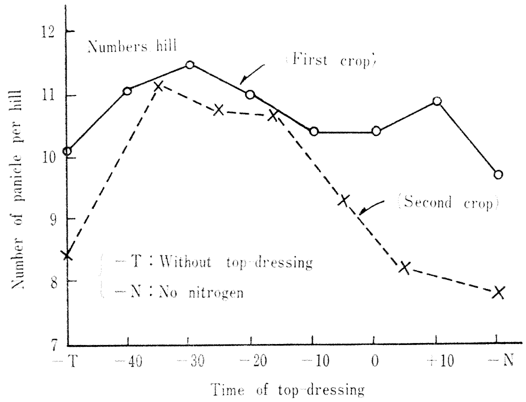

Fig. 30. Number of panicle

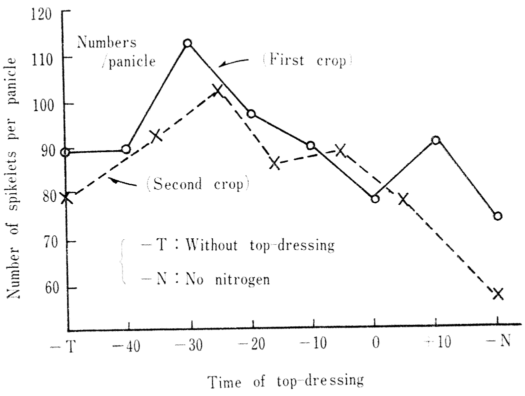

Fig. 31. Number of spikelets

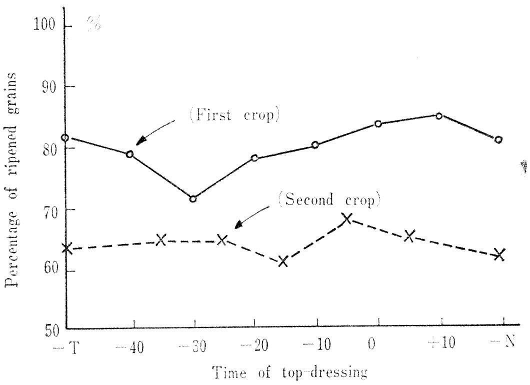

Fig. 32. Percentage of ripened grains

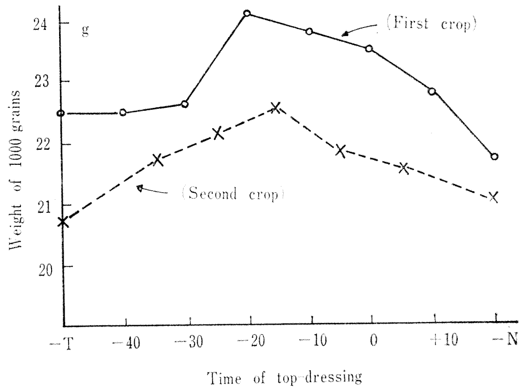

Fig. 33. Weight of 1000 grains

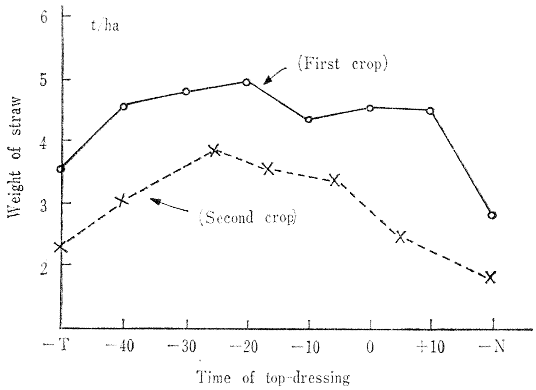

Fig. 34-a. Weight of straw

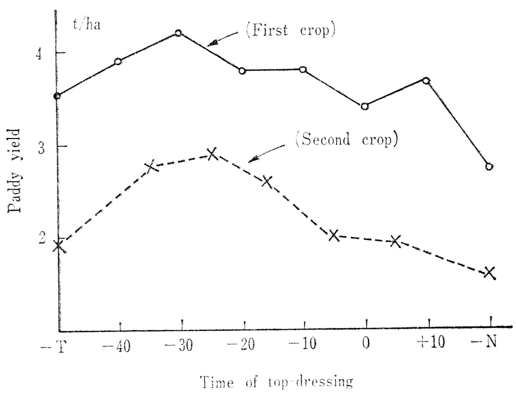

Fig. 34-b. Paddy yield

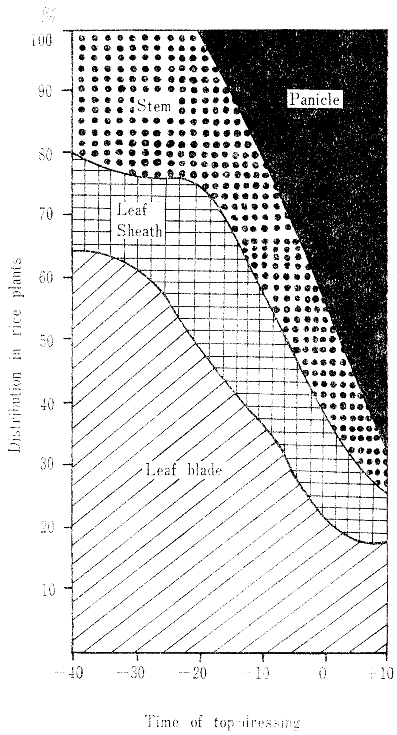

Fig. 35. Distribution of dressed nitrogen in rice plants

conditions. In Japan, however, a lot of experiments have shown that the time 25 days before flowering is the best. The results of the present experiment well coincide with these data, as shown in Fig. 34.

F) Distribution of nitrogen in rice plants

To know the physiological effect of dressed nitrogen, the distribution of absorbed nitrogen in a rice plant was determined.

As shown in Fig. 35, nitrogen applied as top-dressing at an early stage of panicle primordia development was mostly distributed in leaves and stems, while the nitrogen applied at a later stage was distributed in panicles.

For example, when a top-dressing of nitrogen was applied 40 days before flowering, 64% of the nitrogen derived from that top-dressing was distributed in leaf blades, on the contrary, 66% of the nitrogen absorbed from the top-dressing applied at 10 days after flowering was translocated into panicles. Obviously the former was used to built up vegetative organs, while the latter was utilized to built up panicles.

G) Role of soil nitrogen

A high correlation was found between paddy yields and soil nitrogen utilized by rice plants as shown in Fig. 36. This correlation furnishes a strong evidence that soil fertility played an important role in the determination of rice yields under limited nitrogen supply.

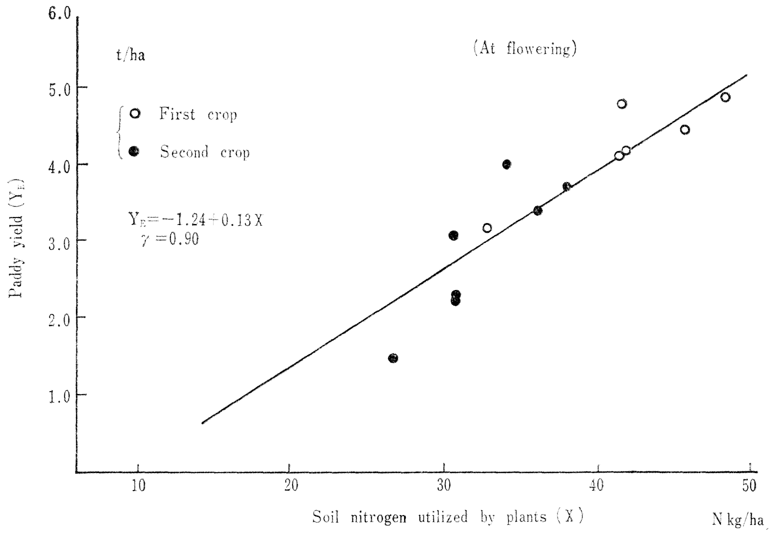

Fig. 36. Relationship between paddy yields and soil nitrogen utilized by plants

VI. Yield Components as Affected by the Timing of Top-dressing of Nitrogen in Relation to the Transplanting Time.

Of many factors possibly influencing yield components, the nitrogen application has been considered to be most effective and practical.

MATSUSHIMA *et al.*,[36] made clear that the effect of nitrogen on yield components differs with different time of application; good nutrition at an early stage of growth leads to more number of tillers and panicles and results in an increased number of spikelets per unit area, whereas good nutrition at a later stage of growth induces increased percentage of ripened grains and increased weight of 1000 grains. That is true as a general principle, but in practice there is always a question of timing of nitrogen top-dressing, because the effect of nitrogen top-dressing on yield components varies with different environmental conditions such as climate, varieties, soil fertility and so on.

Therefore, the authors examined effects of timing of nitrogen top-dressing on yield components in relation to time of transplanting.

METHOD

1) **Location of the experiment**:
The paddy field of Bangkhen Rice Experiment Station in Thailand.

2) **Variety**: Puang Nahk 16, a photoperiod-sensitive local rice variety.

3) **Spacing**: 20×20 cm

4) **Number of seedlings**: three per hill

5) **Treatment**:

As shown in Table 28, a half amount of nitrogen was applied as basal dressing at the transplanting time and the rest was applied at different stages, ranging from 60 days before flowering to 10 days after flowering at 10 day intervals.

Amount of nitrogen utilized by plants was determined by the isotope tracer technique using ^{15}N labelled fertilizer (5% excess ^{15}N). ^{15}N labelled ammonium sulphate was applied in a small sub-plot surrounded by a galvanized iron sheet. The area of this sub-plot was 0.8 M^2 (0.8 M×1.0 M).

6) **Transplanting time**:
Early transplanting, July 1st.
Late transplanting, September 1st.

7) **Replication**: Three replications

8) **Area of one plot**: 25 m^2 (5 m×5 m)

9) **Sampling**:

Plant samples were taken at 30 days after transplanting, 10 days after top-dressing, panicle primordia initiation, flowering and harvesting stage respectively. Analysis of yield compnents was done on 10 hills of rice plant.

Table 28. Design of experiment

Treatment (No.)	Basal-dressing (kg/ha)			Top-dressing N	
	N	P_2O_5	K_2O	(kg/ha)	Time of application
A) Experiment on early-transplanting					
A-1(−20)*	(37.5)	75	75	37.5	20 days before flowering
A-2(−50)	37.5	75	75	(37.5)	50 days before flowering
A-3(−40)	37.5	75	75	(37.5)	40 days before flowering
A-4(−30)	37.5	75	75	(37.5)	30 days before flowering
A-5(−20)	37.5	75	75	(37.5)	20 days before flowering
A-6(−10)	37.5	75	75	(37.5)	10 days before flowering
A-7(−T)**	37.5	75	75	—	No top-dressing
A-8(−N)***	—	75	75	(37.5)	No nitrogen application
A-9(−60)	37.5	75	75	(37.5)	60 days before flowering
B) Experiment on later-transplanting					
L-1(−20)	(37.5)	75	75	37.5	20 days before flowering
L-2(−30)	37.5	75	75	(37.5)	30 days before flowering
L-3(−20)	37.5	75	75	(37.5)	20 days before flowering
L-4(−10)	37.5	75	75	(37.5)	10 days before flowering
L-5(0)	37.5	75	75	(37.5)	Flowering time
L-6(+10)	37.5	75	75	(37.5)	10 days after flowering
L-7(−T)	37.5	75	75	—	No top-dressing
L-8(−N)	—	75	75	—	No nitrogen application
L-9(−40)	37.5	75	75	(37.5)	40 days before flowering

Remarks: Figures in bracket indicate using heavy nitrogen (^{15}N-isotope)
* Days before or later flowering   ** No top-dressing   *** No nitrogen

10) Spraying:

Sevin was sprayed two times in the nursery and three times at 10 day intervals after transplanting.

As Puang Nahk is susceptible to blast, Kasumin was sprayed when a sign of blast infection was recognized.

11) Chemical analysis:

Nitrogen was determined by Kjeldahl method and isotopic ratio was measured by a Mass-Spectrometer.

RESULTS

A) Amounts of fertilizer nitrogen utilized by plants

As shown in Figs. 37, 38, and 39, nitrogen top-dressed was well utilized by plants. The large portion of it was absorbed within 10 days after dressing. Whereas, the recovery rate of basally dressed nitrogen was unexpectedly lower than that of top-dressing.

The uptake pattern of nitrogen showed that about 70% of plant nitrogen was derived from soil nitrogen and the rest from fertilizer nitrogen, one third of which was absorbed from basal dressing and the rest from the top-dressing.

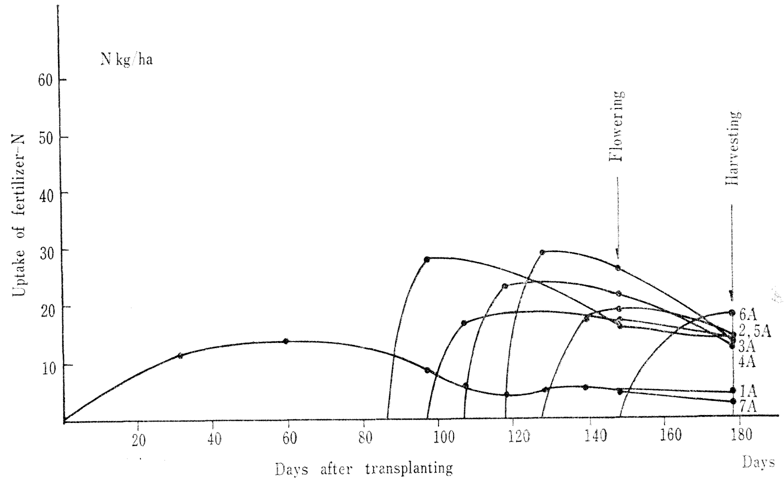

Fig. 37-a. Uptake pattern of fertilizer nitrogen (Early planting)

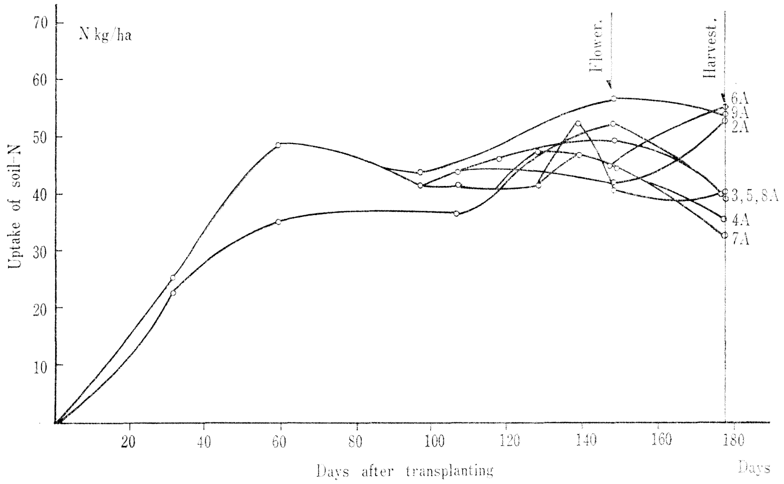

Fig. 37-b. Uptake pattern of soil nitrogen (Early planting)

The percentage contribution of soil nitrogen to the total plant nitrogen was higher than that of PB 76-63 variety (Refer to Chap. 5), because Puang Nahk 16 has a longer growth duration and therefore utilized much more soil nitrogen.

B) Yield components as affected by the timing of top-dressing of nitrogen

a) Panicle numbers

As shown in Fig. 40, the effect of timing of the top-dressing of nitrogen upon panicle numbers was not apparently observed when plants were transplanted early. However, in the late-transplanted plot, number of panicles was obviously increased by the nitrogen top-dressing applied at 35 or 45 days before flowering.

Previous experiment pointed out that the number of panicles is primarily correlative to the grain yield; less number of panicles results in low grain yield. However, the less num-

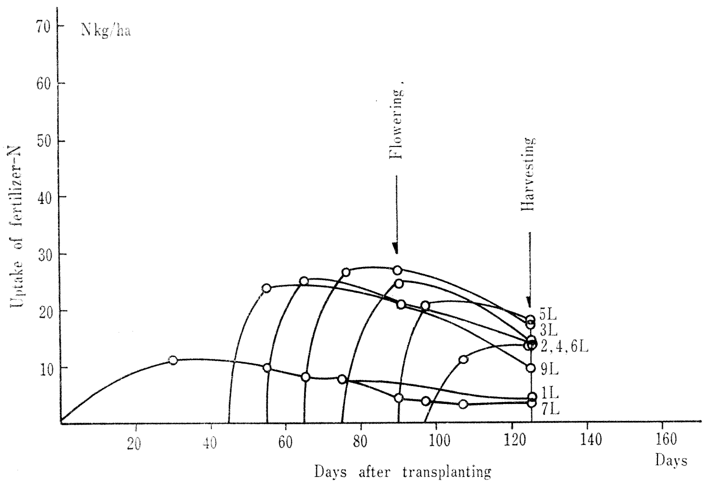

Fig. 38-a. Uptake pattern of fertilizer nitrogen (Late planting)

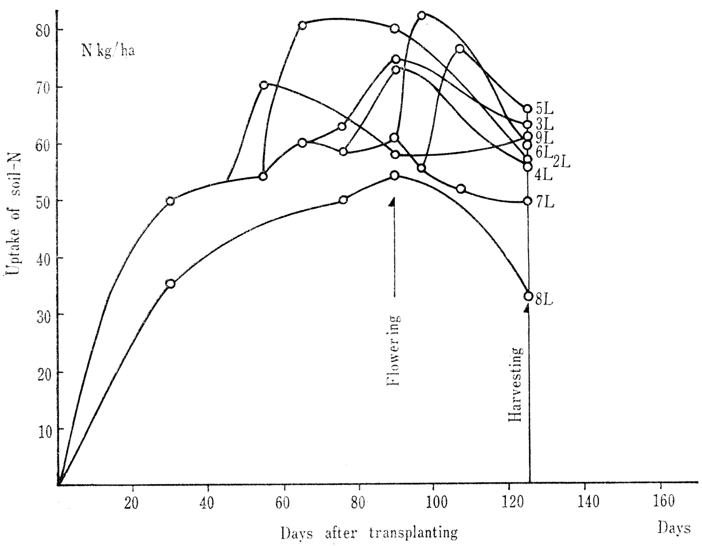

Fig. 38-b. Uptake pattern of soil nitrogen (Late planting)

ber of panicles is not due to the poor tillering ability, but caused by the die-back of small tillers, which were produced lately, probably due to the lack of sun-light and nutrient supply. This relation is shown by the low percentage of effective tillers to the total number of tillers produced. It occurs frequently with a long growth duration of plants.

b) Number of spikelets per panicle

Number of spikelets per panicle was distinctively increased by the nitrogen top-dressing applied before the stage 30 days prior to flowering in the early transplanted plot, and applied at just 35 days before flowering in the late transplanted plot, as illustrated in Fig. 41.

c) Percentage of ripened grains and weight of 1000 grains

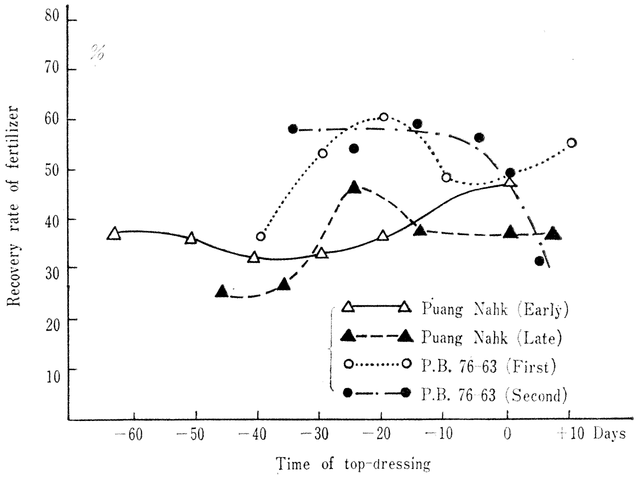

Fig. 39. Relationship between time of top-dressing of nitrogen and recovery rate of fertilizer

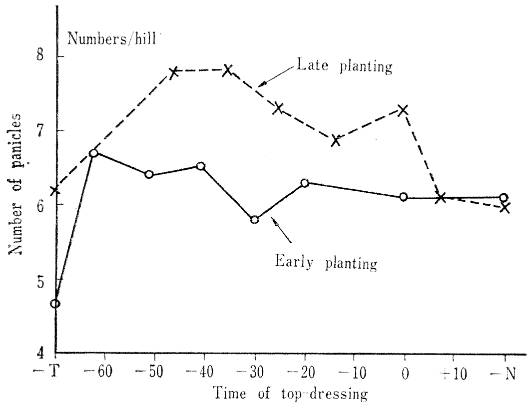

Fig. 40. Number of panicles

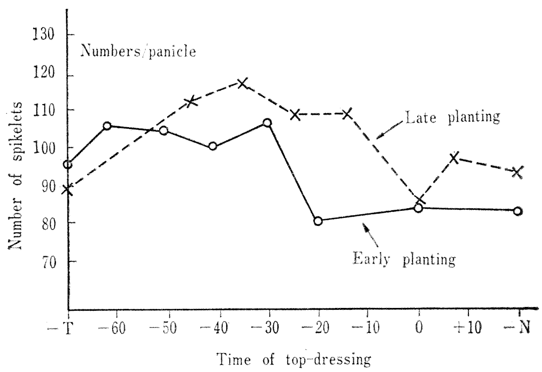

Fig. 41. Number of spikelets

No remarkable change in the percentage of fully ripened complete grains to the total number of grains produced and in weight of 1000 grains was caused by the top-dressing applied at different stages as given in Figs. 42 and 43.

All these data are tabulated in Table 29.

C) Grain yield

In case of early transplanting, the top-dressing of nitrogen did not give a remarkable effect on grain yield, although the earlier the time of application, the higher was the grain yield. With late transplanting, the yield-increasing effect of top-dressing was very remarkable and the application at 35 days before flowering gave the highest yield, as shwon in Fig. 44.

It was expected that nitrogen applied at the flowering stage or stages later than flowering might be effective in increasing yield, because local varieties are used to produce large panicles and these large panicles absorb a large amount of nitrogen from leaves, thus resulting in

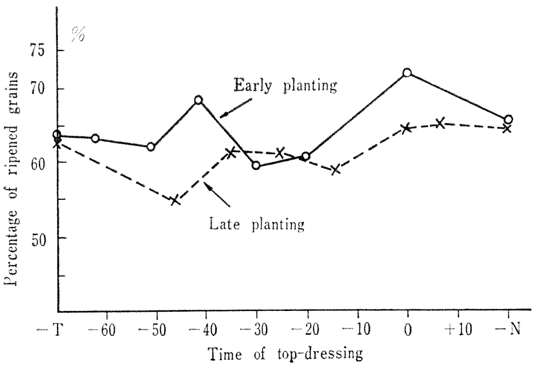

Fig. 42. Percentage of ripened grains

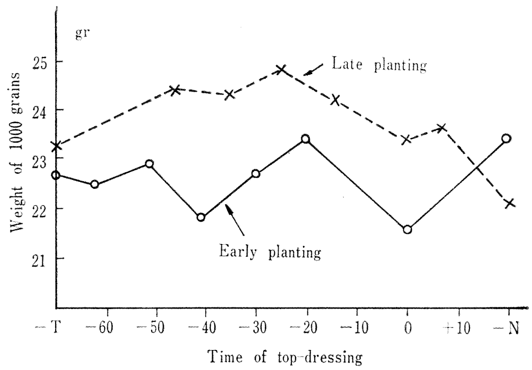

Fig. 43. Weight of 1000 grains

Table 29. Yield Components (Puang Nahk)

Treatment		Number of panicles	Length of panicles (cm)	Number of spikelets per panicles			Weight of 1000 grains (g)	Percentage of ripened grains
				Filled	Unfilled	Total		
Early planting	9A (−62)*	6.7	22.9	67.0	38.9	105.9	22.5	63.3
	2A (−51)	6.4	22.9	61.5	39.5	104.9	22.9	62.2
	3A (−41)	6.5	24.0	68.4	32.1	100.5	21.8	68.1
	4A (−30)	5.8	22.1	63.2	43.5	106.7	22.7	59.2
	5A (−20)	6.3	19.8	48.7	31.8	80.5	23.4	60.5
	6A (0)	6.1	20.3	59.6	23.8	83.4	21.6	71.5
	7A (−T)**	4.7	22.4	61.0	34.8	95.8	22.7	63.7
	8A (−N)***	6.1	21.5	53.6	29.0	82.6	23.4	64.9
Late planting	9L (−46)	7.8	23.6	61.5	50.9	112.4	24.4	54.7
	2L (−35)	7.8	23.0	71.5	45.4	116.9	24.3	61.2
	3L (−25)	7.3	23.6	66.0	42.7	108.7	24.8	60.7
	4L (−14)	6.9	23.1	64.4	44.5	108.9	24.2	58.7
	5L (0)	7.3	21.9	54.4	30.5	84.9	23.4	64.1
	6L (+ 7)	6.1	21.8	62.3	34.5	96.8	23.6	64.4
	7L (−T)	6.2	21.5	56.0	33.1	89.1	23.3	62.9
	8L (−N)	6.0	22.5	59.7	33.3	93.0	22.1	64.2

N. B. * Days before or later flowering ** No top-dressing *** No nitrogen

the nitrogen exhaustion and retarted photosynthetic activity of leaves during the ripening period.

But, the experimental result showed that it is not the case. Nitrogen absorbed from the top-dressing was mainly distributed to panicles and not to leaves, so that photosynthetic activity of leaves might not be enhanced as expected.

D) Productive efficiency of nitrogen

The efficiency of nitrogen for grain production as defined as weight of grains produced per one gram of nitrogen absorbed by plants was calculated as shown in Table 30.

With the photoperiod-sensitive local variety, Puang Nahk, it was found that the productive efficiencies of the nitrogen applied at different stages of growth decreased as the plant growth stage advanced, when this variety was transplanted in early season. While, the

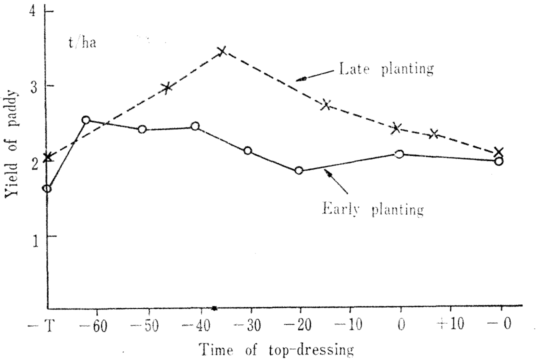

Fig. 44-a. Yield of paddy

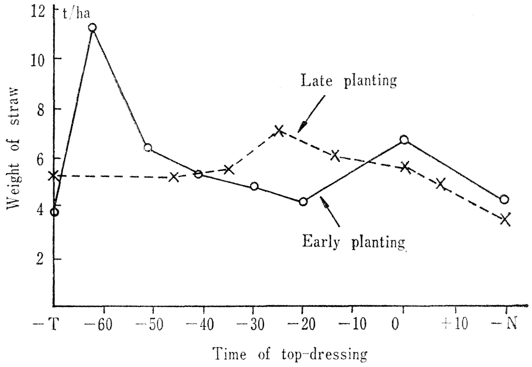

Fig. 44-b. Weight of straw

Table 30. Productive efficiency of fertilizer-^{15}N for grains

Variety	Growing season	Plot	Time of top-dressing of ^{15}N	Top-dressed ^{15}N taken up by plants (kg/ha)	Yield of paddy (kg/ha) excess over without top dressing plot	Productive efficiency of ^{15}N (kg/ha)
Puang Nahk-16	Early-planting	9A	62 days before flowering	13.8	890	64
		2A	51 days before flowering	13.6	750	55
		3A	41 days before flowering	12.3	790	64
		4A	30 days before flowering	12.9	450	35
		5A	20 days before flowering	13.9	170	12
		6A	Flowering	17.9	340	19
	Late-planting	9L	46 days before flowering	9.7	900	93
		2L	35 days before flowering	13.9	1370	99
		3L	25 days before flowering	17.6	960	55
		4L	14 days before flowering	14.3	650	45
		5L	Flowering	18.0	300	17
		6L	7 days after flowering	14.1	220	16
P.B. 76—63	First-crop	9D	40 days before flowering	13.8	310	22
		2D	30 days before flowering	20.0	1110	56
		3D	20 days before flowering	22.8	710	31
		4D	10 days before flowering	18.3	320	17
		5D	Flowering	18.5	30	2
		6D	10 days after flowering	20.7	640	31
	Second-crop	9D S	35 days before flowering	13.9	1480	106
		2D S	25 days before flowering	20.4	1760	86
		3D S	15 days before flowering	22.1	950	43
		4D S	5 days before flowering	21.1	850	40
		5D S	5 days after flowering	12.2	10	1

productive efficiencies of the applied nitrogen attained the maximum at the stage of panicle primordia initiation which fell on the day 35 days before flowering, when this variety was transplanted in later season.

On the other hand, in the case of P.B. 76-63 variety (Chap. 5) (nonphotoperiod-sensitive improved variety), the highest efficiency of nitrogen was obtained when applied at the stage of panicle primordia initiation, which fell on the day 30 days before flowering. Thus, it is clear that the nitrogen application at the stage of panicle primordia initiation is critical in determining the yield of this variety as shown in Fig. 45.

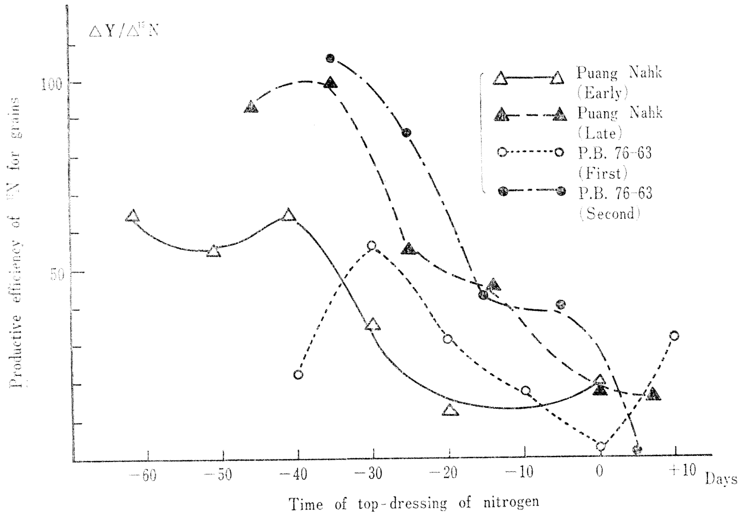

Fig. 45. Relationship between time of top-dressing of nitrogen and productive efficiency of nitrogen for grains

Theoretically, the efficiency of nitrogen for grain production can be analyzed into four components *viz.*, the efficiency of nitrogen for panicle formation, for spikelet formation per panicle, for percentage of ripened grains and for weight of 1000 grains.

Experimental results showed that the efficiency of nitrogen for the panicle formation was gradually decreased as the growth stage advanced, as shown in Table 31. However, a large negative value was obtained for the basal nitrogen with Puang Nahk-16 transplanted early. This was probably due to an extremely long growth duration of this variety. The efficiency of nitrogen for spikelet formation was shown in Table 32.

High efficiency was observed with the basally applied nitrogen and nitrogen applied at the panicle primordia initiation stage, about 30 days before flowering.

The efficiency of nitrogen for percentage of ripened grains seems to be reversely related to the efficiency of nitrogen for the spikelet formation. Fairly high efficiency was observed with nitrogen supply at the later stages of growth as shown in Table 33.

The efficiency of nitrogen for weight of 1000 grains was changed only a little with the time of nitrogen supply. (Table 34)

Table 31. Efficiency of fertilizer nitrogen for panicle formation

Variety			P.B. 76—63			Variety			Puang Nahk-16		
Treatment			N.P.*	$\triangle^{15}N$**	$\frac{N.P.}{\triangle^{15}N} \times 100$	Treatment			N.P.	$\triangle^{15}N$	$\frac{N.P.}{\triangle^{15}N} \times 100$
Basal-^{15}N		First crop	0.4	43.2	0.9	Basal-^{15}N		Early transplanted	−1.4	15.6	−9.0
Top dressing-^{15}N	−40***	First crop	1.0	55.2	1.8	Top dressing-^{15}N	−62	Early transplanted	2.0	55.2	3.6
Top dressing-^{15}N	−30	First crop	1.4	80.0	1.8	Top dressing-^{15}N	−51	Early transplanted	1.7	54.4	3.1
Top dressing-^{15}N	−20	First crop	0.1	91.2	0.1	Top dressing-^{15}N	−41	Early transplanted	1.8	49.2	3.7
Top dressing-^{15}N	−10	First crop	0.3	73.2	0.4	Top dressing-^{15}N	−30	Early transplanted	1.1	51.6	2.1
Top dressing-^{15}N	0	First crop	0.3	74.0	0.4	Top dressing-^{15}N	−20	Early transplanted	1.6	55.6	2.9
Top dressing-^{15}N	+10	First crop	0.8	82.8	1.0	Top dressing-^{15}N	0	Early transplanted	1.4	71.6	2.0
Basal-^{15}N		Second crop	0.6	35.6	1.7	Basal-^{15}N		Late transplanted	0.2	17.6	1.0
Top dressing-^{15}N	−35	Second crop	2.8	55.6	5.0	Top dressing-^{15}N	−46	Late transplanted	1.6	38.8	4.1
Top dressing-^{15}N	−25	Second crop	2.4	81.6	2.9	Top dressing-^{15}N	−35	Late transplanted	1.6	55.6	2.9
Top dressing-^{15}N	−16	Second crop	2.3	88.4	2.6	Top dressing-^{15}N	−25	Late transplanted	1.1	70.4	1.6
Top dressing-^{15}N	− 5	Second crop	0.9	84.4	1.1	Top dressing-^{15}N	−14	Late transplanted	0.7	57.2	1.2
Top dressing-^{15}N	+ 5	Second crop	−0.2	48.8	−0.4	Top dressing-^{15}N	0	Late transplanted	1.1	72.0	1.5
						Top dressing-^{15}N	+ 7	Late transplanted	−0.1	56.4	−0.2

N.B. N.P.*: Partial number of panicles. $\triangle^{15}N$:** Partial absorbed ^{15}N mg/hill
*** Days before or later flowering.

Table 32. Efficiency of fertilizer nitrogen for spikelets formation

Variety			P.B. 76—63			Variety			Puang Nahk-16		
Treatment			N.S.*	$\triangle^{15}N$**	$\frac{N.S.}{\triangle^{15}N} \times 100$	Treatment			N.S.	$\triangle^{15}N$	$\frac{N.S.}{\triangle^{15}N} \times 100$
Basal-^{15}N		First crop	15.2	43.2	35.2	Basal-^{15}N		Early transplanted	13.2	15.6	84.6
Top dressing-^{15}N	−40***	First crop	0.5	55.2	0.9	Top dressing-^{15}N	−62	Early transplanted	10.1	55.2	18.3
Top dressing-^{15}N	−30	First crop	23.6	80.0	29.5	Top dressing-^{15}N	−51	Early transplanted	9.1	54.4	16.7
Top dressing-^{15}N	−20	First crop	10.7	91.2	11.7	Top dressing-^{15}N	−41	Early transplanted	4.7	49.2	9.6
Top dressing-^{15}N	−10	First crop	1.0	73.2	1.4	Top dressing-^{15}N	−30	Early transplanted	10.9	51.6	21.1
Top dressing-^{15}N	0	First crop	−7.6	74.0	−10.3	Top dressing-^{15}N	−20	Early transplanted	−15.3	55.6	−27.5
Top dressing-^{15}N	+10	First crop	1.8	82.8	2.2	Top dressing-^{15}N	0	Early transplanted	−12.4	71.6	−17.3
Basal-^{15}N		Second crop	22.6	35.6	63.5	Basal-^{15}N		Late transplanted	−3.8	17.6	−22.2
Top dressing-^{15}N	−35	Second crop	13.3	55.6	23.9	Top dressing-^{15}N	−46	Late transplanted	23.3	38.8	60.1
Top dressing-^{15}N	−25	Second crop	22.6	81.6	27.7	Top dressing-^{15}N	−35	Late transplanted	27.8	55.6	50.0
Top dressing-^{15}N	−16	Second crop	6.4	88.4	7.2	Top dressing-^{15}N	−25	Late transplanted	19.6	70.4	27.8
Top dressing-^{15}N	− 5	Second crop	9.2	84.4	10.9	Top dressing-^{15}N	−14	Late transplanted	19.8	57.2	34.6
Top dressing-^{15}N	+ 5	Second crop	−2.0	48.8	−4.1	Top dressing-^{15}N	0	Late transplanted	−4.2	72.0	−5.8
						Top dressing-^{15}N	+ 7	Late transplanted	7.7	56.4	13.7

N.B. N.S.*: Partial number of spikelets $\triangle^{15}N$:** Partial absorbed ^{15}N mg/hill
*** Days before or later flowering.

Table 33. Efficiency of fertilizer nitrogen for percentage of ripened grains

Variety / Treatment			P.B. 76—63 P.R.*	$\triangle^{15}$N**	$\frac{P.R.}{\triangle^{15}N}\times 100$	Variety / Treatment			Puang Nahk-16 P.R.	$\triangle^{15}$N	$\frac{P.R.}{\triangle^{15}N}\times 100$
Basal-^{15}N		First crop	0.7	43.2	1.6	Basal-^{15}N		Early transplanted	−1.2	15.6	−7.7
Top dressing-^{15}N	−40***	First crop	−2.3	55.2	−4.2	Top dressing-^{15}N	−62	Early transplanted	−0.4	55.2	−0.7
Top dressing-^{15}N	−30	First crop	−10.0	80.0	−12.5	Top dressing-^{15}N	−51	Early transplanted	−1.5	54.4	−2.8
Top dressing-^{15}N	−20	First crop	−3.7	91.2	−4.1	Top dressing-^{15}N	−41	Early transplanted	4.4	49.2	8.9
Top dressing-^{15}N	−10	First crop	−1.7	73.2	−2.3	Top dressing-^{15}N	−30	Early transplanted	−4.5	51.6	−8.7
Top dressing-^{15}N	0	First crop	2.1	74.0	2.8	Top dressing-^{15}N	−20	Early transplanted	−3.2	55.6	−5.8
Top dressing-^{15}N	+10	First crop	3.2	82.8	3.9	Top dressing-^{15}N	0	Early transplanted	7.8	71.6	10.9
Basal-^{15}N		Second crop	1.9	35.6	5.3	Basal-^{15}N		Late transplanted	−1.3	17.6	−7.4
Top dressing-^{15}N	−35	Second crop	1.4	55.6	2.5	Top dressing-^{15}N	−46	Late transplanted	−8.2	38.8	−21.1
Top dressing-^{15}N	−25	Second crop	1.1	81.6	1.3	Top dressing-^{15}N	−35	Late transplanted	−1.7	55.6	−3.1
Top dressing-^{15}N	−16	Second crop	−2.8	88.4	−3.2	Top dressing-^{15}N	−25	Late transplanted	−2.2	70.4	−3.1
Top dressing-^{15}N	− 5	Second crop	4.1	84.4	4.9	Top dressing-^{15}N	−14	Late transplanted	−4.2	57.2	−7.3
Top dressing-^{15}N	+ 5	Second crop	1.2	48.8	2.5	Top dressing-^{15}N	0	Late transplanted	1.2	72.0	1.7
						Top dressing-^{15}N	+ 7	Late transplanted	1.5	56.4	2.7

N.B. P.R.: * Partial percentage of ripened grains % $\triangle^{15}$N**: Partial absorbed ^{15}N mg/hill
*** Days before or later flowering.

Table 34. Efficiency of fertilizer nitrogen for grain weight

Variety / Treatment			P.B. 76—63 W.G.*	$\triangle^{15}$N**	$\frac{W.G.}{\triangle^{15}N}\times 100$	Variety / Treatment			Puang Nahk-16 W.G.	$\triangle^{15}$N	$\frac{W.G.}{\triangle^{15}N}\times 100$
Basal-^{15}N		First crop	0.8	43.2	1.9	Basal-^{15}N		Early transplanted	−0.7	15.6	−4.5
Top dressing-^{15}N	−40***	First crop	0	55.2	0	Top dressing-^{15}N	−62	Early transplanted	−0.2	55.2	−0.4
Top dressing-^{15}N	−30	First crop	0.1	80.0	0.1	Top dressing-^{15}N	−51	Early transplanted	0.2	54.4	0.4
Top dressing-^{15}N	−20	First crop	1.9	91.2	2.1	Top dressing-^{15}N	−41	Early transplanted	−0.9	49.2	−1.8
Top dressing-^{15}N	−10	First crop	1.3	73.2	1.8	Top dressing-^{15}N	−30	Early transplanted	0	51.6	0
Top dressing-^{15}N	0	First crop	1.0	74.0	1.4	Top dressing-^{15}N	−20	Early transplanted	0.7	55.6	1.3
Top dressing-^{15}N	+10	First crop	0.3	82.8	0.4	Top dressing-^{15}N	0	Early transplanted	1.1	71.6	1.5
Basal-^{15}N		Second crop	−0.3	35.6	−0.8	Basal-^{15}N		Late transplanted	1.2	17.6	6.8
Top dressing-^{15}N	−35	Second crop	1.0	55.6	1.8	Top dressing-^{15}N	−46	Late transplanted	1.1	38.8	2.8
Top dressing-^{15}N	−25	Second crop	1.4	81.6	1.7	Top dressing-^{15}N	−35	Late transplanted	1.0	55.6	1.8
Top dressing-^{15}N	−16	Second crop	1.8	88.4	2.0	Top dressing-^{15}N	−25	Late transplanted	1.5	70.4	2.1
Top dressing-^{15}N	− 5	Second crop	1.1	84.4	1.3	Top dressing-^{15}N	−14	Late transplanted	0.9	57.2	1.6
Top dressing-^{15}N	+ 5	Second crop	0.8	48.8	1.6	Top dressing-^{15}N	0	Late transplanted	0.1	72.0	0.1
						Top dressing-^{15}N	+ 7	Late transplanted	0.3	56.4	0.5

N.B. W.G.: * Partial weight of 1000 grains (g) $\triangle^{15}$N**: Partial absorbed ^{15}N mg/hill
*** Days before or later flowering.

VII. Timing of Top-dressing of Nitrogen at Different Levels of Basal Dressing of Nitrogen

The benefit of nitrogen application at the panicle primordia formation stage of rice plants may vary by the level of basal application of nitrogen.

ISHIZUKA and TANAKA[37] reported that the nitrogen requirements at different stage of growth can be expressed by the partial efficiencies of nitrogen at different stages of growth and, in particular, more clearly in the series of low nitrogen level than in that of high nitrogen level, because rice plants are apt to absorb more nitrogen than they require, and they can store it for a considerable time.

UCHIDA *et al.*[38] also examined effects of the later application of nitrogen and recognized that the top-dressing at panicle primordia formation stage will give slight increase in yield if nitrogen contents in rice plant are getting to be minimum due to the limited supply of nitrogen as basal dressing.

These results suggest that if the rice plants received heavy dose of nitrogen basal dressing, the best time for top-dressing must be changed. This experiment was conducted to clarify this point.

METHOD

1) Soil and variety used:

Two seedlings of RD-3, a non-photoperiod-sensitive, non-glutinous recommended variety were planted to each pot, containing 15 kg of Pathumthani top soil.

2) Replication:

Two replications, consisted of two sets of 12 pots used for each treatment.

3) Treatment:

Experimental treatments were consisted of the combination of four different levels of basal nitrogen and three different times of top-dressing of nitrogen as shown in Table 35.

4) Chemical form of fertilizers:

Nitrogen as $(NH_4)_2SO_4$, phosphorus as superphosphate, potassium as K_2SO_4. Deep placement for basal dressing. 2.0% enriched ^{15}N were used in this experiment, 384 pots in total.

5) Time of planting and harvesting:

Sowing, transplanting and harvesting were made on 1 October, 22 October 1970 and 8 February 1971 respectively.

6) Sampling and measurement:

Plant height, number of tillers and weight of dry matter were measured at the following growth stages: tillering stage (one month after transplanting), 10 days after top-dressing, flowering time and harvesting. Measurement was done using 6 hills for each treatment. Nitrogen was determined by Kjeldahl distillation method. The samples labelled by ^{15}N (heavy nitrogen) were condensed to 2∼3 ml after distillation, then subjected to isotope-ratio measurement.

Table 35. Design of fertilizer application

(g/pot)

Treatment	Basal dressing			Timing of the top-dresing of nitrogen		
	N	P_2O_5	K_2O	−30 days	−20 days	−10 days
A (-30)*	0	2.0	2.0	(1.0)	—	—
B (-20)	0	2.0	2.0	—	(1.0)	—
C (-10)	0	2.0	2.0	—	—	(0.1)
D (-N)	0	2.0	2.0	—	—	—
E (-30)	1.0	2.0	2.0	(1.0)	—	—
F (-20)	1.0	2.0	2.0	—	(1.0)	—
G (-10)	1.0	2.0	2.0	—	—	(1.0)
H (-T)	(1.0)	2.0	2.0	—	—	—
I (-30)	1.5	2.0	2.0	(1.0)	—	—
J (-20)	1.5	2.0	2.0	—	(1.0)	—
K (-10)	1.5	2.0	2.0	—	—	(1.0)
L (-T)	(1.5)	2.0	2.0	—	—	—
M (-30)	2.0	2.0	2.0	(1.0)	—	—
N (-20)	2.0	2.0	2.0	—	(1.0)	—
O (-10)	2.0	2.0	2.0	—	—	(1.0)
P (-T)	(2.0)	2.0	2.0	—	—	—

N.B.: Bracket indicates ^{15}N nitrogen.
* Days before flowering.

Yield components, number of panicles, number of spikelets, percentage of ripened grains, and weight of 1000 grains, were determined using 6 hills for each treatment.

7) **Plant protection:**

Necessary sprayings were made for crop protection.

RESULTS

A) Growth process

1) Plant height

Plant height is not only effected clearly by the level of basal application of nitrogen but also by the time of top-dressing.

As shown in Table 36, the earlier the application of top-dressing, the higher was plant height. However, the effectiveness of top-dressing in increasing plant height depended on the level of basal dressing of nitrogen; a higher effectiveness at a lower level of basal dressing.

2) Number of tillers

Number of tillers was remarkably effected by the level of basal dressing. As shown in Table 36, more tillers were produced at higher level of basal nitrogen. Top-dressing was also effective in increasing number of tillers, except at he highest level of basal dressing of nitrogen. However, the effect of timing of top-dressing of nitrogen on tiller number was not clearly observed.

3) Weight of dry matters

Plant dry matter was greater at higher levels of basal dressing of nitrogen than at lower levels of it as shown in Table 36.

Table 36. Growth process for the timing of top-dressing of nitrogen in different level of basal dressing of nitrogen

Date of sampling	Treatment	Plant height (cm)	Number of tillers per hill	Number of panicles	Length of panicle (cm)	Weight of dry matter g/hill				Leaf length (cm)			
						Leaf	Stem	Panicle	Total	1 st.	2nd.	3 rd.	Flag leaf
(a) At 29 days after transplanting													
October 22	Seedling	25.00	1.00	—	—	—	—	—	0.19	—	—	—	—
November 20(29)*	A	52.10	1.52	—	—	0.18	0.14	—	0.32	—	—	—	—
	B	49.58	1.56	—	—	0.20	0.16	—	0.36	—	—	—	—
	C	46.45	1.41	—	—	0.16	0.14	—	0.30	—	—	—	—
	D	52.00	1.83	—	—	0.24	0.20	—	0.44	—	—	—	—
	E	68.18	8.03	—	—	1.43	0.85	—	2.28	—	—	—	—
	F	69.08	8.00	—	—	1.23	0·95	—	2.18	—	—	—	—
	G	65.25	5.19	—	—	0.89	0.54	—	1.43	—	—	—	—
	H	63.43	7.08	—	—	1.16	0.76	—	1.92	—	—	—	—
	I	68.49	7.34	—	—	1.27	0.79	—	2.06	—	—	—	—
	J	66.42	7.15	—	—	1.31	0.79	—	2.10	—	—	—	—
	K	64.33	4.75	—	—	0.74	0.42	—	1.16	—	—	—	—
	L	62.30	4.93	—	—	0.77	0.46	—	1.23	—	—	—	—
	M	57.00	4.33	—	—	0.45	0.25	—	0.70	—	—	—	—
	N	58.43	4.65	—	—	0.57	0.30	—	0.87	—	—	—	—
	O	61.34	5.91	—	—	0.88	0.51	—	1.39	—	—	—	—
	P	58.99	4.64	—	—	0.65	0.42	—	1.07	—	—	—	—
(b) At 74 days after transplanting													
January 4, 1971 (74)*	A	97.75	13.00	3.38	—	6.09	9.25	1.50	16.84	—	—	—	—
	B	90.42	10.83	1.84	—	3.89	4.50	0.42	8.81	—	—	—	—
	C	73.42	5.83	1.17	—	1.75	2.03	0.20	3.98	—	—	—	—
	D	64.00	2.42	0	—	0.82	1.73	0	2.55	—	—	—	—
	E	108.09	18.75	14.00	—	14.75	30.02	8.20	52.97	—	—	—	—
	F	96.16	15.91	10.67	—	11.75	22.44	5.93	40.12	—	—	—	—
	G	91.63	16.15	9.25	—	10.72	20.89	4.60	36.21	—	—	—	—
	H	86.84	14.17	9.92	—	8.92	21.40	4.33	34.65	—	—	—	—
	I	104.92	18.50	14.00	—	14.48	31.42	6.76	52.66	—	—	—	—
	J	101.25	16.34	10.82	—	12.15	21.52	5.16	38.83	—	—	—	—
	K	102.50	15.25	10.58	—	11.60	23.84	5.04	40.48	—	—	—	—
	L	100.67	16.42	11.83	—	11.09	27.63	5.82	44.54	—	—	—	—
	M	104.75	18.75	15.09	—	16.03	30.05	7.66	53.74	—	—	—	—
	N	105.50	15.17	11.92	—	12.99	23.54	5.50	42.03	—	—	—	—
	O	106.20	18.50	12.92	—	15.04	27.19	6.69	48.92	—	—	—	—
	P	106.00	17.83	13.17	—	13.73	28.60	6.88	49.21	—	—	—	—
(c) At harvesting time													
February 8,(109)*	A	94.55	13.19	12.10	19.96	6.15	13.06	19.09	38.30	—	—	—	38.38
	B	90.90	13.32	12.84	19.40	5.10	9.67	16.89	31.66	—	—	—	45.19
	C	80.60	16.05	13.32	19.39	4.80	9.96	12.79	27.55	—	—	—	38.65
	D	56.60	1.85	1.65	19.15	0.72	1.02	1.65	3.39	—	—	—	15.45
	E	97.08	15.83	15.09	22.59	10.45	17.07	33.91	61.43	—	—	—	41.03
	F	88.34	14.09	18.83	21.81	8.09	14.41	29.49	51.99	—	—	—	36.91
	G	85.59	15.00	13.59	21.42	8.23	14.43	26.17	48.83	—	—	—	29.76
	H	85.59	11.17	9.57	20.54	6.61	10.81	18.40	35.82	—	—	—	26.53
	I	96.42	16.75	15·75	21·12	10.76	18.58	35.07	64.41	—	—	—	36.26
	J	96.67	17.00	16.25	22.09	10.43	17.24	34.89	62.56	—	—	—	32.67
	K	94.75	17.57	15.30	21.11	10.90	19.14	29.28	59.32	—	—	—	34.32
	L	95.25	14.50	13.06	21.60	9.65	14.98	30.18	54.81	—	—	—	35.00
	M	98.58	14.83	14.25	21.76	9.44	15.59	30.38	55.41	—	—	—	44.25
	N	95.60	17.50	16.67	21.88	11.59	18.86	34.94	65.39	—	—	—	33.25
	O	99.92	16.50	16.00	22.11	11.46	20.07	35.23	66.76	—	—	—	31.92
	P	100.23	16.04	15.52	22.27	11.31	18.65	34.82	64.78	—	—	—	36.45

Remarks: * Days after transplanting

Table 37. Nitrogen content (%)

Treatment		Nov. 20 (29)			Jan. 4 (74)			Feb. 8 (109)		
		Blo. 1	Blo. 2	Mean	Blo. 1	Blo. 2	Mean	Blo. 1	Blo. 2	Mean
A	L*	3.63	3.69	3.66	2.89	2.53	2.71	0.68	0.59	0.64
	S*	1.63	1.70	1.67	1.30	0.95	1.13	0.51	0.34	0.45
	P*	—	—	—	1.79	1.40	1.60	1.49	1.39	1.44
	T*	2.80	2.77	2.78	1.96	1.53	1.75	1.00	0.92	0.96
B	L	3.61	3.72	3.67	3.73	3.79	3.76	0.73	0.64	0.69
	S	1.54	1.69	1.62	2.23	2.21	2.22	0.47	0.40	0.44
	P	—	—	—	1.73	2.11	1.92	1.79	1.51	1.65
	T	2.68	2.77	2.73	2.87	2.90	2.89	1.20	1.01	1.10
C	L	3.36	3.84	3.60	3.92	3.97	3.95	0.93	0.94	0.94
	S	1.51	1.70	1.61	2.58	2.52	2.55	0.73	0.69	0.85
	P	—	—	—	2.24	2.07	2.16	1.97	2.02	2.00
	T	2.58	2.89	2.74	3.14	3.16	3.15	1.33	1.38	1.35
D	L	3.78	3.47	3.63	1.29	1.20	1.25	0.52	0.56	0.54
	S	1.73	1.47	1.60	0.54	0.51	0.53	0.54	0.46	0.50
	P	—	—	—	—	—	—	1.39	1.38	1.39
	T	2.88	2.51	2.70	0.80	0.72	0.76	0.94	0.93	0.94
E	L	5.42	5.53	5.48	2.22	2.17	2.20	0.70	0.64	0.67
	S	3.25	3.28	3.27	0.80	1.20	1.00	0.44	0.35	0.40
	P	—	—	—	1.45	1.35	1.40	1.60	1.76	1.68
	T	4.62	4.68	4.65	1.31	1.49	1.40	1.58	1.19	1.16
F	L	5.50	5.52	5.51	2.85	2.31	2.58	0.73	0.72	0.73
	S	3.24	3.25	3.25	1.14	0.82	0.98	0.56	0.53	0.55
	P	—	—	—	1.51	1.41	1.46	1.73	1.74	1.74
	T	4.44	4.48	4.46	1.71	1.33	1.52	1.27	1.22	1.25
G	L	5.36	5.46	5.41	2.69	2.66	2.68	0.76	0.82	0.79
	S	3.36	3.48	3.42	1.12	0.99	1.06	0.54	0.66	0.60
	P	—	—	—	1.71	1.53	1.62	1.79	1.83	1.81
	T	4.62	4.70	4.66	1.67	1.55	1.61	1.25	1.31	1.28
H	L	5.53	5.15	5.34	1.48	1.46	1.47	0.59	0.58	0.59
	S	3.41	3.47	3.44	0.51	0.45	0.48	0.34	0.32	0.33
	P	—	—	—	1.12	1.27	1.20	1.29	1.90	1.60
	T	4.50	4.59	4.55	0.82	0.83	0.83	0.88	1.18	1.03
I	L	5.77	5.16	5.47	2.42	2.38	2.40	0.78	0.72	0.75
	S	3.51	3.20	3.36	1.29	0.88	1.09	0.57	0.57	0.57
	P	—	—	—	1.26	1.27	1.27	1.82	1.72	1.77
	T	4.89	4.42	4.66	1.60	1.34	1.47	1.31	1.20	1.26
J	L	5.54	5.14	5.34	2.93	2.47	2.70	0.76	0.73	0.75
	S	3.55	3.39	3.47	1.34	1.07	1.21	0.54	0.48	0.51
	P	—	—	—	1.73	1.55	1.64	1.82	1.82	1.82
	T	4.83	4.46	4.61	1.95	1.52	1.74	1.31	1.25	1.28
K	L	5.50	5.43	5.47	2.98	2.85	2.92	0.95	0.85	0.90
	S	3.40	3.27	3.34	1.09	1.06	1.08	0.70	0.67	0.69
	P	—	—	—	1.74	1.62	1.68	1.90	1.87	1.89
	T	4.75	4.63	4.69	1.71	1.64	1.68	1.36	1.28	1.32
L	L	5.78	5.35	5.57	1.80	1.45	1.63	0.64	0.60	0.62
	S	3.56	3.38	3.47	0.61	0.63	0.62	0.36	0.37	0.37
	P	—	—	—	1.39	1.20	1.30	1.49	1.47	1.48
	T	4.94	4.60	4.77	1.00	0.91	0.96	1.09	1.02	1.02
M	L	5.87	5.32	5.60	2.63	3.05	2.84	0.94	0.84	0.89
	S	3.43	3.14	3.29	1.11	1.21	1.16	0.92	0.82	0.87
	P	—	—	—	1.59	1.61	1.60	2.03	1.96	2.00
	T	5.00	4.53	4.77	1.63	1.82	1.71	1.51	1.47	1.49

Table 37. (continued) (%)

Treatment		Nov. 20 (29) Blo. 1	Blo. 2	Mean	Jan. 4 (74) Blo. 1	Blo. 2	Mean	Feb. 8 (109) Blo. 1	Blo. 2	Mean
N	L	5.64	5.60	5.62	2.61	3.36	2.99	0.78	0.75	0.77
	S	3.44	3.44	3.44	1.33	1.28	1.31	0.74	0.78	0.76
	P	—	—	—	1.44	1.59	1.52	1.89	1.97	1.93
	T	4.84	4.26	4.55	1.73	1.98	1.84	1.39	1.38	1.39
O	L	5.42	5.46	5.44	2.98	2.67	2.83	1.02	0.77	0.90
	S	3.26	3.44	3.35	1.22	0.94	1.08	0.82	0.72	0.77
	P	—	—	—	1.76	1.60	1.68	2.11	1.87	1.99
	T	4.64	4.71	4.68	1.85	1.54	1.69	1.54	1.32	1.42
P	L	6.35	5.42	5.88	2.11	2.12	2.12	0.43	0.67	0.55
	S	3.27	3.42	3.34	0.71	0.70	0.71	0.74	0.43	0.59
	P	—	—	—	1.53	1.57	1.55	1.65	1.48	1.57
	T	5.13	4.57	4.85	1.21	1.22	1.22	1.11	1.06	1.08

*N.B.: L : Leaf blade, S : Stem, P : Panicle. T : Total, Blo : Block

As to the effect of top-dressing on dry matter, it was observed that the earlier the time of top-dressing, the greater was the plant dry matter, and also the effectiveness of top-dressing was more remarkable at lower levels of basal dressing.

B) Nitrogen content

Owing to the lower soil fertility as to nitrogen, nitrogen content of plants was clearly effected by the application of nitrogen. During the vegetative stage, nitrogen content in plants was remarkably increased by the basal dressing at all levels, with no apparent differences among the different levels.

It appears that nitrogen absorbed by plants is mainly utilized to increase the weight of dry matter and therefore no increase in percentage content of nitrogen occurs.

However, the application of top-dressing caused an increase in percentage content of nitrogen.

As shown in Table 37, nitrogen content in leaf blades was remarkably changed with the time of top-dressing.

The earlier the top-dressing, the higher was the nitrogen content, when the level of basal nitrogen was not very high.

C) Amount of fertilizer nitrogen utilized by plants

As shown in Table 38, fertilizer nitrogen was efficiently absorbed by the plants.

Experimental results revealed that about a half of the applied basal nitrogen was utilized by the plants.

Interesting enough is that the more the dose of basal nitrogen, the higher the recovery rate of fertilizer nitrogen.

It is usual that the recovery rate of fertilizer tends to decrease with the increase of application dose. However, this was not the case in the present experiment.

Low soil fertility of the soil used in the experiment might be a cause for such unusual case.

As to the top-dressing of nitrogen, high recovery rate was shown. At the moderate level of basal nitrogen, it was found that the earlier the application of top-dressing, the higher was the recovery rate. On the other hand, in the plot without basal dressing and with 1.0 g of nitrogen as top-dressing the recovery rate of fertilizer nitrogen increased with the delaying application.

Table 38. **Amount of soil and fertilizer nitrogen utilized by plants at several stages of growth**

mgN/hill

Plot	Tillering stage (20/Nov.) Basal-^{15}N in plant	Soil-^{14}N in plant	$^{15}N+^{14}N$ in plant	Proportion % Fertilizer-^{15}N	Soil-^{14}N	Flowering stage (4/Jan.) Basal-^{15}N in plant	Top dressed-^{15}N in plant	Soil-^{14}N in plant
A	0	11	11	0	100	0	255	44
B	0	11	11	0	100	0	180	35
C	0	11	11	0	100	0	106	26
D	0	11	11	0	100	0	0	16
E	62	7	69	89. 9	10. 1	230	370	107
F	62	7	69	89. 9	10. 1	230	366	89
G	62	7	69	89. 9	10. 1	230	278	71
H	62	7	69	89. 9	10. 1	230	0	62
I	58	5	63	92. 1	7. 9	382	437	87
J	58	5	63	92. 1	7. 9	382	272	16
K	58	5	63	92. 1	7. 9	382	320	47
L	58	5	63	92. 1	7. 9	382	0	81
M	72	5	77	93. 5	6. 5	513	350	143
N	72	5	77	93. 5	6. 5	513	275	1
O	72	5	77	93. 5	6. 5	513	289	68
P	72	5	77	93. 5	6. 5	513	0	87

Plot	Flowering stage (4/Jan.) $^{15}N+^{14}N$ in plant	Proportion % Fertilizer-^{15}N	Soil-^{14}N	Harvesting time (8/Feb.) Basal-^{15}N in plant	Top dressed-^{15}N in plant	Soil-^{14}N in plant	$^{15}N+^{14}N$ in plant	Proportion % Fertilizer-^{15}N	Soil-^{14}N
A	299	85. 3	14. 7	0	253	74	327	77. 4	22. 6
B	215	83. 7	16. 3	0	295	67	362	81. 5	18. 5
C	132	80. 3	19. 7	0	375	84	459	81. 7	18. 3
D	16	0	100	0	0	31	31	0	100
E	707	84. 8	15. 2	235	389	151	775	80. 5	19. 5
F	685	87. 0	13. 0	235	392	125	752	83. 4	16. 6
G	579	87. 7	12. 3	235	328	86	649	86. 7	13. 3
H	292	78. 8	21. 2	235	0	70	305	77. 0	23. 0
I	906	90. 4	9. 6	396	394	116	906	87. 2	12. 8
J	670	97. 6	2. 4	396	382	99	877	88. 7	11. 3
K	749	93. 7	6. 3	396	325	24	745	96. 8	3. 2
L	463	82. 5	17. 5	396	0	104	500	79. 2	20. 8
M	1006	85. 8	14. 2	564	272	46	882	94. 8	5. 2
N	789	99. 9	0. 1	564	306	31	901	96. 6	3. 4
O	870	92. 2	7. 8	564	309	26	899	97. 1	2. 9
P	600	85. 5	14. 5	564	0	115	679	83. 1	6. 9

D) **Yield components** (Table 39)

1) **Number of panicles per hill.**

Number of panicles increased with the increasing dose of basal nitrogen. The effect of top-dressing of nitrogen on number of panicles was remarkable at the low level of basal nitrogen application, but no difference was observed among different time of application as shown in the Fig. 46.

Table 39. Yield and its components

Treatment	Block*	Number of panicles/hill	Number of spikelets/panicle	Percentage of ripened grains %	Weight of 1000 grains (g)	Weight of grain (g)/hill	
						Filled	Unfilled
A	I	11.0	100.8	57.7	21.2	13.62	1.29
	II	13.3	145.8	52.5	21.6	22.00	1.74
	M**	12.1	123.3	55.1	21.4	17.81	1.52
B	I	12.7	91.5	62.2	21.9	15.14	1.45
	II	13.0	96.4	56.8	21.8	15.50	2.34
	M	12.9	94.0	59.5	21.9	15.32	1.90
C	I	16.2	80.6	40.6	22.6	12.10	3.48
	II	11.0	80.4	38.3	20.3	6.92	3.02
	M	13.6	80.5	39.5	21.5	9.51	3.25
D	I	1.5	59.0	83.4	23.7	1.76	0.04
	II	1.8	51.2	88.5	22.5	1.84	0.05
	M	1.7	55.1	86.0	23.1	1.80	0.05
E	I	16.0	122.1	84.1	23.4	39.75	1.32
	II	15.0	117.7	82.7	23.3	33.90	1.14
	M	15.5	119.9	83.4	23.4	36.83	1.23
F	I	15.3	126.5	82.1	23.8	36.00	1.40
	II	13.4	111.3	79.0	24.9	29.29	1.90
	M	14.4	118.9	80.6	24.4	32.65	1.65
G	I	15.2	101.6	72.7	24.9	28.27	1.56
	II	15.0	85.8	77.2	25.4	24.85	1.07
	M	15.1	93.7	75.0	25.2	26.56	1.32
H	I	9.0	98.7	87.1	24.0	18.68	0.54
	II	10.2	98.7	82.1	23.8	20.42	0.65
	M	9.6	98.7	84.6	23.9	19.55	0.60
I	I	16.5	116.6	86.4	24.5	40.49	1.06
	II	15.0	104.5	84.6	24.2	31.88	1.08
	M	15.8	110.6	85.5	24.4	36.19	1.07
J	I	18.0	108.1	79.6	24.5	37.66	1.83
	II	14.7	108.9	81.5	24.8	32.22	1.25
	M	16.4	108.5	80.6	24.7	34.94	1.54
K	I	15.6	116.1	71.8	25.0	32.39	1.71
	II	16.0	99.9	74.7	25.7	29.86	2.00
	M	15.8	108.0	73.3	25.4	31.13	1.86
L	I	12.0	109.7	84.9	25.8	28.85	1.11
	II	13.8	116.7	84.9	25.5	34.63	1.28
	M	12.9	113.2	84.9	25.7	31.74	1.20
M	I	14.6	109.9	81.1	24.8	33.35	1.58
	II	15.0	106.4	79.4	26.4	33.00	1.76
	M	14.8	108.2	80.3	25.6	33.18	1.67
N	I	16.3	110.4	77.8	26.5	37.21	1.57
	II	16.8	98.1	79.5	26.5	34.28	1.73
	M	16.6	104.3	78.7	26.5	37.75	1.65
O	I	14.8	119.7	77.7	25.8	35.09	1.54
	II	17.8	122.8	72.0	24.4	38.33	2.51
	M	16.3	121.3	74.9	25.1	36.71	2.03
P	I	15.9	106.6	78.7	23.4	30.88	1.35
	II	15.2	127.6	81.2	24.9	39.00	2.45
	M	15.6	117.1	80.0	24.2	34.94	1.90

* Each block consisted of at least 3 pots. ** Mean

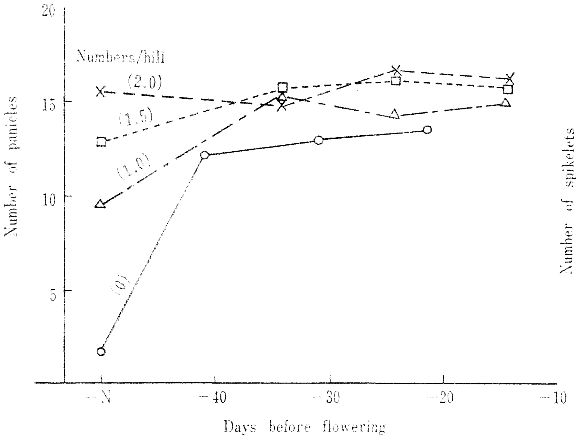

Fig. 46. Number of panicles

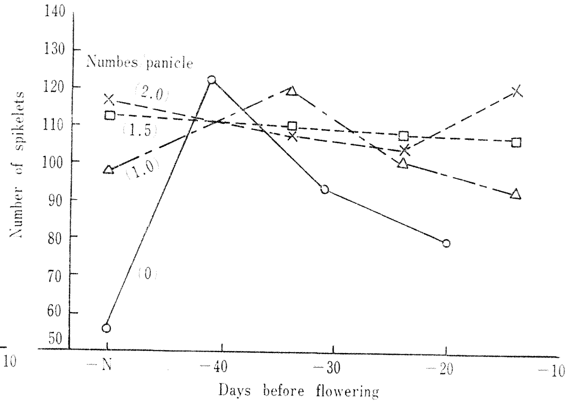

Fig. 47. Number of spikelets

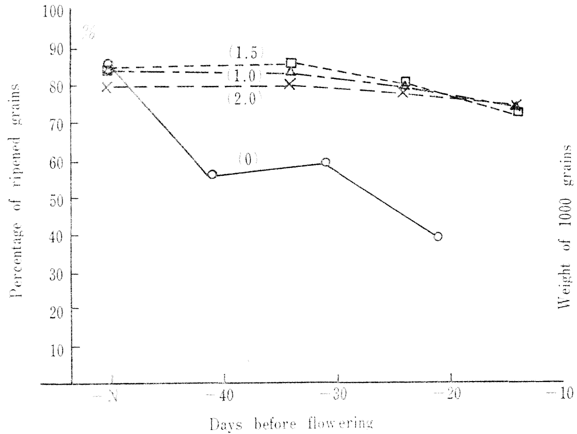

Fig. 48. Percentage of ripened grains

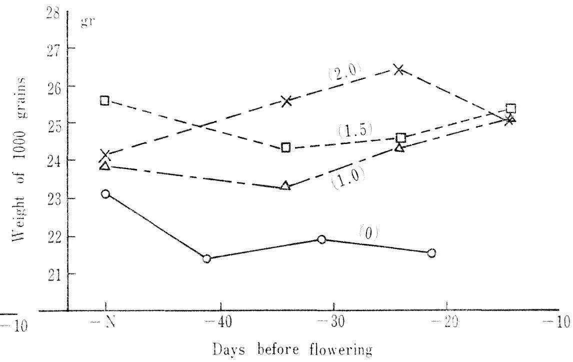

Fig. 49. Weight of 1000 grains

2) Number of spikelets per panicle

When the dose of basal nitrogen was small, top-dressing of nitrogen exerted a marked effect on spikelet formation; the earlier the time of top-dressing, the more spikelets were produced.

However, at high levels of basal nitrogen, no significant difference between number of spikelets per panicle and time of top-dressing was found as shown in Fig. 47.

3) Percentage of ripened grains

Effect of top-dressing of nitrogen percentage of fully ripened grain to the total grains produced was not clear in the plots which received basal dressing of nitrogen. In the plots without basal dressing, the percentage of ripened grains was markedly decreased by top-dressing, as shown in Fig. 48.

4) Weight of 1000 grains

Weight of 1000 grains seemed to be increased when nitrogen was applied about 20 days before flowering, though not obvious as shown in Fig. 49. All these results were summarized in Table 5.

E) Grain yield

As shown in Fig. 50, a heavy application of nitrogen as basal dressing at the time of transplanting reduced the nitrogen requirement of plants during the panicle formation stage. When plants received small or moderate dose of nitrogen at transplanting, a high efficiency of top-dressing in grain production appeared at the beginning of the reproductive stage, whereas such an effect was not observed in the case of higher dose of basal dressing.

Thus, the best time for nitrogen top-dressing varys depending upon the level of basal dressing.

At a low or moderate level of basal dressing, the top-dressing of nitrogen has to be applied at 30 days before flowering.

On the other hand, when ample amount of nitrogen was supplied at the time of transplanting, the best time for top-dressing fell on 10 days before flowering, although not significant. Therefore, referring to the many previous field experiments, it can be safely concluded that the best time for nitrogen application during the panicle-formation stage falls on 30 days before flowering under the ordinary growing condition of non-photosensitive rice varieties.

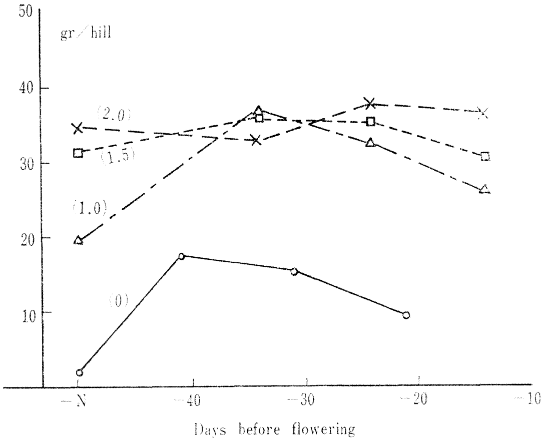

Fig. 50. Paddy yield

Table 40. Recovery rates of fertilizer nitrogen and its productive efficiency

Plot	Recovery %		Productive efficiency	
	Basal-^{15}N	Top-dressed-^{15}N	Basal-^{15}N	Top-dressed-^{15}N
A (−41)*	0	50.6	0	46.9
B (−31)	0	59.0	0	45.4
C (−21)	0	75.0	0	27.6
E (−34)	47.0	77.8	72.0	54.2
F (−24)	47.0	78.4	72.0	44.2
G (−14)	47.0	65.6	72.0	29.2
I (−34)	52.8	78.8	68.4	29.5
J (−24)	52.8	76.4	68.4	23.1
K (−14)	52.8	65.0	68.4	10.9
M (−34)	56.4	54.4	51.6	9.1
N (−24)	56.4	61.2	51.6	20.7
O (−14)	56.4	61.8	51.6	13.6

N.B.: * Day before flowering.

F) Productive efficiency

Productive efficiency of nitrogen for grain yield was calculated and presented in Table 40.

Without basal dressing or with small amount of basal dressing of nitrogen applied, the productive efficiency of top-dressing of nitrogen showed the maximum value with earlier application, whereas with heavy dose of basal dressing, the efficiency showed the maximum when applied at 20 days before flowering.

Productive efficiency of basal nitrogen was decreased with an increasing dose. The efficiency of nitrogen of top-dressing was decreased with an increasing dose of basal dressing of nitrogen.

GENERAL DISCUSSION

A) Nitrogen Application Technology and Soil Factors

A number of research works[39–44] have so far been conducted on the efficient utilization of nitrogen by rice plants in field trials, because nitrogen utilization is a key factor in determining rice yields. In order to increase nitrogen utilization by plants, application of nitrogenous fertilizer is practiced as the most practical and effective method.

However, it is usually difficult to assess accurately the yield-increasing effect of applied nitrogen by field experiments because the natural supply of nitrogen is abundant, and rice plants generally utilize much more soil nitrogen than the applied fertilizer nitrogen.[6] Therefore, it is necessary to distinguish the nitrogen originated from the soil from the nitrogen supplied by fertilizer. For this reason, the authors utilized ^{15}N, heavy nitrogen for their field experiments. Chemical properties of ^{15}N, a stable isotope, are identical with those of the normal form, and its behavior in soils and plants is also identical with the normal nitrogen.

1) Temperature and Soil Nitrogen Mineralization

As almost all soil nitrogen is in an organic form, many studies in Japan have focused on the availability and recovery of the organic nitrogen, especially on factors influencing mineralization of soil nitrogen in flooded rice soils.

Harada[21] concluded that the natural supply of nitrogen in flooded paddy field soils comes from so called readily decomposable organic matter and the mineralization of nitrogen from that readily-decomposable organic matter is influenced by a number of factors such as drying of soils, temperature rise, change of soil reaction, addition of humus peptizable salt and so on. Among these factors, the effect of soil temperature rise is most important. Temperature higher than 20 °C induces very rapid mineralization.

2) Regional Difference in Nitrogen Application

Yanagisawa and Takahashi[3] reported that in the northeast districts of Japan, where soil temperature is relatively lower than the other districts during the early growth period, nitrogen absorbed during the early half of growth duration accounts for only 20~30% of the total quantity of nitrogen absorbed during the whole growth duration up to harvest. On the contrary, in the southeast districts of Japan where soil temperature is rather high, rice plants can absorb more than 50% of the total quantity of nitrogen during the early half of growth duration. Thus, it is evident that the mineralization of soil nitrogen is determined by soil temperature depending upon the local climatic conditions.

Since the purpose of fertilizer application is to supplement the natural nutrient supply to meet the nutrient requirement of crops, not only soil fertility but also process of soil nitrogen mineralization must be taken into consideration for designing method of fertilizer application for lowland rice.

Actually, in an area with high soil fertility or cool climate, the top-dressing of nitrogen is usually not practiced, because the basal dressing alone is sufficient enough to meet nutrient requirement of plants. On the contrary, in an area with poor soil or warm climate two or three times of top-dressing is usually practiced.

Thus, the regional difference in nitrogen application technique can simply be expressed by the proportion of basal dressing to the top-dressing of nitrogen—the higher proportion of top-dressing in the warmer region.[45]

Ishizuka and Tanaka[46–48] reported that in colder area like Hokkaido the yield-increasing effect of top-dressing applied at the panicle primordia formation stage was not apparent, and they recommended to apply whole dosage of nitrogen as a basal dressing.

Kiuchi *et al.*[49] also obtained the similar result in the Tohoku region where temperature is low during the early half of growth duration. On the contrary, a split application of nitrogen was found very effective in increasing yield in warm regions.

Goto[50] reported that in warm areas like Kyushu nitrogen should be applied at the stage of panicle primordia formation, because at that stage nitrogen can be absorbed most efficiently and utilized for grain production most effectively.

Saito *et al.*[51] also examined the effectiveness of nitrogen split application in Kyushu, and recognized that it is necessary to apply nitrogen not only at the stage of panicle primordia formation but also at the stage prior to the maximum tiller number.

3) Nitrogenous Soil Fertility and Grain Production

As stated above, the practice of nitrogen split application varies depending upon the level of soil fertility and the seasonal pattern of soil nitrogen mineralization at a given location.

From this standpoint of view the authors attempted to make clear the status of soil fertility and seasonal pattern of soil nitrogen mineralization of the Bangkhen paddy field soil by the use of ^{15}N tracer method.

The results revealed that the nitrogenous soil fertility status of the Bangkhen soil was 120 kg/ha in terms of "A-value"; that is about a half of the value for the fertile Nagano soil and almost comparable to infertile Saitama soil in Japan (Chap. 1 B).

In order to make clear the extent of contribution of nitrogenous soil fertility to grain production, the relationship between soil nitrogen utilization and grain yield was studied under the growth condition of double-cropping in a rainy season.

Field tracer experiment using ^{15}N isotope demonstrated that the first and the second crop were almost identical in the utilization of fertilized nitrogen, but a marked difference was found in the absorption of soil nitrogen: second crop absorbed 17% less soil nitrogen than the first crop did (Chap. 2B). Grain yield of the second crop was lower than the first crop by almost 1 ton/ha, inspite of the fact that the second crop was blessed with more favorable climatic condition than the first crop (Chap. 2A). This decrease in grain yield of the second crop can be attributed to the degradation of nitrogenous soil fertility.

Thus, it is shown that the soil fertility plays a critical role in determining grain yields at a level of 75 kg/ha of nitrogen that has been regarded as a standard rate of application.

4) Seasonal Pattern of Soil Nitrogen Mineralization

Concerning the mineralization of soil nitrogen, the ^{15}N tracer field experiment demonstrated clearly a remarkable difference in the utilization of soil nitrogen by rice plants during the reproductive growth phase between the Bangkhen soil and soils of Nagano and Saitama in Japan.

Although there was no distinct difference in the utilization of soil nitrogen and fertilizer nitrogen between these three soils during the vegetative growth phase, a marked difference was observed during the later stages of growth after panicle primordia initiation; almost no utilization of soil nitrogen with the Bangkhen soil in contrast to other soils which released a large amount of soil nitrogen (Chap. 1E).

This difference can be attributed to the fact that the Bangkhen soil releases soil nitrogen mainly in an early stage, while the soils of Nagano and Saitama are able to release nitrogen continuously up to the end of plant growth. This nature of the Bangkhen soil is observed evidently in the no-fertilizer plot where rice plants absorbed 28.8 kg/ha of soil nitrogen during the vegetative phase, but only 3.9 kg/ha during the reproductive phase, and 4.4 kg/ha during the ripening phase (Chap. 1E).

B) Nitrogen Application Technology and Physiological Factors

These facts suggested that nitrogen has to be applied mainly at the middle and later stages of rice growth. However, the yield-increasing effect of fertilizer nitrogen is determined not only by the soil factor as an availability of soil nitrogen, but also by the following four physiological factors: (1) Ability of plants to absorb nitrogen applied (2) Share of the nitrogen derived from the fertilizer to the total plant nitrogen (3) Translocation and distribution of fertilizer nitrogen in rice plants, and (4) nitrogen requirement and effectiveness of nitrogen for grain production at different stages of growth. Then, the rate of recovery of fertilizer nitrogen by plants was determined by the field experiments at Bangkhen using ^{15}N tracer (1969).

1) Recovery of Nitrogen Applied to Soils

The result showed that the plant recovery rate of fertilizer ^{15}N was 17.5% when applied at transplanting. 21.6% when applied at the active tillering stage, 37.7% at the panicle primordia initiation stage, and 54.7% at the flowering time (Chap. 4B). Thus, it was clear that the later was the application of top-dressing of nitrogen, the higher was the recovery rate.

Following factors can be pointed out for the reason why such a remarkable difference in the recovery of ^{15}N applied at different stages of growth occurred:

a) Root system was not yet fully developed during the early growth stage.

b) A portion of nitrogen absorbed by plants from fertilizer during the early stage of growth was lost from the plants due to dieback of leaves which occurs during the middle and late stage of growth, and

c) Immobilization or denitrification of fertilizer nitrogen took place in soils. Particularly, an unexpectedly low rate of recovery of ^{15}N applied as a basal dressing can be explained by a loss of nitrogen by denitrification, as evidenced by the experimental results that the practice of deep placement of ^{15}N fertilizer or an addition of nitrification inhibitor to the fertilizer were very useful in increasing the recovery rate of ^{15}N fertilizer applied as the basal dressing (Chap. 3A).

Concerning the top-dressing at the tillering stage, it was expected that the application on the fourteenth day after transplanting might show a higher recovery rate because the plant root system had developed by that time. However, contrary to the expectation no increase in the recovery rate of nitrogen was observed, because the application at that time caused a serious weed growth, and a considerable amount of applied fertilizer was consumed by weeds (Chap. B).

On the other hand, the top-dressing applied at the panicle primordia initiation stage and at flowering stage showed 40~50% recovery rates (Chap. 4B). These rates are lower than those obtained in Japan[52] where many experimental results indicated that rice plant usually absorbed as much as 60~70% of nitrogen applied at these stages of growth, a loss of fertilizer might have occurred on the Bangkhen fields because it was difficult to drain sufficiently the surface water before the fertilizer application.

2) Nitrogen Application and Plant Uptake of Soil Nitrogen

Several facts of highly significant are found in the persent study. Firstly, a very interesting fact was observed regarding the relationship between fertilizer application and the uptake of soil nitrogen by plants; the uptake of soil nitrogen was promoted by the fertilizer application.

A number of workers[15-17] have recognized that the application of inorganic nitrogen, either in ammonia- or in nitrate-form, to soils induced an increased uptake of soil nitrogen by plants, which resulted in an increased content of nitrogen derived from soil nitrogen in harvested crops.

There are two alternative interpretations. First, an enhancement of mineralization of soil organic nitrogen caused by an addition of inorganic nitrogen, as proved by BROADBENT[18] in his experiment using ^{15}N. Second, a promotion of root growth due to added fertilizer, and the resulted increase in soil nitrogen absorption.

The increments of soil nitrogen uptake induced by the addition of fertilizer nitrogen in the Bangkhen soil actually constituted as much as 15～29% of the total nitrogen contained in plants (Chap. 1C). In the light of the fact that an increase in soil nitrogen uptake caused by an addition of fertilizer may be occured only after the mineral nitrogen pool is exhaused to a very low level. Therefore this phenomena are worth noting under a fertilized condition in the tropical region, because tropical soil is characterized by the low fertility of nitrogen.

3) Contribution of Fertilizer Nitrogen to the Plant Nitrogen

Secondly, the results presented the importance of examining the proportion of two kinds of nitrogen in plants, one derived from fertilizer and the other originated from soil nitrogen, in the evaluation of fertilizer effect, which used to be made so far merely based on the amount of fertilizer absorbed by plants. The evaluation of fertilizer effect based on the quantity of fertilizers absorbed by plants tells only a part of the whole picture.

OKUDA and KAWASAKI[53-56] pointed out in their study using ^{32}P that not only the quantity of phosphorus absorbed by plants, but also the proportion of phosphorus derived from fertilizer to the total plant phosphorus should be examined. At Bangkhen, nitrogen which came from the fertilizer shared 33% of the total plant nitrogen at the tillering stage, when 37.5 kg/ha of nitrogen were applied as basal-dressing, but the share decreased to as low as 12% at the harvesting time, when the additional nitrogen was not applied. However, the top-dressing of additional 37.5 kg/ha of nitrogen applied at the panicle primordia initiation stage resulted in a remarkable increase of the share (Chap. 1D).

This fact furnishes an evidence that the application of nitrogen top-dressing at the panicle primordia initiation stage is essential to increase rice yield so that the yield-increasing effect of top-dressing is remarkable with the Bangkhen soil. As already described before, the more nitrogen is required to get the more yield. However, as the availability of mineralized soil nitrogen is limited, the plants have to depend more and more upon the additional nitrogen supply by fertilizer application.

Thus, a close relationship among the total nitrogen utilized by plants, contribution of fertilizer nitrogen to the total plant nitrogen, and the grain yield was found with Bangkhen soil (Chap. 4E).

4) Translocation and Distribution of Fertilizer Nitrogen in Plants

Thirdly, it is also important to examine the distribution of translocated fertilizer-originated-nitrogen in different organs of plant, because different organs possess different physiological functions.

OZAKI and MITSUI[57,58] studied the effect of nitrogen fertilizer (^{15}N) applied at the panicle primordia development stage, and found that nitrogen applied at 20 days before heading accumulated mainly in the flag leaf, culm and panicles. This implies that nitrogen was principally utilized to promote the activities of these organs.

Experimental results with Bangkhen field showed that nitrogen applied as top-dressing at an early stage of panicle primordia development was mostly distributed in leaves and stems, while that applied at a later stage was distributed in panicles. For example, 64% of nitrogen applied at 40 days before flowering was distributed in leaf blades, while 66% of nitrogen applied at 10 days after flowering was translocated into panicles (Chap. 5F). Obviously, the former was used to build up vegetative organs, while the latter was utilized to build up panicles. These facts well support that the effect of top-dressing of nitrogen varies remarkably with the time of application.

5) Timing of Nitrogen Application and Growth Stages

The fourth problem is the grain production efficiency of fertilizer nitrogen absorbed at different growth stages. Kimura and Chiba[59] conducted water culture experiments to study the effectiveness of nitrogen absorbed at a definit growth period on the production of grain and straw. They found that there are two stages at which the nitrogen applied shows maximum efficiencies with regard to grain yield. The first one is not related to any particular growth stages but is determined, primarily by the quantity of nitrogen absorbed per hill (170 mg N). The second one is related to a particular growth stage, *i.e.*, the stage of panicle elongation which occurs two weeks before flowering, and is irrelevant to the amount of nitrogen absorbed by plants. Ishizuka and Tanaka[37] reported that the nitrogen requirement at different stages of growth can be recognized more clearly with plants growing at a low level of nitrogen than at a high nitrogen level, because rice plants are able to absorb more nitrogen than they require, and store it for a considerable period of time. In general, japonica varieties are considered to have a higher fertilizer response than indica varieties, as a result of continued variety improvement of japonica rice.[60,61] Therefore, it is expected that indica varieties differ from japonica ones not only in the over-all efficiency of nitrogen for grain production, but also in the partial efficiency at different stages of growth.

Working with an Indica varieties in India, Tanaka *et al.*[62] found two peaks of partial efficiency under the condition of low levels of nitrogen supply; the first peak occurred during the vegetative stage about 35 days before flowering and the second peak occurred just after flowering. At high levels of nitrogen supply, however, only one peak of partial efficiency was observed at the early stage of growth, about 50 days before flowering.

Determination of the efficiency of fertilizer nitrogen for grain production has so far been carried out only by solution culture experiments, because it has been impossible to distinguish the effect of fertilizer nitrogen from that of soil nitrogen released during the growth period of plants in any field experiment. Therefore, all these data reported before were obtained by solution culture experiments, and have not yet been confirmed on fields.

However, the use of ^{15}N tracer technique makes it possible to determine the efficiency of fertilizer nitrogen applied at any time under the field condition because ^{15}N tracer technique enables to distinguish the nitrogen originated from soils from the nitrogen supplied by fertilizers.

Taking this advantage of the ^{15}N tracer technique the authors carried out the field experiment at Bangkhen, in which ^{15}N-tagged fertilizer nitrogen was applied at a 10 day interval before and during the period of panicle development.

6) Timing of Nitrogen Application and Growth Duration

With a photoperiod-sensitive local variety, Puang Nahk, a plateau of high efficiency of nitrogen was observed at earlier than 41 days before flowering when the variety was transplanted in an early season and therefore the growth duration was prolonged to 207 days, while the variety showed the maximum efficiency of nitrogen at 35 days before flowering when transplanted in a late season with the growth duration of 155 days (Chap. 6D).

On the other hand, with a photoperiod-nonsensitive improved variety, P. B. 76-63 (the growth duration of this variety is fixed to be about 130 days), the highest efficiency of nitrogen top-dressing was observed at the stage of panicle primordia initiation, that is about 30 days before flowering, irrespective of the time of transplanting (Chap. 5E, Chap. 6D).

Thus, it was made clear that the length of growth duration also exhibits an effect on the efficiency of nitrogen. In other words the right time for top-dressing of nitrogen varies with the length of growth duration, even with a same variety.

Namely, in case of a moderate length of growth duration of about 130～150 days, the right time for applying top-dressing of nitrogen comes to about 30 days before flowering, whereas it comes to earlier than 41 days before flowering in case of a long growth duration more than 200 days.

7) Timing of Nitrogen Application and Nutritional Conditions

With an assumption that such a variation of fertilizer response might be caused by the difference in nutritional condition of plant with regard to nitrogen at the time of nitrogen application, Ishizuka and Tanaka[37] reported that the nitrogen requirement at different stages of growth can be recognized more clearly with plants growing at a low level of nitrogen than at a high nitrogen level, because rice plants are able to absorb more nitrogen than they require, and store it for a considerable period of time. Then, an experiment was carried out with different levels of basal dressing of nitrogen. In the plots without basal dressing or with a small amount of basal dressing, the highest efficiency of nitrogen for grain production was observed with an early application of top-dressing, whereas a late top-dressing exhibited the highest efficiency when a heavy basal dressing was applied(Chap. 7F). Thus it was made clear that a depression of nitrogen content in plants as a result of the prolonged length of growth duration and hence the prolonged length of vegetative period made the early application of top-dressing of nitrogen more effective than the late application.

As clearly shown in the foregoing discussion the effectiveness of top-dressing of nitrogen depends not only upon the time of application but also upon the dose of basal dressing. A further experiment was carried out to determine in detail this relationship. The result showed that in case when nitrogen top-dressing was applied at the panicle primordia initiation stage, a marked yield-increase was obtained by increasing the dose of basal dressing from 37.5 kg/ha up to 75 kg/ha of nitrogen, and also a remarkable yield-increase was obtained by increasing the dose of top-dressing at the panicle primordia initiation stage, when the amount of nitrogen supplied before that stage was less (Chap. 4E).

C) Nitrogen Application Technology and Yield Constitutional Factors

Since the grain yield consists of four yield components, the effect of nitrogen top-dressing on rice yield can be analysed from the viewpoint of yield components.[63]

1) Timing of Nitrogen Application and Number of Panicles

Matsushima[34] examined the yield-increasing effect of nitrogen applied at different stages of growth from the viewpoint of the effect of nitrogen on each yield component, by studying when and how each yield component is developed. He made clear that nitrogen applied at an early stage of growth contributed to increase the number of panicles as a result of an increased number of tillers, particularly the tillers produced during the early stage after transplanting were most effective in increasing yield.

However, experimental results obtained at Bangkhen showed that the basal-dressing of nitrogen was not so effective, but top-dressing applied at the panicle primordia initiation stage was much more effective in increasing number of panicles. As pointed out already in the foregoing chapter (Chap. 5D), it is more important to prevent the reduction in number of tillers that occurs in the later growth stage rather than to promote the tillering at the early growth stage, because an increased number of tillers does not directly lead an increased number of panicles under the tropical rice growing condition (Chap. 6B).

2) Timing of Nitrogen Application and Number of Spikelets

As to the number of spikelets per panicle, it is widely recognized that nitrogen application at the time from the panicle neck-node differentiation stage to the initial stage of spikelet differentiation is effective to increase the number of spikelets developed per panicle.[64] The authors' experiment at Bangkhen gave the same result, namely, nitrogen applied at the panicle primordia initiation stage increased remarkably number of spikelets and resulted in an increased yield.[65] (Chap. 5D, Chap. 6B).

It is often pointed out that, in case when the panicle primordia initiation takes place prior to the stage of maximum number of tillers, nitrogen top-dressing at the panicle primordia initiation stage tends to decrease grain yield, because it brings about a reduction in percentage of ripened grains although number of spikelets is increased.[66] However, such a case is considered extremely seldom or never happen with tropical rice, except for extremely early maturing varieties or extremely delayed planting of photoperiod-sensitive varieties.

3) Timing of Nitrogen Application and Percentages of Ripened Grains

Concerning the percentage of ripened grains, many research workers[67–70] in Japan claimed that nitrogen shortage during the ripening period must be avoided in order to improve the percentage of ripened grains.

For this purpose, the top-dressing of nitrogen at flowering time is recommended except on the field with a high nitrogenous soil fertility or with sufficient nitrogenous fertilizer applied at the panicle primordia initiation stage.

Many research workers[71–73] in Japan demonstrated that an increased nitrogen content in leaves accelerates photosynthetic activity of leaves and that the favorable effect of nitrogen application at about heading stage on percentage of ripened grains and weight of 1000 grains can be explained by an increased nitrogen content of leaves and, hence, an accelerated photosynthesis caused by nitrogen application.

However, the authors' result obtained at Bangkhen showed that a yield-increasing effect of nitrogen application at heading stage was not apparent except when the level of nitrogen supply was very low as stated above. In this case, nitrogen was mostly translocated into panicles and consumed to increase protein content of grains, rather than translocated into leaves, and also the ripening period of indica varieties was only 30 days, as compared to 45 days of Japonica varieties, suggesting that there was not enough period for an accelerated photosynthesis, if any, to contribute to the grain development with indica rice.

4) Timing of Nitrogen Application and Weight of 1000 Grains

As to the weight of 1000 grains, BABA[74] reported that, in case of Japonicas, it was not closely related to the nitrogen supply when the level of nitrogen was very high, but it decreased with an increasing supply of nitrogen when the level of nitrogen was low or moderate.

The results at Bangken field showed that weight of 1000 grains of an improved variety, P. B. 76—63, increased clearly by adding nitrogen during the stage from 10 to 20 days before flowering(Chap. 5D), while such an effect was not observed with a local variety, Puang Nahk (Chap. 6B).

5) Proper Timing of Nitrogen Top-Dressing

In Japan, many experimental results indicate that grain yields are primarily correlated with number of panicles. However, it seems that the grain yields of the tropical rice are more closely correlated to the number of spikelets per panicle rather than to the number of panicles, unlike Japanese rice, as pointed out by MORIYA[75] and FUKUI.[76] In fact, a very high yield-increasing effect of nitrogen observed in the authors' study at Bangkhen with the application at 30 days before heading was due to a remarkable increase in the number of spikelets

(Chap. 5D, Chap. 6B, Chap. 7D).

As shown in the foregoing discussions, many factors are involved in the determination of the best time for nitrogen top-dressing in practice. However, it is concluded safely on the basis of the results of a series of field experiments conducted at Bangkhen that the best time of nitrogen top-dressing is at the panicle primordia initiation stage, about 30 days before heading, on the Bangkhen field, except when the growth duration of rice plants is extremely long or when the plants have a considerably high content of nitrogen at that time as a result of an ample supply of nitrogen before that stage.

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