5. NITROGEN RESPONSES TO THE RICE PLANT AT DIFFERENT STAGES OF GROWTH

Seizo MATSUSHIMA*

Most important growth stages for nitrogen requirement from the viewpoint of yield-determining process in the rice plant[2)3)].

From the consideration of yield-determining process, the author pointed out four important stages at which the effect of nitrogen should be most conspicuous, i. e. (1) just after rooting, (2) at the neck-node differentiation stage, (3) just before the stage of reduction division of PMC, and (4) at the full heading stage. However, the most suitable stages of top-dressing with nitrogen differs with conditions under which the plants grow. Under conditions which produce plants with a high percentage of ripened grains and a small number of spikelets, a top-dressing stage which makes the plant increase its number of spikelets is suitable, while under conditions which produce the reverse effect, a top-dressing stage which makes the plant increase its percentage of ripened grains is suitable. Accordingly, it is necessary for the growers to choose the most suitable stage of topdressing by examining the rice plants in their paddy fields in each season. However, in case of the percentage of ripened grains and the number of spikelets per unit area being both moderate in value or both components being well balanced, the stages of top-dressing which increase the number of spikelets per unit area and those which increase the percentage of ripened grains as well as the number of spikelets would be the most suitable. For details, see the author's "Crop Science in Rice" (p. 328-336).

Quantitative relation of the amount of nitrogen absorbed by the rice plant at different growth stages to the magnitude of yield and yield-components[6)].

Using several varieties under various cultural conditions over several seasons (from 1957 to 1965), the authors examined the relation quantitatively between the amount of nitrogen absorbed by the rice plant at different growth stages and the magnitude of yield and yield-components. Among the relations obtained only important ones or definite ones will be mentioned in the following.

1) The relation between the number of panicles per m^2 and the amount of nitrogen in the rice plant per m^2 at the neck-node initiation stage can be seen in Fig. 1. There is a high correlation coefficient between them. Unfortunately, they did not sample the rice plants at the maximum tiller number stage, if they had done it, the higher correlation coefficient than this might have been obtained regardless of the varieties, seasons and cultural conditions used.

2) The relation between the number of differentiated spikelets per m^2 and the amount of nitrogen in the rice plant per m^2 at the late spikelet initiation stage is shown in Fig. 2. In any place, however different the varieties, season and cultural conditions may be, a very high positive correlation between them will definitely be obtained as in Fig. 2. But there is almost no relation between the number of differentiated spikelets per m^2 and the per-

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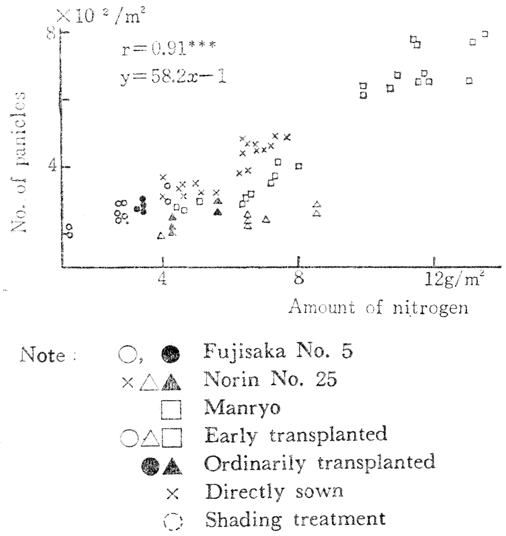


Fig. 1. Relation between the number of panicles per unit area and the amount of nitrogen in rice plant at the neck-node initiation stage.

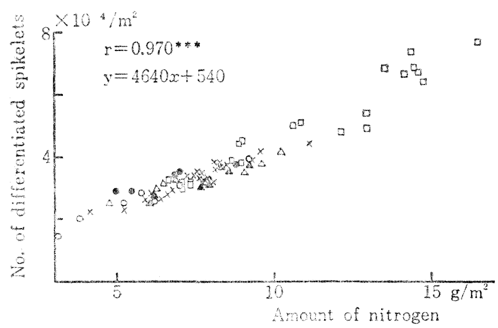


Fig. 2. Relation between the number of spikelets per unit area and the amount of nitrogen in rice plant at the late spikelet initiation stage.

centage of nitrogen in the leafblades. In most cases, as the number of degenerated spikelets per unit area is much less than that of differentiated ones, the actual number of spikelets is always closely correlated with the amount of nitrogen in the rice plant at the late spikelet initiation stage as well as at the heading stage as shown in Fig. 3, except the cases where the large amount of nitrogen is applied or the amount of solar radiation is extremely short during the period from the late spikelet initiation stage to the heading stage.

3) The relation between the number of differentiated spikelets per panicle and the amount of nitrogen per panicle at the late spikelet initiation stage is shown in Fig. 4. A very high correlation coefficient can be seen between them, but only a very low correlation

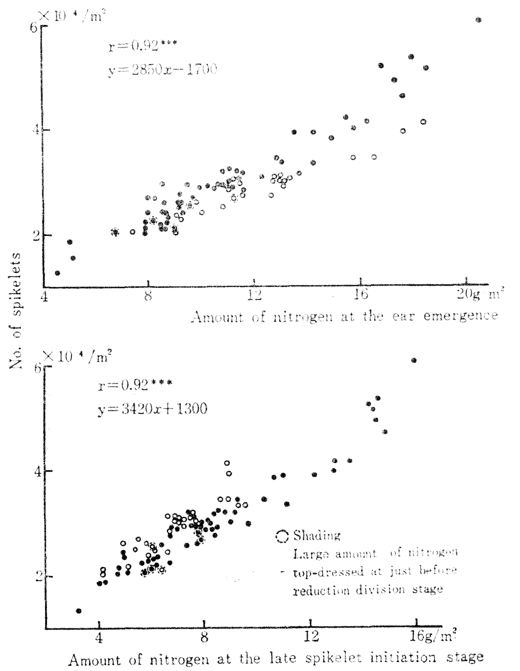


Fig. 3. Relation between the number of spikelets per unit area and the amount of nitrogen at the ear emergence and the late spikelet initiation stage.

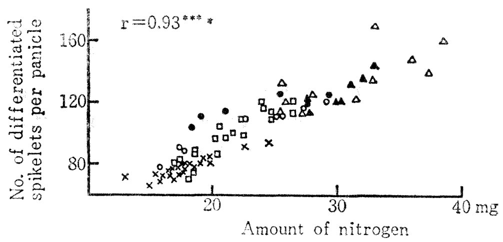


Fig. 4. Relation between the number of differentiated spikelets per panicle and the amount of nitrogen per panicle at the late spikelet initiation stage.

coefficient is seen between the number of differentiated spikelets per panicle and the percentage of nitrogen in the leafblades at the late spikelet initiation stage.

4) The relation between the amount of nitrogen absorbed per m² after the heading stage and the percentage of ripened grains is shown in Fig. 5. From Fig. 5 it can clearly be recognized that there is no correlation between them, but in case of much amount of nitrogen being absorbed after the heading stage there is no plot which shows a low percentage of ripened grains. Until recently, it has been believed that an increase of the amount of nitrogen absorbed during the period after the heading stage reduces the percent-

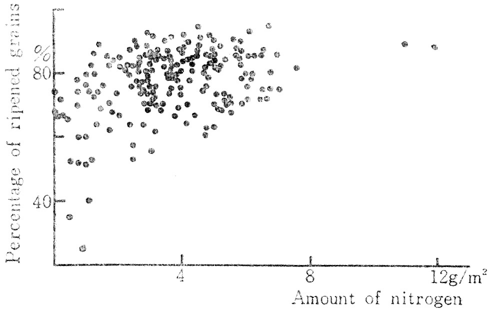


Fig. 5. Effect of the amount of nitrogen absorbed after the ear emergence on the percentage of ripened grains (1957 ~'65).

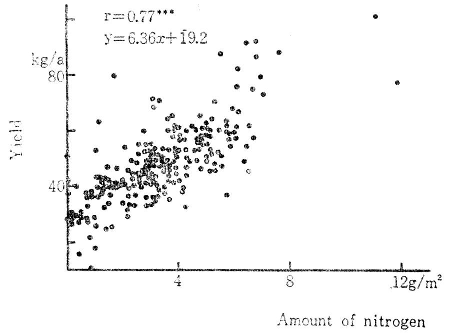


Fig. 6. Relation between the yield and the amount of nitrogen absorbed after the ear emergence.

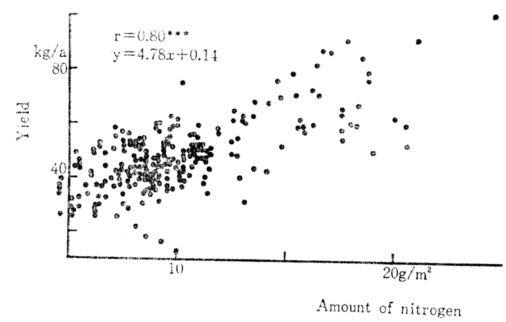


Fig. 7. Relation between the yield and the amount of nitrogen in rice plant at the ear emergence.

age of ripened grains. However, in fact, an increase of the amount of nitrogen absorbed during the period after the heading stage increases the percentage of ripened grains in many cases, because of the enhancement of photosynthetic rate.

5) The relation between the grain yield and the amount of nitrogen absorbed per m^2 after the heading stage is shown in Fig. 6. There exists a considerably high correlation coefficient between them.

6) The relation between the grain yield and the amount of nitrogen in the rice plant per m^2 at the heading stage can be seen in Fig. 7. There also exists a considerably high correlation coefficient between them.

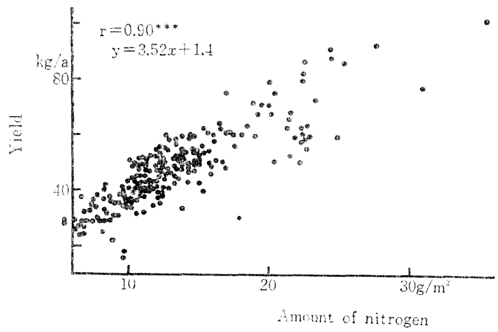


Fig. 8. Relation between the yield and the amount of nitrogen in rice plant at maturity.

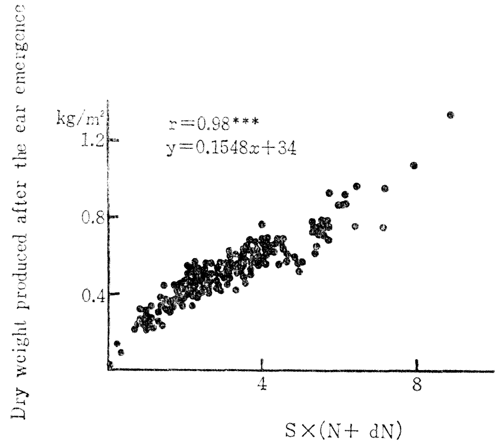


Fig. 9. Relation between the dry weight produced after the ear emergence and the product of the amount of solar radiation (S) and the sum of the amount of nitrogen in leaf-blades (N) and the amount of nitrogen absorbed after the ear emergence (dN).

7) The relation between the grain yield and the amount of nitrogen in the rice plant per m^2 at maturity is shown in Fig. 8. In Fig. 8 there exists much higher correlation coefficient between the grain yield and the amount of nitrogen than in Fig. 6 and Fig. 7. From the figure it can be recognized that so long as the upper limit of the yield of brown rice is nearly 10 tons per hectare, the more amount of nitrogen the rice plant absorbs during the whole growth period, the more the yield is produced. (In this case there is neither lodged plot nor seriously insufficient plot in the amount of solar radiation after the heading stage.)

8) The dry weight produced after the heading stage, which is the most closely correlated with the grain yield, shows a very high correlation coefficient with the product of the amount of solar radiation during the ripening period(S) and the sum of the amount of nitrogen in leaf-blades at the heading stage (N) and the amount of nitrogen absorbed after the heading stage (dN), as can be seen in Fig. 9.

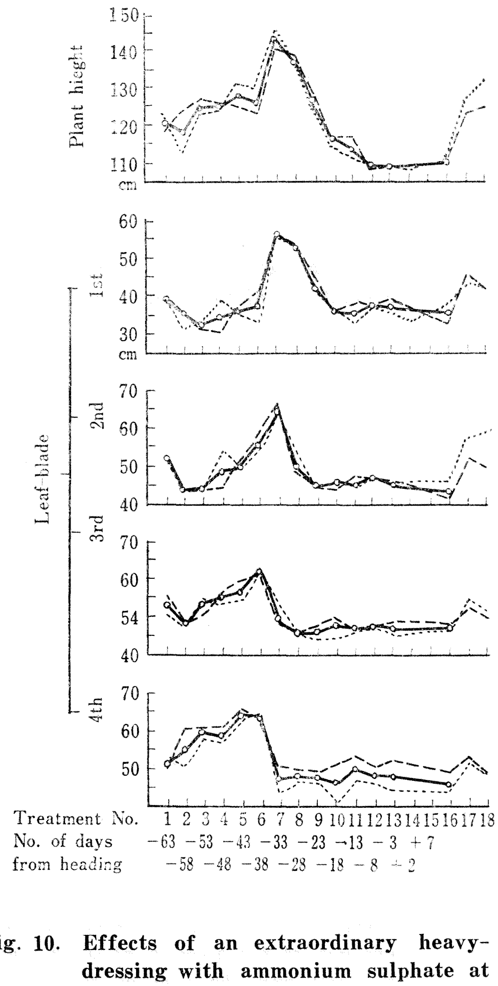


Fig. 10. Effects of an extraordinary heavy-dressing with ammonium sulphate at various growth stages on the plant height and the length of each leaf-blade.

The effects of an extraordinary heavy-dressing with nitrogen at successive growth stages on the yield, yield-components, growth, morphological characters and chemical composition of the rice plant[1)2)4)].

An extraordinary amount of ammonium sulphate (756 kg. per hectare) was top-dressed under the field condition to the rice plant, which had been grown without nitrogenous fertilizer, at intervals of 5 days at successive growth stages during 3 seasons with 3 replications. (Adequate amounts of P and K were basically fertilized.) Among the results only a few important ones will be mentioned as follows.

1) The effects of nitrogen top-dressing at successive growth stages on the plant height and the leaf-length are shown in Fig. 10. From the figure the most effective time for lengthening the plant height and each leaf-length can clearly be seen. Furthermore, it

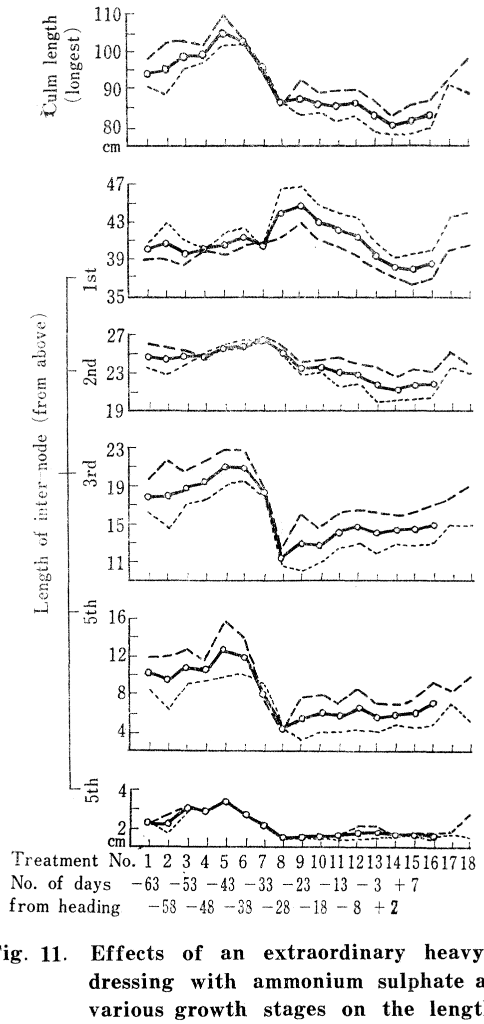


Fig. 11. Effects of an extraordinary heavy-dressing with ammonium sulphate at various growth stages on the length of the longest culm and each inter-node.

has also made clear that the most effective time for lengthening each leaf-sheath and each leaf-width is nearly 5 days later than the most effective time for lengthening each leaf-blade. Moreover, as a result of investigating the degree of drooping of each leaf-blade, it has also been clarified that the most effective time for lengthening each leaf-blade is also the most effective time for drooping each leaf-blade.

2) The effects of nitrogen top-dressing at successive growth stages on the culm length and the length of each inter-node are shown in Fig. 11. From the figure the most effective time for lengthening the culm length as well as each inter-node and no effective times for lengthening them can be seen.

3) The effects of nitrogen top-dressing at successive growth stages on the heading date are shown in Fig. 12. From the figure it can be well understood that the top-dressings at and just before the neck-node intiation stage (Treatment 6 and 7) are quite effective in delaying the heading date, and the top-dressings after the initiation stage of young panicles (Treatment 8), at which the total number of leaves on the main stem has already been determined, sometimes seem to quicken the heading date.

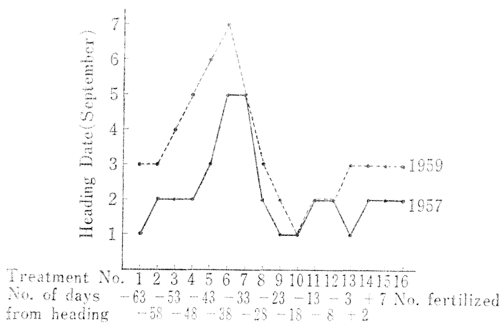


Fig. 12. Effects of extroardinary heavy-dressing with ammonium sulphate at successive growth stages on the heading date.

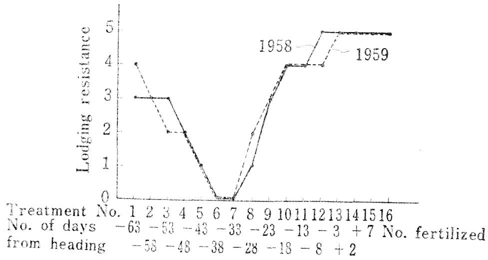


Fig. 13. Effects of an extroardinary heavy-dressing with ammonium sulphate at successive growth stages on lodging resistance of rice plants.

Note : The larger in the figure of 'lodging resistance', the higher in the resistance.

4) The effects of nitrogen top-dressing on lodging resistance are shown in Fig 13. From the figure it can be seen that the most effective stages for decreasing the lodging resistance are the flag-leaf initiation stage(Treatment 6) as well as the neck-node initiation stage (Treatment 7), and also top-dressings during the period from 48 days to 28 days before heading are quite effective for decreasing the lodging resistance.

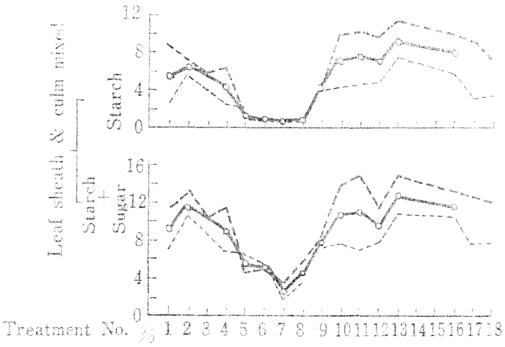


Fig. 14. **Effect of an extraordinary heavy-dressing with ammonium sulphate at various growth stages on the chemical composition of the rice plant.**

5) The effects of nitrogen top-dressing on the accumlation of starch and sugar in leaf-sheaths and culms at the full heading stage are shown in Fig. 14. The figure shows that the top-dressings during the period from 43 days to 28 days before heading are quite effective for reducing the percentage of starch and sugar stored in the plant at the full heading stage, which causes the low percentage of ripened grains.

6) The effects of nitrogen top-dressing at successive growth stages on the grain yield and yield-components can be seen in Fig. 15. The top-dressings of nitrogen at successive growth stages are classified in the following five groups on the basis of their role in determining grain yield.

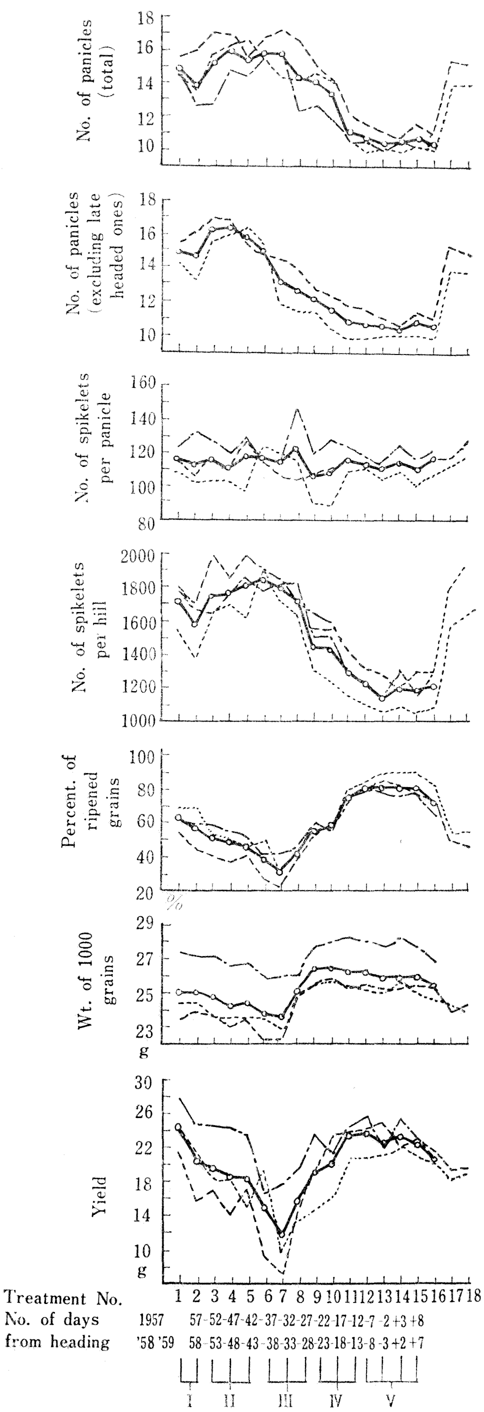
Group 1 (a base dressing and a top-dressing just after rooting, Treatment 1 and 2) increase large and strong tillers and consequently increase grain yield stably.

Group 2 (top-dressings at the early and middle tillering stage, Treatment 3, 4 and 5) contribute toward yield by increasing the number of panicles but some times bring about late-emerging tillers and reduce the percentage of ripened grains as well as yield.

Group 3 (top-dressings at the invalid tillering stage, neck-node differentiation stage, and primary rachis-branch differentiation stage, Treatment 6, 7 and 8) are most effective in increasing the number of differentiated spikelets per panicle and consequently are liable to produce an excessive number of spikelets per unit area, reducing the percentage of ripened grains as well as yield and causing lodging. The nitrogen top-dressing at these stages, therefore, are risky.

Group 4 (top-dressings at the spikelet differentiation stage and at the early reduction-division stage of meiosis, Treatment 9, 10 and 11) increase yield mainly by preventing the plant from degenerating spikelets and by increasing the weight of 1,000 grains.

Group 5 (top-dressings at and after the late reduction-division stage up to the early ripening stage. Treatment 12, 13, 14 and 15) contribute to grain yield by increasing the percentage of ripened grains as well as the weight of 1,000 grains. These top-dressings do



Note: 1. ——1957, ----1958, ······1959, ○—— Average of 3 years
2. Treatment No. 1: basically fertilized. No. 16: non-fertilized. No. 17: fertilizer distributed to 8 times, i. e. at the date of treatment No. 1, 3, 5, 7, 9, 11, 13 and 15. No. 18: fertilizer distributed to 5 times, i. e. at the date of treatment No. 1, 2, 7 10 and 13.

Fig. 15. Effects of an extraordinary heavy-dressing with ammonium sulphate at various growth stages on the yield and the yield-components.

not increase yield so much but have no effect at all on lodging.

In the experiment, the most striking fact is that the curve for the percentage of ripened grains as well as yield shows a V-shaped line, i. e., a first maximum is found at base dressing and the value descends as the growth advances, attaining a minimum at the top-dressing of the neck-node differentiation stage, thereafter, it again shows an upward trend, attaining a second maximum at the reduction-division stage, until finally it shows nearly the same values as the second maximum. The V-shaped line suggests clearly that much nitrogen should not be top-dressed at all at the stages centering around the neck-node initiation. On the basis of the V-shaped line the following V-shaped rice cultivation has been established.

The V-shaped rice cultivation—A method for maximizing grain yield on the basis of nitrogen requirements at different stages of growth[3)4)5)].

As a result of investigating the reason why the top-dressing at the stages centering around the neck-node initiation reduces the percentage of ripened grains markedly, the author found the plant type is one of the most influential factors determining the percentage of ripened grains. The main issue in maximizing the yield of rice is to maximize the number of grains per unit area and, at the same time, to raise as high as possible the percentage of ripened grains, because the yield of rice is mostly determined by the product of the number of spikelets per unit area and the percentage of ripened grains. These two components, however, are inversely related and often show a strong negative correlation. Since the author struggled for a long time to solve this problem, getting a hint from the plant type, he induced the idea of an ideal plant type[3)4)] for maximizing the yield of rice on the basis of many experiments conducted by the author himself as well as others who made studies on growth analysis.

The characteristics of an ideal plant were proposed as follows.

1) The plant should have the necessary and sufficient number of spikelets per plant (per unit area) to obtain the target yield.
2) It should be short in culm height (in particular lower 3 inter-nodes) as well as in panicle length and have many culms to protect against lodging and to increase the percentage of ripened grains.
3) Its upper three leaf-blades should be short, thick, and erect to increase the light-utilizing efficiency and consequently the percentage of ripened grains. (The "leaf-area index" should be 5 to 7).
4) It should keep absorbing nitrogen even in the period after heading to increase the percentage of ripened grains.
5) It should have as many green leaves per culm as possible (the number can be considered as an index of healthiness).
6) Its heads should emerge at a proper time so that it may possess at least 25 sunny days continuously after heading to increase the amount of photosynthetic products at the most active ripenening stage.

Furthermore, getting a hint from Fig. 10 and 11, the author found a method which makes it possible to control, at one's disposal, the length of a given leaf-blade, sheath and inter-node of the rice plant[3)]. From the results of the various experiments, it has been found that the restriction of nitrogen absorption during the period from 69 to 93 in the "leaf-number index" can be said a key to establish the "ideal plant type". (The critical period, from 69 to 93 in the "leaf-number index", is roughly corresponding to nearly 43 days to 18 days before heading.) Moreover, referring to the characteristics of the ideal plant mentioned above and other experimental results related to creating the characteristics, the author established a cultural method which makes it possible to maximize the yield of rice through the ideal plant. The method has been called "V-shaped rice cultivation" and the main points in practising the V-shaped rice cultivation can be summarized as in Fig. 16. For details, see the author's paper[5].

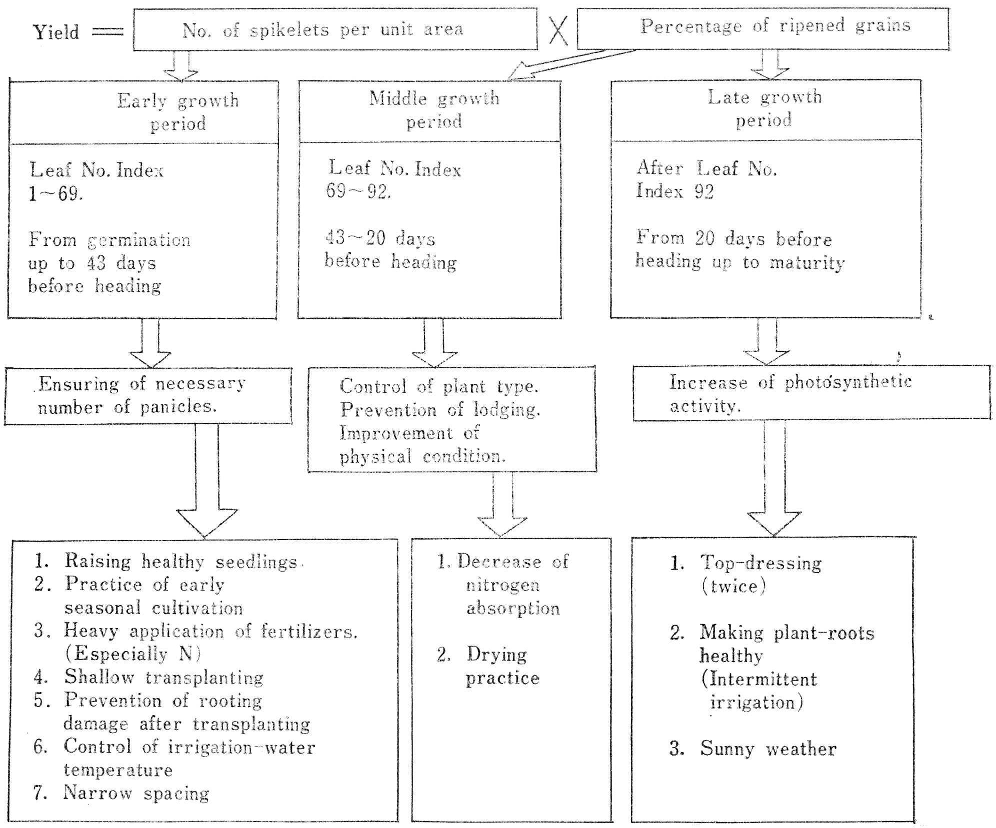


Fig. 16. Schematic representation on points in practice of V-shaped rice cultivation.

By using the cultivation method, the author succeeded in obtaining 10.2 tons of brown rice per hectare in water culture under a community condition (10 square meters in area, excluding border effects) and in obtaining 7.7 tons of brown rice in an experimental paddy field, which has never been obtained so far by any other means in his experimental field. Furthermore, by using the method, a farmer in Furukawamachi of Gifu Prefecture yielded 9.6 tons in 1967 and 9.7 tons of brown rice per hectare in 1969, each yield of which was the nearly the highest one in Japan in each year, respectively, and some Japanese experts (Dr. Hirano and others) yielded 8.5 tons of brown rice per hectare in Cambodia (near Battambang).

Discussion

A. Tanaka, Japan: In relation to Fig. 1-6, what are the factors determining the amount of nitrogen absorbed by the plants per m^2?

Answer: One of the largest factors is the amount of the growth of plants per m^2 such as the planting density per m^2 and the size of plants.

A. Tanaka, Japan: Can we expect to have a similar tendency as Fig. 15, if an ordinary amount of nitrogen is applied at different stages of growth or if some amount of nitrogen is given as basal application?

Answer: In order to magnify the characteristics of the nitrogen responses to the rice plant at different stages of growth, an extraordinary amount of nitrogen was applied at each stage in this experiment. So, if an ordinary amount of nitrogen is applied, the tendency will sometimes become much obscure. But, as the results of an experiment in the crop science laboratory of University of Tokyo proved, in which experiment half an amount of nitrogen was given as basal application, a similar tendency as in Fig. 15 will be obtained in many cases, if much amount of nitrogen is top-dressed.

A. Tanaka, Japan: Generally, soils with large cation exchange capacity are good in obtaining high rice yield. Do you think it is possible to control the level of nitrogen in the soil as you like during growth period with such good soil?

Answer: It is true that the control of nitrogen level in the soil is much more difficult in the soil with large cation exchange capacity than in the soil with small one. However, it is not impossible, but it is considerably possible to control the nitrogen level by using various agronomical practices.

Y. Murata, Japan: Does the depletion of N supply from 43 days to 18 days before heading not badly affect the size of hulls and as a result limit the grain yield?

Answer: From my experiments it has been clarified that the size of hulls is affected by the nutrition of plants during the period from 25 days before heading (initial stage of spikelet differentiation) up to 5 days before heading (end stage of reduction division of PMC) and the size of hulls is most strongly affected in the period of reduction division. Since the reduction division stage generally starts at the earliest on the 15th day before heading, if we top-dress on the 18th day before heading, the effect of top-dressing appears on the growth of hulls during the period of reduction division and increases the size of hulls in manv cases.

S. K De Datta, IRRI: At IRRI we obtained 10.47 metric tons per hectare of rough rice (at 14% moisture) from a replicated experiment conditioned farmers field. This may correspond to about 8 metric tons per hectare of brown rice. Such instances have been reported from many countries such as West Pakistan (Dokri Station). These yields have been obtained under less elaborate practices and less complicated fertilizer application than those of Dr. Matsushima's V-Shaped rice cultivation.

Answer: In tropical countries in not a few cases the amount of sunshine during the growth period of rice plants is much more than in Japan, so under less elaborate practices and less complicated fertilizer application sometimes much more yields than in Japan will easily be obtained. However, if you utilize the V-Shaped rice cultivation, you will surely be able to obtain much higher yield than your highest yield at present.

References for Paper 5

1. Matsushima, S. and T. Manaka 1961: Analysis of developmental factors determining yields and its application to yield prediction and culture improvement of lowland rice. LVIII. Effects of an extraordinary heavy-dressing with ammonium sulphate at various

growth stages on the yield, yield-components, growth, morphological characters and the chemical composition of the rice plant. Proc. Crop Sci. Soc. Japan 29 (2).

2. Matsushima, S. 1964 : Nitrogen requirements at different stages of growth. The mineral nutrition of the rice plant. IRRI. The Johns Hopkins Press, Baltimore, Maryland.
3. Matsushima, S. 1966 : Crop science in rice. Fuji Publishing Co. (1-26, Nishigahara, Kitaku, Tokyo).
4. Matsushima, S. 1967 : Ecology of ripening in rice with special reference to rising the percentage of ripened grains under luxurious growth condition for maximizing grain yield. IRC Newsletter Special Issue 1967.
5. Matsushima, S. 1969 : A method for maximizing rice yield on the basis of V-shaped rice cultivation theory. JARQ (Japanese Agricultural Research Quarterly) 4 (1-2).
6. Wada, G. 1969 : The effect of nitrogen nutrition on the yield-determining process of rice plant. Bull. National Inst. Agri. Sciences Series A. No. 16.