Method of Nitrogenous Fertilizer Application in Direct-Sowing Rice Culture with High Plant Density

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Although grain yields are relatively high, cost of production of rice is also high in Japan. Productivity increase and development of technology for resource-saving and environment conservation are urgently needed.

Direct-sowing rice culture on well-drained paddy fields has been practiced in some areas because of its easiness of saving labor by the use of machines. However, due to several disadvantages[2),5),7)] such as greater percolation loss of water, soil fertility decrease, need of increased fertilizer application, difficulties in scheduling sowing operation due to rainfalls and unreliable germination, it has been adopted to a limited extent (1.7%[10)] in national average in 1973).

A direct-sowing culture with shallow tillage and high plant density is considered as a promising method for overcoming such disadvantages for saving labor and resources (with less fertilizers) and for environment conservation as well as stable high yields. The present study was carried out from this point of view in 1974 and 1975 at the Chugoku National Agricultural Experiment Station (Fukuyama City, Hiroshima Prefecture).

Density of sowing and transplanting

Two levels of plant density, i.e., a standard (usual) density and the density higher than the standard, were given for both direct-sowing (referred to SS and DS respectively) and tarnsplanting culture (SP and DP) as shown in Table 1. The purpose of giving such a high density is to obtain sufficient number of panicles depending not on tillering but directly on number of seeds sown and seedlings planted.

The number of dibbled holes in DS and hills in DP was 83.3/m², which is three times of the standard (27.8/m²) and as much as four times that of the general practice of farmers (about 20/m² in an average).[10)] It is far higher than the density (less than 30/m²) of high-yielding culture of rice.[3)]

Table 1. Space, number and weight of seeds, and number of young plants

Treatment	Number of dibbled holes or hills/m²	Number and weight of seeds, or number of seedlings/m²
Dense direct-sowing (DS)	83. 3 holes (12×10 cm)	417 seeds (5 seeds/hole, 12 g/m²)
Standard direct-sowing (SS)	27. 8 holes (12×30 cm)	139 seeds (5 seeds/hole, 4 g/m²)
Dense transplanting (DP)	83. 3 hills (12×10 cm)	250 seedlings (3 plants/hill)
Standard transplanting (SP)	27. 7 hills (12×30 cm)	83 seedlings (3 plants/hill)

In the DS plot, five seeds were sown per hole to give a rate of 417 seeds/m², by considering a possible decrease of germination percentage, and expecting some tillerings but finally the production of one panicle per one seed. Thus, the DS plot aimed at securing sufficient number of panicles without depending on fertilizer as far as possible. The seed rate was 120 kg/ha. The seeds were dibbled at 12 × 10 cm by hands. This is the minimum spacing which the seeder can work.

Growth of rice plants

1) Number of tillers at panicle initiation stage

The experiment with DS, SS, DP and SP plots was carried out in paddy fields of different nitrogenous soil fertility without nitrogen application (Fig. 1). At the standard density, only about 400 tillers/m² were obtained even in fertile fields, whereas nearly 800 tillers/m² were obtained at the most at the high density. In general, more tillers were produced by direct-sowing than transplanting, and 530 tillers/m² of the DS plot were 55% more than the SS plot, whereas 466 tillers/m² of the DP plot were 35% more than the SP plot. Without nitrogen application, almost all tillers produced by the panicle initiation stage bear panicles, so that it is possible to obtain about 500 panicles/m² in the DS plot without fertilizer application on paddy fields of moderate soil fertility.

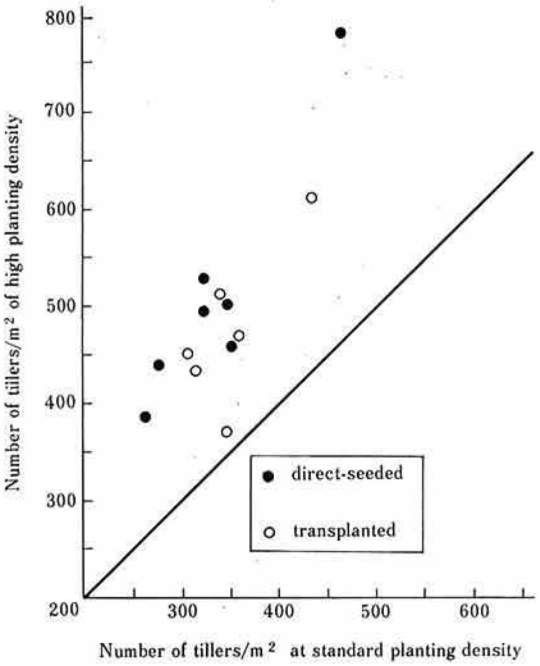

Fig. 1. Number of tillers at panicle initiation stage (No N applied)

2) Dry weight of plants and stem/leaf blade ratio at panicle initiation stage

While dry weight of stem and leaf blade per m² increased with the increase of tillers as shown in Fig. 2, dry weight of leaf blade of no-nitrogen plots (–N) was considerably smaller than that of NPK plots, but that of stem in the former was almost similar to or slightly smaller than the latter. Therefore

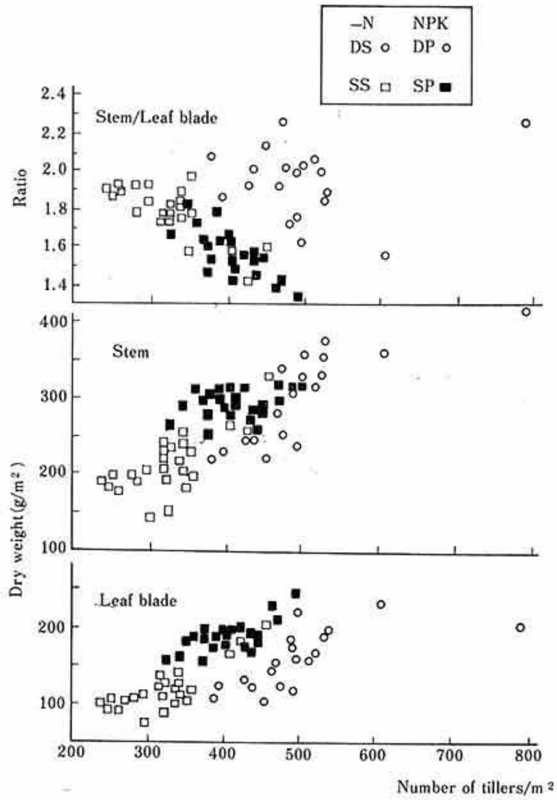

Fig. 2. Relationship between number of tillers and dry weight of leaf blades and stems at panicle initiation stage

ratios of stem/leaf blade were high in the –N plots. Among the –N plots, DS and DP gave very high ratio, and the same tendency was observed among NPK plots.

This fact indicates that the production of stem was greater in proportion to the leaf blade production at a high density without nitrogen application. The ratio of stem/leaf blade reached more than 1.6 at the high density with about 500 tillers/m². Dry weight of leaf blade at that density was only 150–200 g/m², showing LAI of about 3.5. LAI was increased by top dressing of nitrogen at the panicle initiation stage by about 2, but seldom exceeded 6 at the heading stage. Such a plant type is regarded as beneficial in warm areas of southern Japan, where vegetative overgrowth is apt to occur, in promoting dry matter production during the reproductive period by an improved light-receiving efficiency, with a result of good ripening.[11] That plant type is also resistant to lodging.

3) Relation between nitrogen content and stem/leaf blade ratio at panicle initiation stage

Although the relation between stem/leaf blade ratio and number of tillers (Fig. 2) varied to some extent with nitrogen application and spacing, the stem/leaf blade ratio showed an increase with a decrease of N content of straws, irrespective of different treatments (Fig. 3). This fact indicates that the lower the N content of plants, the higher is the proportion of stem to leaf blade, and the high planting density causes low N content in either plots with or without nitrogen application.

In the usual cultivation with standard spacing, a large amount of nitrogen is applied at an early stage of growth in order to secure enough number of panicles. This method causes high N content of plants, which induces a decreased ratio of stem/leaf blade, not favorable for the later growth. On the other hand, plants grown at the high density without nitrogen application or with small amount of nitrogen can produce easily target number

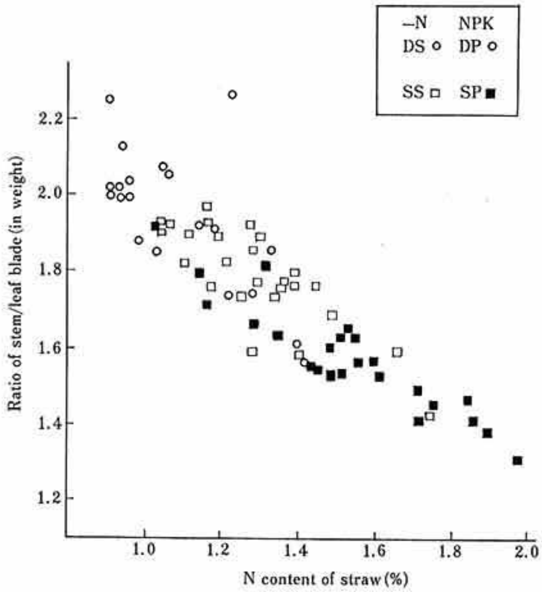

Fig. 3. Relationships between N content of straw and ratio of stem/leaf blade (in dry weight) at the panicle initiation stage

of panicles with the good plant type at low N content of plants. At the tiller number of 500/m², the ratio of stem/leaf blade was more than 1.6, and N content at the panicle initiation stage was about 1.4%.

It has been said that growth and yield of rice depend to a great extent on soil fertility, particularly nitrogenous soil fertility,[1,4] and measures to increase nitrogenous soil fertility are important in obtaining high yields. As observed in the present study, production of tillers which depends on soil fertility can be achieved at lower N content of plants with higher ratio of stem/leaf blade as compared with plants depending on nitrogenous fertilizers. This may be a reason why high yields can be obtained on fertile fields.

4) Trends of N content with growth

N content of straw is shown in Fig. 4. As DS plot with NPK did not receive nitrogen in an early stage, N content was maintained low, showing a marked difference with SS plot. After the top dressing of nitrogen applied at 35 days before heading (26 July), the N content increased to a level similar to

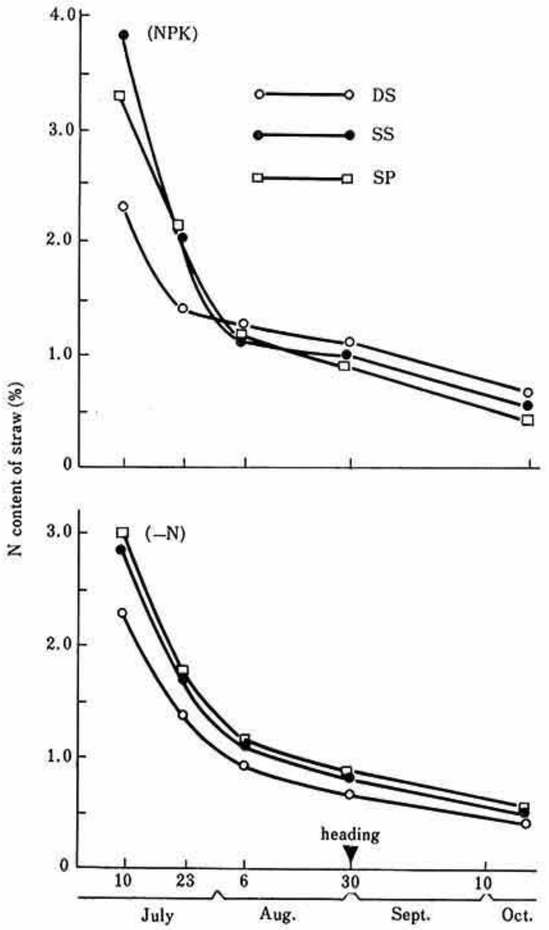

Fig. 4. N content of straw in NPK and −N plots

or slightly higher than other plots. DS plot without nitrogen application showed always low N content: the difference with SS plots was apparent in leaf color. At the standard density, N content of transplanted rice was maintained slightly higher than that of direct-sown rice, suggesting that more nitrogen was released from the soil of transplanted plot.[9]

Utilization of soil nitrogen

Amount of nitrogen absorbed by plants and that of residual NH_4-N (extracted by 10% KCl solution) in the top soil (0–10 cm depth) were determined in the SP plot without nitrogen fertilizer (Fig. 5). The residual N showed an increase by the time of mid-season drainage (end of July), reaching about 10 kg N/ha, which is almost similar to the amount absorbed by plants by that time. This amount of residual N could be utilized by dense sowing or dense planting.

Therefore, uptake of soil-N was compared between standard density and high density (Fig. 6). The uptake by the panicle initiation stage was increased by 10% by DP and 13% (about 5 kg N/ha) by DS. Thus, it was made

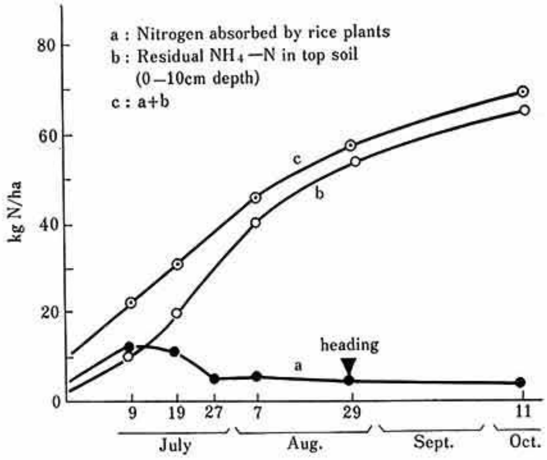

Fig. 5. Supply of available N from soil to which no nitrogenous fertilizer was applied (SP plot)

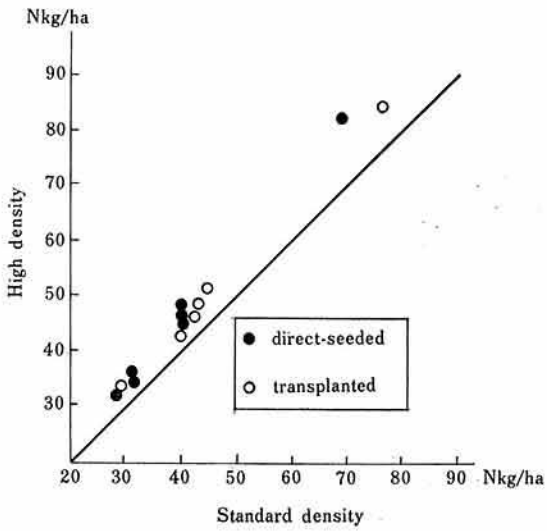

Fig. 6. Amount of N absorbed by plants from soil. (No nitrogenous fertilizer applied. At panicle initiation stage)

clear that soil nitrogen can be utilized more efficiently in DS and DP than SS and SP.

Dense direct-sowing with shallow tillage

Shallow tillage (3–5 cm depth) offers better trafficability for machines, being less influenced by rainfalls, than the deep tillage (about 12 cm depth). It also gives better germination in clayey soils due to favorable soil structure (moisture condition). In addition, mineralization of soil nitrogen is less at an early growth stage: an advantage of reducing useless release of N.

The most labor-saving method is to till shallowly after seeds are broadcast. In this case, the tillage does the job of covering, weeding and levelling. In the present experiments, however, compost was applied, tilled shallowly (twice), levelled, seeded, and then covered with charcoaled rice husks.

1) Time of nitrogen application

As shown in Table 2, basic dressing was omitted, and top dressing at the tillering stage was made by considering a case of poor germination or extremely low soil fertility which may not be enough to secure the target number of tillers. Top dressing at 35 days before heading aimed at increasing panicle size, and can be omitted on very fertile soils. According to Matsushima[6], the top dressing at this stage accerelates an elongation of lower internodes, that causes lodging, and an increase of size of upper leaves, which lowers the light-receiving efficiency, resulting in the poor ripening. However, such effects were not observed with DS plants without basic and top dressing at the tillering stage, because of low N content. Instead, the top dressing at that stage contributed to an increase of number of spikelets per panicle, as described later.

2) Yield and yield components

DS gave brown rice yields more than 6.5 ton/ha with 6.8 ton/ha as the maximum, in contrast to 5.2 ton/ha of SS. Without N application, DS outyielded SS. A major difference between DS and SS was found with number of panicles. In SS it was 368/m^2 even with top dressing of 60 kg N/ha, whereas in DS it was 435/m^2 without N application and more than 500/m^2 when nitrogen was applied at 35 days before heading.

It is usual that dense sowing is liable to

Table 2. Dense direct-sowing rice culture with shallow tillage

Treatment: Space	Treatment: *Time of application of nitrogenous fertilizer (N kg/ha) B T −35 Y −10	Plot number	Yield (t/ha)	Number of ears (/m^2)	Number of spikelets ($\times 10^2$/m^2)	Percentage of ripened grains (%)	Weight of 1,000 grains (g)	Ratio of grain to straw	Ratio of ears to seeds in number
High density	−N	(1)	4.5	435	224	87.6	23.0	0.85	1.04
	0+30+ 0+30+ 0	(2)	6.5	543	319	86.2	23.7	0.92	1.30
	0+ 0+30+30+ 0	(3)	6.8	510	355	83.7	22.9	0.96	1.22
	0+30+30+30+ 0	(4)	6.5	530	369	79.1	22.3	0.86	1.27
	0+30+30+30+20	(5)	6.7	521	360	83.6	22.3	0.85	1.24
Standard density	−N	(6)	3.9	276	176	94.3	23.6	0.87	1.98
	0+(30+30)+0+30+0	(7)	5.2	368	236	93.6	23.6	0.88	1.65

Notes 1) *B : basal, T : tillering (Jun. 27 and Jul. 3), −35 : 35 days before heading (Jul. 26), Y : young panicle formation stage (Aug. 10), −10 : 10 days before heading (Aug. 20).
2) Application of manure: 20 t/ha in March.
3) Sowing: May 24, Submerging: from Jun. 19 to Sept. 30 (groundwater level: 0∼20 cm).
4) Application of P_2O_5: 30∼60 kg/ha, Application of K_2O: 60∼110 kg/ha.
5) Variety: Nakate-shinsenbon.

Table 3. High dense direct sowing culture of rice in shallow tilled paddy field

Treatment		Plot number	Weight of dry matter/spikelet at heading time (mg)			LAI at heading time	Total amount of supplied nitrogenous fertilizer (N kg/ha)	Nitrogen absorbed by rice plant (N kg/ha)	Percentage of absorbed nitrogen to supplied nitrogen (%)
Space	Time of application of nitrogenous fertilizer (N kg/ha) BT−35Y−10		ear	l.b.	stem				
High density	−N	(1)	4.5	8.8	25.8	3.7	—	83	—
	0+30+ 0+30+ 0	(2)	4.7	9.0	23.9	5.3	60	125	70.7
	0+ 0+30+30+ 0	(3)	6.0	7.8	19.3	5.2	60	136	88.8
	0+30+30+30+ 0	(4)	5.4	8.5	19.6	6.0	90	147	70.7
	0+30+30+30+20	(5)	5.6	8.3	17.9	—	110	155	65.6
Standard density	−N	(6)	4.4	8.3	24.7	2.8	—	67	—
	0+(30+30)+0+30+0	(7)	5.3	8.8	23.6	3.9	90	99	34.9

produce small panicles, but in this experiment the number of spikelets per panicle was increased by the top dressing at 35 days before heading. Percentages of ripened grains were high as a whole in spite of large number of spikelets produced, and weight of 1000 grains and grain/straw ratio were more or less unchanged by the dense sowing.

3) Growth characteristics at heading stage

Dry weight of plant organs per one spikelet at the heading stage is shown in Table 3. Leaf blade/spikelets was not significantly decreased by DS although number of spikelets was greater than SS. Among DS plots, leaf blade/spikelets tended to increase by top dressing at the tillering stage, while it decreased due to an increased spikelets by top dressing at 35 days before heading. Stem weight/spikelets was also reduced to less than 20 mg by top dressing at that stage, while it was more than 23 mg in other plots. Stem weight/spikelets at the heading stage is known to have a close relation to the ripening percentage: the greater the ratio the higher is the ripening percentage. Therefore, the top dressing at 35 days before heading is not necessarily effective in improving ripening, because it reduces stem weight/spikelets. However, in the present study the ripening percentage higher than 80% was obtained because stem weight/spikelet more than about 18 mg was produced. LAI of DS was small with the maximum of 6.0 in spite of a large number of spikelets produced.

4) Amount of nitrogen applied and absorption efficiency

Although the average rate of N application to direct-sowing rice culture on well-drained fields is 120–150 kg/ha, 60–90 kg/ha was sufficient enough in this experiment. In the former case, a great amount of N is applied at an initial growth stage and which causes low absorption efficiencies. With DS culture, N was applied after the roots of plants developed so that small amount of N might be utilized with high efficiencies. However, further studies will be needed as the efficiency of DS plots seems to be too high.

Conclusion

It became apparent that DS and DP are high-yielding and resource-saving technology judging from the utilization of soil fertility, rate of fertilizer applied, sbsorption efficiency of N, and growth characteristics of rice plants (panicle number and plant type). In additoin, direct-sowing with shallow tillage can be practiced with a result of good germination and trafficability of sowing and harvesting machines in areas of clayey soils and high ground water table, thus making easy to schedule farm operations[7].

In practice, DP is difficult to be done because it requires much labor, while DS is easy to be done. If an efficient machine will be developed for DS with shallow tillage, this method of culture will be widely adapted to well-drained paddy fields of southern Japan. There still remain several problems to be solved: a danger of lowering soil fertility because the method depends more on soil fertility, and a disadvantage of occupying paddy field for a longer period as compared with transplanting culture, limiting an intensive land use such as growing of second crops (wheat and vegetables etc.). Studies on shortening or shifting of growth duration will be needed.

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