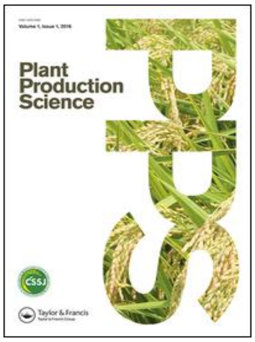

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Effects of Deep-Flooding Irrigation on Growth, Canopy Structure and Panicle Weight Yield Under Different Planting Patterns in Rice

Masamichi Ohe, Noriko Okita and Hiroyuki Daimon

(Graduate School of Life and Environmental Sciences, Osaka Prefecture University, Sakai, Osaka 599-8531, Japan)

Abstract: For rice cultivation in Japan, deep-flooding irrigation is used as a growth control method. To clarify the effects of deep-flooding cultivation under the different planting-pattern, we arranged conventional (Con, 22 hills m^{-2}), narrow (Nar, 33 hills m^{-2}) and very narrow (broadcast direct-seeding Model:BDSM, 100 hills m^{-2}) planting plots under shallow-flooding (SF: 5 cm) and the deep-flooding (DF: 27 cm) conditions from active to maximum tillering stage and evaluated the growth, panicle weight yield, panicle components and community structure. DF was effective in controlling the weak tiller over the whole planting plots arranged. The panicle weight yield (m^{-2}) was high in DF and high yield was kept even in BDSM. The panicle weight yield (m^{-2}) increases in DF was based on the panicle weight (panicle^{-1}) increased by increasing secondary rachis-branches and their grains (Con and Nar), or on the panicle numbers (m^{-2}) increase (BDSM). Shoot nitrogen content (tiller^{-1}), reported to have the correlation with panicle components, was high in the Con and Nar in DF, and this might contribute to the increase in secondary rachis-branch grains. In BDSM in DF, the marked decrease in the percentage of productive tillers and serious lodging observed in SF were improved. The lodging resistance value in DF was higher than that in SF over the whole planting plots. The light transmission in DF was superior to that in SF in spite of the large LAI. Thus, the growth improving effect of DF was obvious over the wide planting pattern range.

Key words: Deep-flooding, Irrigation, Nitrogen, Panicle weight, Planting pattern, Rice, Tillering.

Deep-flooding management in rice culture has been used for many years for protecting the seedlings or young panicles from cool weather damage, and for weed control. In recent years, it comes to be practiced widely by diligent farmers as a growth control method, and is called “deep-flooding cultivation.” However, the water depth, treatment time and treatment period, vary with the farmer. Therefore, very little practical information about this is available, and there is significant divergence in the evaluation made by the farmers who adopted deep-flooding cultivation. It is therefore necessary to provide practical information applicable to all cases, and we clarified the growth responses of rice, i.e., culm elongation, tiller emergence, dry matter production and lodging under deep-flooding conditions, and recommended the suitable depth of water, and treatment time for applying the deep-flooding management into conventional rice cultivation systems (Ohe et al., 1994, 1996; Ohe and Mimoto, 1998, 1999, 2002). When an appropriate treatment was given, obvious improvements on the percentage productive tillers, yield and lodging tolerance were observed (Ohe and Mimoto, 2002). However, the panicle number per hill sometimes becomes lower than that in the conventional irrigation due to restricted tiller number (Ohe et al., 1995; Watanabe et al., 2006). One of the effective methods for keeping the number of the panicles per hill is narrow-space transplanting. However, it is known that the yield increase by the increase of the planting density reaches the ceiling at a certain density, and it is known that excessive density causes the fall of the yield (Yamada et al., 1960; Takeda and Hirota, 1971). The negative influences are regarded as the competition for the light and nutrition in the community, and lodging problems (Tanaka and Matsushima, 1971). In the case of the deep-flooding cultivation, the light transmission and spatial use of community may be good because of the restriction of the non-productive tillers in deep-flooding. Under such an environment, the increase in the yield or stable high-yield can be expected. To verify the above hypothesis, we evaluated the growth, yield components and community structure of rice under the different planting pattern, i.e., conventional, narrow and very-

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Table 1. Climatic conditions during the experimental period.

Month	Mean air temperature (°C)	Rain fall (mm)	Duration of sunshine (hr)
June	22.8 (102)	155 (80)	126.2 (84)
July	24.5 (93)	123 (97)	118.7 (63)
August	27.4 (99)	227 (237)	205.3 (90)
September	24.8 (106)	133 (86)	214.8 (139)
October	16.8 (97)	97 (100)	181.6 (114)

Percent to long-term average (1979–2000) was given in parentheses.

narrow like broadcast direct-seeding under shallow- and deep-flooding conditions.

Materials and Methods

1. Experimental place and climatic conditions

A field experiment was conducted at the experimental paddy (10 m×5 m) in the Osaka Prefecture University experimental field (N: 34°32′38″, E: 136°30′20″, Alt. 28 m). Climatic conditions in the experimental place during the experimental period are shown in Table 1. The rain fall of the experimental year was high in August, and sunshine duration was short in comparison with that of the long-term averages (rain fall: 237%, sunshine duration: 63%). However, climatic conditions of experimental year were enough for the average growth.

2. Experimental design

Nippon-bare, a Japanese paddy rice cultivar, was used. Three kinds of planting plots (plot size: 4 m×1.5 m), conventional (Con), narrow (Nar) and very narrow like broadcast direct-seeding (broadcast direct-seeding model: BDSM), were arranged (Fig. 1). Hill distance and row distance of each plot was 15 cm×30 cm (22 hills m^{-2}, 3 plants hill^{-1}), 10 cm×30 cm (33 hills m^{-2}, 3 plants hill^{-1}) and 10 cm×10 cm (100 hills m^{-2}, one plant hill^{-1}). Con plot is the general pattern of rice planting machine transplanting. Nar plot is the narrowest planting in which the seedlings can be transplanted with a rice planting machine. The BDSM plot was arranged as a model of a broadcast direct-seeding cultivation. In the BDSM plot, in order to make the community structure similar to that of the direct-seeding conditions, 8-day-old seedlings (leaf age 1.5) were transplanted with one seedling per one hill. In other two plots, 15-day-old seedlings (leaf age 3.2) were transplanted, and each hill had three seedlings. The transplanting depth in each spacing-plot was 2 cm. The transplanting date was 11 June, 2003.

Two irrigation plots i.e., the shallow-flooding (SF) plot and the deep-flooding (DF) plot were set up for each spacing-plot. Two irrigation plots were arranged in one paddy-field, and spacing plots were arranged in each irrigation plot.

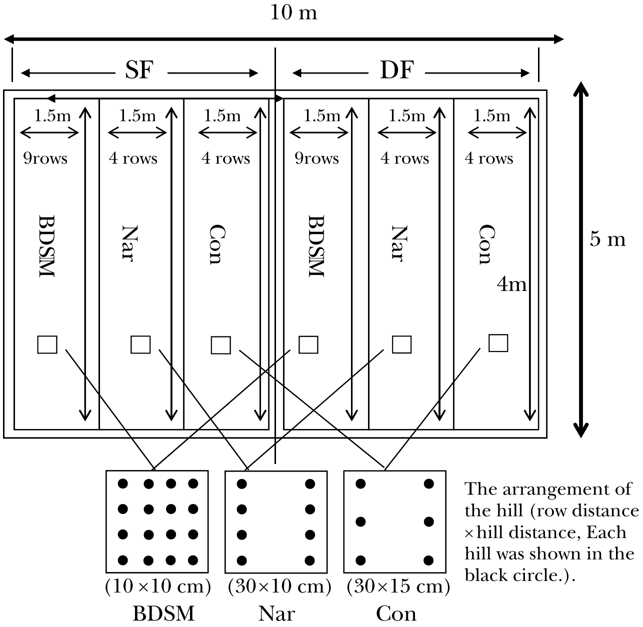

Fig. 1. Outline of the design of this experiment. Experimental paddy (10 m×5 m). SF, shallow-flooding plot; DF, deep-flooding plot. Con, conventional planting; Nar, narrow planting; BDSM, broadcast direct-seeding model. Ply wood frame was used to keep the water depth of deep-flooding plot.

DF was started at the active tillering stage (26 d after transplanting (DAT), 7 July) adjusting the water depth to about 27 cm at which the leaf sheath of the fully expanded leaf on the main stem submerges (start from plant age 9.7 to plant age 11.3, for 18 d). The treatment method used in this study was based on our previous work (Ohe and Mimoto, 1998, 2002).

Compound fertilizer (8:8:8) were uniformly applied to top soil at 62.5 g per square meter each (5 g of N, P_2O_5, and K_2O) at the time of transplanting. Topdressing at panicle formation stage was applied at 51 DAT and at 61 DAT at 25 g of compound fertilizer per square meter each.

Plant height and the number of culms were counted every 5–7 d after the transplanting for random selected 10 hills.

3. Evaluation of yield potentials

Panicle weight yields in each plot were determined by using all panicles from the random sampled 10 hills. In order to estimate the difference in the panicle yield, the number of primary and secondly rachis, percentage ripening grains and ripening grain number were measured in the main stem panicles chosen from random sampled 20 hills (included the yields surveyed 10 hills).

4. Evaluation of lodging resistance

Lodging resistance was evaluated with a digital-force gage (Aikoh engineering Co., Ltd. MODEL-9500).

Measurement was made with it by pushing a part of the hill 30 cm above the ground. Lodging resistance was evaluated from the maximum value shown when the hill inclines to the angle of 45 degrees. We defined this value as the lodging resistance value in this study.

5. Evaluation of nitrogen

The nutritional conditions were evaluated by total-Nitrogen at the end of the deep-flooding treatment (45 DAT, panicle differentiation stage) using a nitrogen-carbon analyzer (NC-80, Sumitomo Chemical Inc.).

6. Evaluation of community structure

The production structure of the rice canopy was evaluated by light conditions using a quantum sensor (LI-1000, Li-Cor inc). The sensor was moved upward in the canopy at 10-cm increments. Measurement was made at end time of the deep-flooding treatment (growth stage of panicle differentiation, 44–45 DAT) and a ripening stage (90–92 DAT). In order to clarify the correlation between light transmittance and community structure, two randomly selected plants were harvested from each plot, clipped at 10-cm intervals starting from the top of the canopy, and the leaf area was determined using a leaf area meter (AAM-8, Hayashi-denkoh Co., Ltd). Extinction coefficient (K) and leaf area index (LAI: leaf area/land area) were calculated from the value obtained by the above-mentioned method.

7. Sampling methods

The growth survey hills and sampling hills were determined by random sampling, setting aside hills along the levee or the plot border to avoid the influence of border-effect and the interference-effect from another plot.

Results and Discussion

1. Number of tillers

The number of tillers at the maximum tiller number stage was smaller in DF than in SF in all planting plots. However, the number of panicles was almost the same in both water plots in all planting plots, and the percentage of productive tillers in DF was high in all planting plots (Table 2, Fig. 2). The improvement of the percentage productive tillers by deep-flooding treatment in this study is in agreement with the results of our previous investigation (Ohe and Mimoto, 1998, 2002), and this

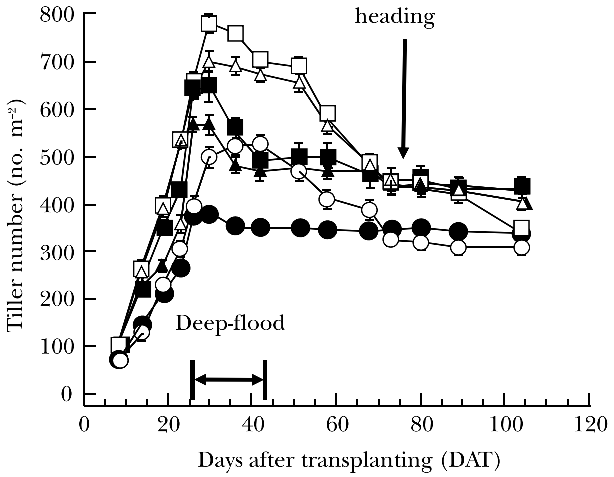

Fig. 2. Time course of rice tiller development as affected by deep-flooding irrigation under different planting patterns. ○: SF・Con, △: SF・Nar, □: SF・BDSM, ●: DF・Con, ▲: DF・Nar, ■: DF・BDSM. SF, shallow-flooding; DF, deep-flooding. Con, conventional planting; Nar, narrow planting; BDSM, broadcast direct-seeding model. Deep-flooding irrigation: from 26 DAT, 18 d. Date of heading: 75 DAT. Vertical bars indicate standard errors, and they are not shown when smaller than symbols. n = 10. Data of tiller number included the both productive and non-productive tillers except the final data (104 DAT, panicle number).

Table 2. Effect of deep-flooding treatment on percentage of productive tillers and several characteristics of rice at the ripening stage.

Water Management	Planting pattern	Max. tiller number		Panicle number		Productive tillers	Plant length	Panicle weight	Panicle weight yield	Lodging resistance value	Frequency of lodging
		(no. hill^{-1})	(no. m^{-2})	(no. hill^{-1})	(no. m^{-2})	(%)	(cm)	(g panicle^{-1})	(g m^{-2})	(N)	(%)
SF	Con	24.4 a	537 c	14.7 a	323 d	60.1	94.3 b	2.04 b	659 bc	5.1 b	0
	Nar	21.3 b	703 ab	11.9 b	391 b	55.6	96.6 ab	1.78 c	698 b	3.1 d	0
	BDSM	7.9 d	790 a	3.9 c	385 bc	48.7	95.4 ab	1.56 d	600 c	0.4 e	55
DF	Con	17.6 c	387 d	15.3 a	337 cd	87.1	96.4 ab	2.25 a	759 a	7.1 a	0
	Nar	17.9 c	591 c	11.9 b	391 b	66.2	95.1 ab	1.95 b	762 a	4.3 c	0
	BDSM	6.7 d	670 bc	4.5 c	450 a	67.2	97.8 a	1.78 cd	801 a	0.7 e	0

SF, shallow-flooding; DF, deep-flooding. Con, conventional planting; Nar, narrow planting; BDSM, broadcast direct-seeding model. Different letters within each culm indicate significant difference at the 5% level (Tukey HSD test). n = 10. Measurements of lodging resistance value; n = 20.

effect is clear even at a high planting density and very narrow planting condition. On the other hand, the improvement of the percentage productive tillers by DF showed some variance. It was high in the conventional planting as compared with the narrow planting plots (Con: 26.5 points, Nar: 12.7 points and BDSM: 20.3 points). In Nar and BDSM, the plant number per square meter of BDSM was the same as that in Nar (100 plants m^{-2}), however, the improvement was striking in the BDSM (Nar: 12.7 points, BDSM: 20.3 points). These results suggest that the degree of improvement of the percentage productive tillers by deep-flooding treatment vary with the plant number in one hill and planting pattern, and that DF is effective in the planting pattern such as broadcast direct-seeding cultivation.

2. Lodging resistance

The resistance value of lodging decreased with the narrowing of planting space in both water plots (Table 2). The resistance value of lodging, however, was larger in DF than in SF over the whole planting plots. In BDSM, the statistical difference was not recognized between SF and DF because of an insufficient number of measurement data in SF due to lodging, but the problem of lodging was improved by DF obviously. From the above results, the deep-flooding treatment can be said to contribute effectively toward the increase in the resistance to lodging under the field conditions, and it is thought to be particularly effective under the very narrow planting conditions such as direct-seeding cultivation. We reported that the culm diameter was markedly increased and the breaking strength of the basal internodes tended to be increased by deep-flooding treatment (Ohe et al., 1996). Won et al. (1999b) also reported the thicker culm and heavier culm breaking weight in deep-water treatment somewhat contributed to the reduction of culm-breaking lodging in direct-seeded rice. The increase in lodging resistance in this study was interpreted as the basal internode diameter increase. On the other hand, Won et al. (1999b) reported that the lodging degree was also affected by the cultivation method i.e., transplanting, dry-seeded and water-seeded, and that in water-seeded cultivation, soil surface sowing of the seeds led to serious root lodging. From this point, deep-flooding irrigation is thought to be effective for solving the lodging problems of direct-seeding cultivation, but special precaution to the sowing depth would be needed.

3. Production Structure

LAI at the panicle differentiation stage (44 DAT, end of the deep-flooding treatment) in DF was large in Con, and was the same as in Nar and BDSM in SF, whereas the stem number was small in DF plots (Table 3; Fig. 2). LAI in DF at ripening stage (90 DAT, 25 d after heading) was large in all planting plots, although there was little difference in the stem (panicle) numbers (m^{-2}) between DF and SF in each planting plot.

Table 3. Effect of deep-flooding treatment on leaf area index (LAI) and extinction coefficient (K) of rice.

Planting pattern	Water Management	44 DAT		90 DAT	
		LAI	K	LAI	K
Con	SF	2.7	0.24	3.5	0.75
	DF	2.9	0.14	4.2	0.62
		*	*	*	*
Nar	SF	3.5	0.28	4.7	0.60
	DF	3.5	0.22	5.7	0.53
		ns	*	*	*
BDSM	SF	4.5	0.21	4.8	0.85
	DF	4.3	0.26	5.3	0.61
		ns	*	*	*

Con, conventional planting; Nar, narrow planting; BDSM, broadcast direct-seeding model. SF, shallow-flooding; DF, deep-flooding. 44 DAT: End of the deep-flooding treatment. 90 DAT: Ripening stage. *: significantly different between SF and DF at the 5% level. ns: non significantly different at the 5% level (t-test). n=2.

The extinction coefficient is evaluated by K. The lower the K value, the better seems to be the light transmission. K values in Con and Nar in DF at the panicle differentiation stage (44 DAT) were lower than those in the same planting plots in SF, and K values were lower in all planting plots of DF of ripening stage (90 DAT) than in the same planting plots in SF (Table 3). Transmission of light decreased with the increase in the leaf area (Murata and Osada, 1959; Hayashi and Ito, 1962) and, in some case, it is mainly limited by light-receiving angle of leaf blade (Hayashi and Ito, 1962). The result that the light transmission in DF tended to be improved in DF in spite of their large LAI was explained by the canopy-structure change by deep-flooding treatment. In deep-flooding rice plants, it would be advantageous to change the plant type so the tip of the leaf sheath reaches the water level to let the leaf blade develop over the water surface and keep each leaf erect to receive more light.

4. Panicle number and panicle weight and nitrogen contents of shoots

The panicle weight yield in DF was high and a high yield was maintained even in BDSM, while in SF, it decreased markedly in BDSM (Table 2). Generally, the yield increases with the increase in planting density within the range of lower density, but their increment begins to decrease gradually as the density increases, and finally yield comes to show a constant value at a density beyond a certain rate. Furthermore too narrow spacing resulted in the reduction of yield due to over luxuriant growth (Yamada, 1960). The

Table 4. Effect of deep-flooding treatment on panicle characteristics of rice under different planting patterns.

Water Management	Planting pattern	Rachis-branch number (no. panicle^{-1}) 1st	Rachis-branch number (no. panicle^{-1}) 2nd	Grain number# (no. panicle^{-1}) 1st	Grain number# (no. panicle^{-1}) 2nd	Total grain number# (no. panicle^{-1})	Grain weight (mg grain^{-1}) 1st	Grain weight (mg grain^{-1}) 2nd	Ripened grain percentage (%)
SF	Con	9.0 a	14.1 b	46.4 a	35.5 bc	81.0 b	28.9 ab	26.6 a	91.9 a
	Nar	8.7 ab	11.9 cd	44.8 ab	29.7 cd	73.4 c	28.9 ab	26.4 a	92.0 a
	BDSM	8.4 c	10.7 d	41.9 bc	23.6 e	65.5 d	27.7 b	24.8 a	86.2 b
DF	Con	9.0 a	16.4 a	47.3 a	45.0 a	92.2 a	29.8 a	27.0 a	93.7 a
	Nar	8.5 bc	12.8 bc	43.5 b	38.4 b	81.9 b	29.5 ab	26.0 a	95.3 a
	BDSM	8.0 d	12.3 c	40.8 c	31.5 c	72.3 cd	28.3 ab	24.5 a	85.8 b

SF, shallow-flooding; DF, deep-flooding. Con, conventional planting; Nar, narrow planting; BDSM, broadcast direct-seeding model. Means followed by different letters are significantly different at the 5% level (Tukey HSD test). n = 20 panicles. #Ripened grain.

Table 5. Effect of deep-flooding treatment on dry weight and N content of rice shoot under different planting patterns (44 DAT: end of the deep-flooding treatment).

Water Management	Planting pattern	Tillers (no. hill^{-1})	Shoot dry weight (g hill^{-1})	Shoot dry weight (g tiller^{-1})	Total N content (mg hill^{-1})	Total N content (mg tiller^{-1})	Total N content (g m^{-2})	Nitrogen requirement[1)] (mg)
SF	Con	22.0 a	9.3 a	0.4 ab	168.3 a	7.65 c	3.7 c	5.7
	Nar	20.0 ab	8.0 a	0.4 b	147.7 a	7.39 c	4.9 a	7.2
	BDSM	7.5 d	3.3 b	0.4 ab	52.6 b	7.01 c	5.3 a	9.1
DF	Con	17.5 bc	9.4 a	0.5 a	165.7 a	9.47 ab	3.7 c	4.8
	Nar	14.0 c	7.6 a	0.5 a	145.9 a	10.42 a	4.8 ab	6.3
	BDSM	5.5 d	2.8 b	0.5 a	43.9 b	7.98 bc	4.4 bc	5.5

SF, shallow-flooding; DF, deep-flooding. Con, conventional planting; Nar, narrow planting; BDSM, broadcast direct-seeding model. 1) Nitrogen requirements for producing 1g of panicle. Total N content (g m^{-2}) / Panicle weight (g m^{-2}). Means followed by different letters are significantly different at the 5% level (Tukey HSD test). n = 2 hills.

tendency reported by Yamada (1960) was observed in SF, but not in DF (Table 2). In BDSM in DF, improvement of low ratio of the productive tillers (from 49% to 67%), panicle number (from 385 panicles m^{-2} to 450 panicles m^{-2}) and lodging problem were observed. On the other hand, the degree of the improvement of panicle weight yield (g m^{-2}) by deep-flooding treatment in Con and Nar was different from that in the BDSM. The panicle weight yield (g m^{-2}) increases in Con and Nar in DF was based on the panicle weight increase (g panicle^{-1}), which was based on the increase in the number of secondary rachis-branches and their grains (Table 4). The number of differentiated spikelets is strongly influenced by the nitrogen contents of the shoot at the panicle growing stage (Kobayashi and Horie, 1994; Kobayashi et al., 2001), and the large number of spikelets depends on the increase in the number of spikelets on the secondary rachis-branches (Hoshikawa, 1989; Kobayashi and Horie, 1994), which may not be affected by planting density (Kobayashi et al., 2001). In DF, the number of the tillers was small, but no reduction in nitrogen absorption per hill was observed, and the nitrogen content of the individual tiller was higher than that in SF (Table 5). The increase in the panicle weight due to the increase in the number of the grains on the secondary rachis-branches in Con and Nar in DF is interpreted as the result of the high nitrogen content of the individual tillers. The difference in nitrogen content of the individual tillers between SF and DF may be due to the tillers in DF are strong and bear panicles later, or/and the nitrogen absorbed by the plants in SF disperse to a large number of tillers including a weak tiller.

The amount of nitrogen required to produce 1 g of panicle weight was smaller in DF than in SF over the whole planting plots. Won et al. (1999a) reported similar results that the utilization efficiency of indigenous soil nitrogen was improved by deep-flood treatment of dry-seeded rice cultivation, and they also suggested that this might increase the yield. Thus, the difference in the nitrogen requirement for producing 1 g of panicle weight in this study seems to be interesting, but it is not clear whether the difference was caused by tiller restriction or canopy structure improvement (ex. improvement of photosynthesis). A detailed study to clarify this point is necessary.

In conventional rice cultivation, it is said that too narrow spacing causes the reduction of yield by over luxuriant growth (Yamada et al., 1960). The negative influence is regarded as the competition for the light and nutrition in the community, and lodging problems. In deep-flooding cultivation, however, the reduction of yield (panicle weight yield) by the increase in the density or narrow spacing was not observed (Table 2). This is interpreted as the result of improvement of light transmission, nitrogen use efficiency and lodging by DF. We concluded that the deep-flooding irrigation effectively increases yield, and lodging tolerance over a wide range of planting pattern. The panicle number might decrease due to restriction of the number of bearing tillers in deep-flooding, and this point should be solved by combining the deep-flooding irrigation with narrow planting. In direct-seeding planting, the negative influence such as lodging and low-yielding which occurs due to excessive growth may be avoided, and a stable high-yield is expected. In this study, we used Nippon-bare considering our previous work, and we arranged the BDSM plot as the plot representative of direct-seeding cultivation because broadcast direct-seeding cultivation would be cost-saving. However, the kind of cultivar and the direct-seeding itself may influence the effect of the deep-flooding treatment and we are planning a new experiment in consideration of these points.

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References

Hayashi, K. and Ito, H. 1962. Studies on the form of plant in rice varieties with particular reference to the efficiency in utilizing sunlight. *Jpn. J. Crop Sci.* 30: 329-333*.

Hoshikawa, K. 1989. The Growing Rice Plant. Panicle, Flower and Grain. Nobunkyo Tokyo.

Kobayashi, K. and Horie, T. 1994. The effect of plant nitrogen condition during reproductive stage on the differentiation of spikelets and rachis-branches in rice. *Jpn. J. Crop Sci.* 63: 193-199*.

Kobayashi, K., Nakase, H. and Imaki, T. 2001. Effect of planting density and topdressing at panicle initiation stage on spikelet number per unit area. *Jpn. J. Crop Sci.* 70: 34-39*.

Murata,Y. and Osada, A. 1959. Studies on photosynthesis in rice plant. XI Significance of the “light-receiving-coefficient” of rice varieties in their dry-matter production at growing stage. *Jpn. J. Crop Sci.* 27: 422-425.

Ohe, M., Goto, Y. and Hoshikawa, K. 1994. Effects of the deep water treatments on the emergence of tillers of rice plant. *Jpn. J. Crop Sci.* 63: 576-581*.

Ohe, M., Tamura, A. and Mimoto, H. 1995. Effects of the deep water treatment on the growth response of rice cultivars. *Rep. Soc. Crop Sci. Breed., Kinki* 40: 17-21**.

Ohe, M., Tamura, A. and Mimoto, H. 1996. Effects of deep water treatment on the growth of culms and lodging resistance in japonica type paddy rice (*Oryza sativa* L.) cultivars. *Jpn. J. Crop Sci.* 65: 238-244*.

Ohe, M. and Mimoto, H. 1998. Effects of the time of deep-water treatment on growth and lodging resistance in japonica type paddy rice (*Oryza sativa* L.). *Jpn. J. Crop Sci.* 67: 153-158*.

Ohe, M. and Mimoto, H. 1999. Changes in the characteristic of dry matter production of japonica type paddy rice (*Oryza sativa* L.) due to the deep-water treatment. *Jpn. J. Crop Sci.* 68: 482-486*.

Ohe, M. and Mimoto, H. 2002. Appropriate time of deep-water treatment for regulation of rice growth. *Jpn. J. Crop Sci.* 71: 335-342*.

Takeda, T and Hirota, O 1971. Relationship between spacing and grain yield of rice plant. *Jpn. J. Crop Sci.* 40: 381-385*.

Tanaka,T. and Matsushima, S. 1971. Analysis of yield-determining process and its application to yield-prediction and culture improvement of lowland rice. CII. Relation between the leafiness of rice plant communities and their light-curves of carbon assimilation. *Jpn. J. Crop Sci.* 40: 356-365*.

Watanabe, H., Hidaka, H., Saigusa, M., Ohe, M. and Shibuya, K. 2006. Growth and yield characteristics of rice (*Oryza sativa* L.) grown under deep-flood irrigation in hilly and mountainous regions. *Jpn. J. Crop Sci.* 75: 257-263*.

Won, J. G.., Choi, C. D. and Lee, S. C. 1999a. Interaction between N application and water management in dry-seeded rice. *Plant Prod. Sci.* 2: 109-114.

Won, J. G.., Choi, C. D. and Lee, S. C. 1999b. Tillering, lodging and yield under deep water treatment in direct-seeded rice. *Plant Prod. Sci.* 2: 200-205.

Yamada, N., Ota, Y. and Nakamura, H. 1960. Ecological effects planting density on growth of rice plant. *Jpn. J. Crop Sci.* 29: 329-333.

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* In Japanese with English abstract

** In Japanese.