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Effect of Mid- Drainage on Root Physiological Activities, N Uptake and Yield of Rice in North East Japan

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Summary

Two years field experiments were conducted to evaluate the effect of water management on root physiological activities, N uptake and yield of rice. The experiment consisted of three treatments with three replications mentioned as flooding from transplanting to 20 days before harvest (Flooded), mid-season drainage (MSD) and early mid-season drainage (EMSD). In Flooded treatment, the water level was kept at depth of 5-6 cm and drainage from June 25 to July 5 was carried out in MSD in the year 2009. Flooded treatment was carried out same as 2009 and drainage from June 21 to July 1 was carried out in MSD in the year 2010. Drainage from June 15 to July 5 was carried out in EMSD20 in the year 2009 and drainage from June 14 to June 24 was carried out in EMSD10 in the year 2010. The trend of root respiration rate was higher in MSD than Flooded at 38 days before heading (DBH) and 53 DBH. The xylem exudation rate was higher in MSD than Flooded treatments during 38DBH and 11 BAH. Therefore, root physiological activities in MSD tended to be higher than those in Flooded. Root physiological activities in EMSD20 and EMSD10 were lower than MSD and higher than Flooded treatments. Nitrogen uptake in plant was larger in MSD treatment during the drainage period and had no statistically significant differences. The trend of the brown rice yield of MSD treatment was larger than Flooded in the year 2010. On the other hand, the trend of the brown rice yield of EMSD20 was larger than MSD and smaller than Flooded treatments in the year 2009, while EMSD10 was smaller than MSD and Flooded treatments in the year 2010.

Key words : Root physiological activities, EMSD, MSD, respiration rate, xylem exudation rate, N uptake, yield

Introduction

Rice is one of the most important cereal crops supplying 20% of the total food calories in the world (IRRI, 2005).Worldwide, there are about 150 million hectares of rice land, which provide around 550-600 million tons of rough rice annually (Maclean *et al.*, 2007). The irrigated rice ecosystem accounts for 55% of the global harvested rice area and contributes 75% of global rice production (IRRI, 2005).

Generally rice was cultivated with flooding during the most growing periods. The main benefit of flooding is weed control. Other plants, including weeds, are less able to grow under these conditions. However, many findings have proved that more water during the early growth stage results less aeration, less ion transport, slowing down of metabolism, stoppage of microbial activities, and accumulation of salt in root zone and hampers the root development which ultimately affects entire growth and development of rice plant (Arashi 1996). If root decline in health, the rate of carbon assimilation will never be improved even in the cases of desirable plant types and high nitrogen concentrations in leaf-blades (Kawata and Katano, 1977). Therefore, water management for making plant roots healthy is important.

Mid-Season Drainage (MSD) conventional cultural practice in Japan involves the removal of surface water from the crop for about 7 or more than 7 days towards the end of tillering. It can be considered that the MSD has to protect roots from various damages caused by the reductive condition of soil due to the shortage of oxygen in soil and to increase the activity of roots. In North East Japan (Yamagata prefecture) during MSD, there are many rainfalls (Japan Metrological Agency, 2009-2010) and that much rainfall affects the soil drying delaying or keeping moisture like a conventional flooding. Under these conditions, effect of MSD on root physiological activity was not understood.

For minimizing much rainfall effect, early mid-season drainage (EMSD) could better ways to solve that problem and might be expected to decrease soil moisture significantly from the field because during EMSD less rainfall occurred. The timing of drained condition and duration of drainage also affect rice growth and root health, but information about above mentioned is limited.

Many scientists mentioned that MSD has both positive and negative effect. Goto *et al.*, 2000 mentioned high yield in MSD where Mizuguchi *et al.*, 1992 mentioned MSD reduced yield. During vegetative stage water stress usually affects the growth and consequently decrease yield (Kamoshita *et al.*, 2004, Botwright Acuna *et al.*, 2008) and also agree with Mori and Fujii, 2007.

MSD decrease primary crown root number but increase lateral root number, specially in deeper soil layers (Kawata and Katano, 1977); increase root respiration rate and root oxidation power (Yamada and Ota, 1961); increase leaf photosynthetic rate (Koyama *et al.*, 1962); and leaf longevity (Iida *et al.*, 1990). Improved root condition increase in soil redox potential, which induces a prolonged synthesis and transport of cytokinins in roots and also extended photosynthetic activity, which may increase the deposition of carbohydrates in the grains and ultimately increasing the grain yield. (Matsushima *et al.*, 1971 and Tanaka, 1972).

Root respiration and sap exudation rate are useful index of root physiological activity. Root respiration is closely linked to energy intensive uptake, reduction and assimilation of nitrate and ammonium ions (Bloom *et al.*, 1992) and to active water uptake (Hirasawa *et al.*, 1983; Lee *et al.*, 1994; Yamaguchi *et al.*, 1995). Xylem exudation represents active water uptake capacity (Yamaguchi *et al.*, 1995). Since measuring stem sap exudation is relatively easier than determination of other root activity, such as nutrient uptake and root respiration, the possibility of using stem sap exudation to evaluate root system have been explored (Yamaguchi *et al.*, 1995; Morita *et al.*, 2000; Morita and Abe, 2002).

Many findings of field experiments proved that MSD has both positive or negative effect on yield, positive effect on root physiological activities and negative effect on N uptake. Actually yield level is depends on root activities and N uptake of rice and varied with them and need to make balance.

Therefore, this study was conducted to know 1) the combined effect of water management, such as MSD on root physiological activities, N uptake and yield 2) the effect of EMSD on root physiological activities, N uptake and yield of rice in the year of 2009 and 2010.

Materials and Methods

General Information

Field experiments were conducted in Yamagata University Experimental Farm, Tsuruoka, Japan in 2009 and 2010. The soil properties were as follows: sandy loam with a pH of 5.1, CEC of 15.1 cmol(+) kg^{-1}, total-N content of 2.4 of g kg^{-1}, organic-C content of 25.7 g kg^{-1}, available P_2O_5 and exchangeable K_2O of 0.17 and 0.13 g kg^{-1} soil, respectively.

Cultural Practices

Same dose of basal chemical fertilizer was applied as N, P_2O_5, and K_2O @ $6gm^{-2}$ and top-dressing application as N and K @ $2gm^{-2}$ at panicle initiation stage in both years. Seedlings (*Oryza sativa* L., c.v. Sasanisiki) at about three and half leaf stage were transplanted on May 14 in 2009 by manually and May 17 in 2010 by mechanically (30 x 15 cm). Average four seedlings were planted on each hill in 2009 and 2010. All of the cultural practices except water management were followed by conventional cultural practices in local area of Shonai plain, NorthEast Japan.

Treatments

The experiment consisted of three treatments with three replications mentioned as flooding from transplanting to 20 days before harvest (Flooded), mid-season drainage (MSD) and early mid-season drainage (EMSD). In flooded treatment, the water level was kept at depth of 5-6 cm in both years. In MSD drainage from June 25 to July 5 {42 days before heading (DBH) to 32 DBH)} and June 21 to July 1 (45 DBH to 35 DBH) were carried out in the year 2009 and 2010 respectively. In addition, drainage from June 15 to July 5 (52 DBH to 32 DBH) was carried out in EMSD in the year 2009 (EMSD20) and drainage from June 14 to June 24 (52 DBH to 42 DHB) was carried out in EMSD in the year 2010 (EMSD10). In the both year, the duration and timing of EMSD was different as because to compare the long and short drainage either affect on rice root physiological activities or not.

All the plots were arranged in Latin Square (LS) design with 3 replications. The dimensions of the plot were 28 m length and 8 m width.

General Sampling

Plant N uptake was determined periodically from 5 weeks after transplanting to heading stage. The interval between samplings was less than two weeks. Average rice plant (tiller number same as average growth plant in treatment) in two hills per plot was used for nitrogen analysis. Nitrogen content in each sample was determined by Kjeldahl method (Keeney and Nelson, 1982; Bremner and Mulvaney, 1982).

Harvesting was done from 2.7m^2 plots (equivalent to 60 hills) from undisturbed central area of the plot for yield measurement. After counting each panicle number of hills, ten hills based on average were selected for yield components and remaining 50 hills were harvested for yield examination.

Measurement of Root Respiration (Yamaguchi method)

Root respiration was measured in the year 2009, (38, 31 DBH, and 11 days after heading (DAH)) and 2010, (43, 36, 24 DBH, and 7 DAH) respectively. Two hills (average rice plants) per plot were taken using a monolith (30 cm long, 15 cm wide and 15 cm high) method for the analysis of root respiration. A monolith was placed on one hill and roots were carefully washed and after washing, roots were cut immediately for measurement (Yoshida, 1981). According to the method of Yamaguchi *et al.* (1995), root respiration was evaluated as follows.

Barium solution [12.878 g $Ba(OH)_2$ plus 1.172 g $BaCl_2$ into 1L distilled water], Oxalic acid (0.045 mol) and 0.1% phenapthelien indicator solution were prepared. Immediately weighed about 8 g fresh small pieces of root and then inserted into small net pocket with cotton thread. Ten ml Barium solution contained conical flask with net pocket was air tight with cork and incubated for 2 hours and then titrated by oxalic acid solution.

Measurement of Xylem Exudation

Xylem exudation rate was measured in the year 2009, (38, 31 DBH, and 11DAH) and 2010, (37, 23 DBH and 8DAH (almost same date of measuring of root respiration)) respectively using the method of San-Oh *et al.* (2004). Plants in two hills per plot were cut 10 cm from the soil surface and pre-weighed absorbent cotton in plastic bag was attached to the cut end of each stem with rubber bands. To immobilize the cotton and avoid vaporization, the cotton was covered with a plastic bag. After 2 hours, each bag was detached, sealed and weighed, and the weight of the exudates was calculated by subtracting the weight of the bag and pre-weighed absorbent cotton.

Measurement of Root Mass Density

To measure root mass density, roots were taken from the field using the monolith method (average rice plant 2 hills per plot 224 m^2) at 2 week intervals between the times of after 5 weeks transplanting to heading stage. Root mass density was measured by the water displacement method of putting all roots in a measuring area (Zhang *et al.*, 1994).

Results

Rainfall and Soil Moisture Percentage:

Fig.1 showed the daily rainfall of Tsuruoka in the year 2009 and 2010. Drainage from June 25 to July 5 was carried out in MSD in 2009. Total rainfall was 33.0 mm from June 25 to July 5 in 2009. On the other hand, from June 21 to July 1 was carried out in MSD and during that time total rainfall was 73.5 mm in 2010.

Additionally, drainage from June 15 to July 5 was carried out in EMSD20 and 72.5 mm rainfall was recorded in the year 2009. Drainage from June 14 to June 24 was carried out in EMSD10 and recorded total rainfall was 54 mm in the year 2010.

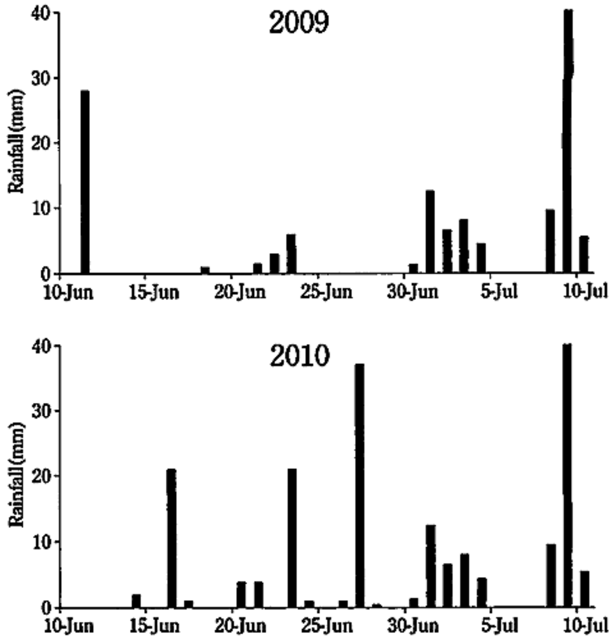
Fig.2 indicated the soil moisture percentage (V/V) of fresh soil of the year 2009 and 2010. After MSD beginning and after finishing the drainage treatment soil moisture content of MSD had no apparently different than Flooded treatment in 2009 and 2010 as because during that time rainfall occurred so that the dryness of the drained field was not so dried.

On the other hand, in 2009, just after EMSD beginning the soil moisture were 50.7%, 46.3% and 47.5% in Flooded, EMSD20 and MSD and 53.3%, 49.8% and 53.0% in Flooded, EMSD10 and MSD in the year 2010, respectively. Though statistically had no significant different, the dryness tendency was higher in both EMSD20 and EMSD10 than MSD and Flooded treatments from field observation in this study.

N Uptake in Plant

Fig.3 showed that, in the year 2009 during 51, 46, 41 and 31 DBH the nitrogen accumulation in plant was almost same among the treatments. But MSD treatment showed little bigger value than other treatments and had no significant difference. In the year 2010, 41DBH showed the significant bigger amounts of N in plant in MSD than Flooding treatments and also 36 DBH showed the greater value than other treatments although no statistically significant differences.

Additionally, N uptake of EMSD20 in the year 2009 was larger than Flooded at 51 and 46 DBH and smaller than Flooded treatments at 41 and 31 DBH. N uptake of



Source: Japan Metrological Agency, 2009-2010

Fig.1 Daily rainfall (mm) of the month of June and July in the year 2009 and 2010

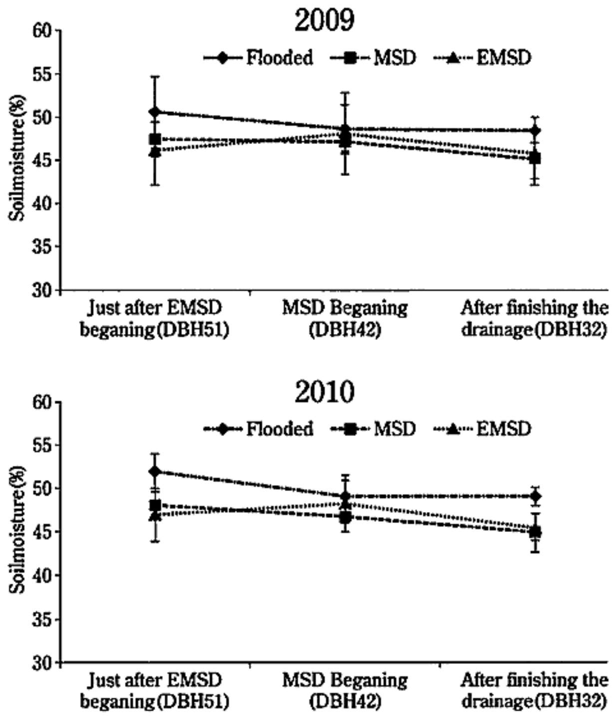


Fig.2 Soil moisture percentage during the drainage time in the year 2009 and 2010 Flooded: continuous flooding, MSD: mid-season drainage, EMSD: early mid-season drainage, DBH: days before heading

EMSD10 in the year 2010 was larger than Flooded at 46 DBH and smaller than Flooded treatments at 41 and 36 DBH, respectively.

Root Physiological Parameter

(1) Root respiration rate

The respiration rate of rice root was shown in Fig.4. The trend of respiration rate was higher in MSD than Flooded at 38 DBH and that at 31 DBH in MSD showed the significantly (5% level) higher value comparing to Flooded in the year 2009. The trend of root respiration rate was MSD>EMSD20>Flooded in 2009.

In 2010, the root respiration rate was higher in MSD at 36 DBH and 24 DBH. After that, the value of MSD and Flooded declined gradually and it was almost same at 7 DAH (Fig.4). Respiration rate of Flooded at 36 DBH was significantly lower than MSD (5% level). At later stage, MSD showed the better performance than Flooded even though insignificant.

On the other hand, the trend of respiration rate of EMSD20 was higher than Flooded at 38, 31 DBH and had no significant different in the year 2009 and EMSD10 in the year 2010 was higher than MSD at 43 DBH but lower than MSD at 36, 24 DBH respectively.

(2) Xylem exudation rate

Fig.5 showed the xylem exudation rate. Although no significant differences were observed between MSD and Flooded treatments in both years, the xylem exudation rate showed higher trend in MSD than Flooded at 38 DBH in 2009. In 2010, the trend of the MSD treatment showed the larger value than Flooded.

Additionally, the trend of xylem exudation rate of EMSD20 was smaller than MSD and higher than Flooded treatments at 38, 31 DBH, 11 DAH in the year 2009 and EMSD10 in the year 2010 was similar than 2009.

(3) Root mass density

Rice root mass density was shown in Fig.6. In 2009 the root mass density was higher in MSD at only after heading stage (11 DAH) and had no significant differences at 38 and 31 DBH. The same trend was occurred in 2010.

On the other hand, the trend of root mass density of

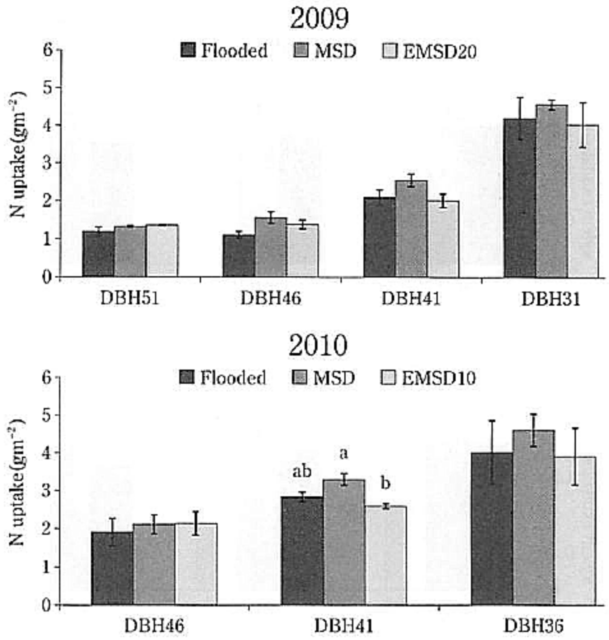


Fig.3 N uptake in plant at days before heading (DBH) in Flooded, EMSD and MSD treatments in 2009 and 2010, vertical represents standard error, Flooded: continuous flooding, MSD: mid-season drainage, EMSD20: early mid-season drainage 20 days, EMSD10: early mid-season drainage 10 days, DBH: days before heading

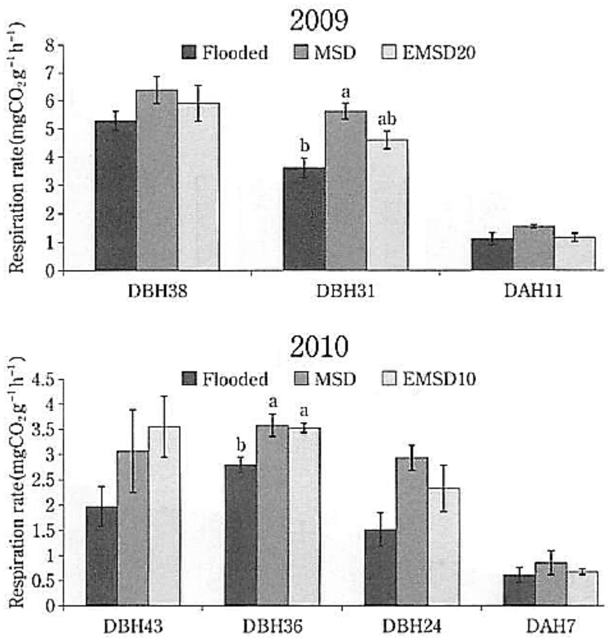


Fig.4 Root respiration rate ($mgCO_2$ DWg^{-1} h^{-1}) at DBH 38, 31, DAH 11 and DBH 43, 36, 24, DAH 7 in flooded, EMSD and MSD treatments in 2009 and 2010, vertical bar indicates standard error, Flooded: continuous flooding, MSD: mid-season drainage, EMSD20: early mid-season drainage 20 days, EMSD10: early mid-season drainage 10 days, DBH: days before heading, DAH: days after heading

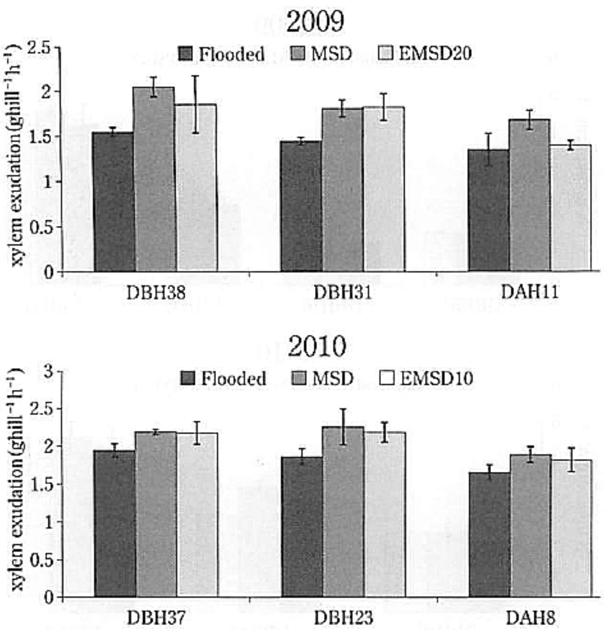


Fig.5 Xylem exudation rate at DBH 38,31, DAH 11 and DBH 37, 23, DAH 8 in flooded, EMSD and MSD treatments in 2009 and 2010, vertical bar indicates standard error, Flooded: continuous flooding, MSD: mid-season drainage, EMSD20: early mid-season drainage 20 days, EMSD10: early mid-season drainage 10 days, DBH: days before heading, DAH: days after heading

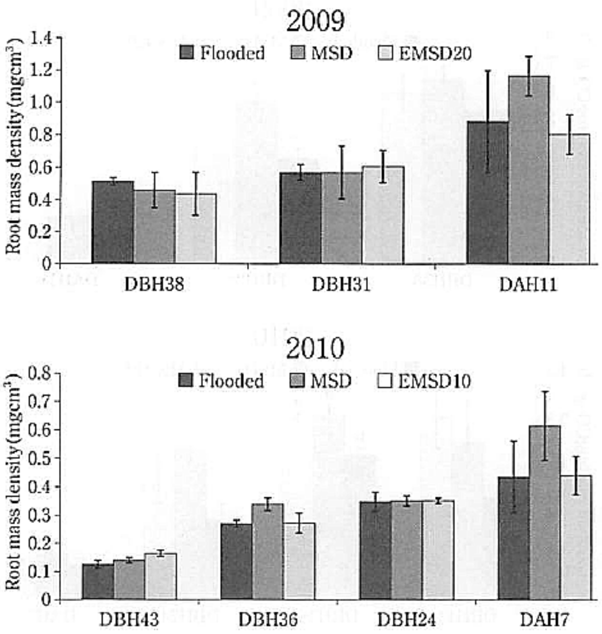


Fig.6 Root mass density (15cm) at DBH 38, 31, DAH 11 and DBH 43, 36, 24, DAH 7 in flooded, EMSD and MSD treatments in 2009 and 2010, vertical bar indicates standard error, Flooded: continuous flooding, MSD: mid-season drainage, EMSD20: early mid-season drainage 20 days, EMSD10: early mid-season drainage 10 days, DBH: days before heading, DAH: days after heading

EMSD20 or EMSD10 was almost same at different days before and after heading in the both years.

Yield and Yield Components

There was no significant difference in brown rice yield among the treatments in the year of 2009 and 2010. In the year 2009, the brown rice yield of MSD treatment was very low because of lodging immediately after the flowering stage (Table 1). The grain yield in the same experiment was 664 g m^{-2} for Flooded. In the year 2010, the brown rice yield of MSD (653 g m^{-2}) treatment was larger than Flooded (635 g m^{-2}) treatments. The number of spikelets per m^2 tended to be larger in flooded treatment than MSD treatment in the 2009 but in the 2010 the opposite trend was observed. The number of panicles m^{-2} in MSD smaller than Flooded treatments in 2009 and same trend was observed in 2010. The number of spikelets m^{-2} in Flooded was 36,000 and 35,000 which was 75% and 102% of that in MSD in 2009 and 2010. The number of spikelets m^{-2} of MSD treatment was significantly smaller than Flooded in 2009 but in 2010 the treatments did not show any significant differences. The difference in 1000-grain weight between the treatments was negligible.

In addition, yield and yield components data indicate that drained duration (EMSD20 or EMSD10), drained timing (EMSD and MSD) and drainage (MSD and Flooded) had no adverse effect on yield. The grain yield of EMSD20 was 594 g m^{-2} which was larger than MSD but smaller than Flooded treatments in the year 2009. On the other hand, the brown rice yield of EMSD10 (623 g m^{-2}) was smaller than MSD and Flooded treatments in the year 2010. The number of spikelets per m^2 tended to be smaller than Flooded and MSD treatments in the both years. The number of panicles m^{-2} in EMSD20 smaller than Flooded and MSD respectively in 2009 where in 2010, the number of panicles m^{-2} showed the opposite trend. The number of spikelets m^{-2} of EMSD20 and MSD treatment was significantly smaller than Flooded in 2009 but in 2010 the treatments did not show any significance differences.

Table 1. Brown rice yield and yield components

Year	Treatment	Brown rice yield (g m^{-2})	Panicle no. (m^{-2})	Spikelet no.per panicle	Spikelet number (10^3 m^{-2})	Ripened grains (%)	1000- grain wt. (g)
2009	Flooded	664±59	475±19	76±0.9	36±1a	76±5	23.6±0.1
	MSD	534±15	433±19	62±2	27±0.2b	82±1	23.8±0.1
	EMSD20	594±12	391±30	72±5	28±1b	87±3	24.1±0.1
	P-value	0.112	0.113	0.077	0.003	0.211	0.083
2010	Flooded	635±19	495±19	67±5	35±2	79±2	22.7±0.6
	MSD	653±51	481±32	70±5	34±5	84±4	22.9±0.6
	EMSD10	623±12	510±12	62±2	32±1	86±3	22.8±0.1
	P-value	0.813	0.692	0.516	0.747	0.425	0.967

Values represent mean of three replications ±standard error. Same letter in the same column are not significantly different. Flooded: continuous flooding, MSD: mid-season drainage and EMSD20: early mid-season drainage 20 days, EMSD10: early mid-season drainage 10 days

Discussion

Soil moisture among the treatments and the between the both year showed the same trend and statistically had no significant different. As observed in this study the dryness tendency was higher in MSD than Flooded. Drainage supply oxygen to soil (Stoop *et al.*, 2002) and root activities or root mass might be affected by oxygen supplied although no significant different in soil moisture among the treatments.

Drainage (MSD and EMSD20 or EMSD10) is believed to improve oxygen supply to rice roots, with potential advantages for nutrient uptake (Stoop *et al.*, 2002), and to avoid accumulation of toxic substances such as ferrous iron and hydrogen sulfide, which are potentially toxic to root growth (Hayashi *et al.*, 1960). Improved root condition increase in soil redox potential, which induces a prolonged synthesis and transport of cytokinins in roots and also extended photosynthetic activity, which may increase the deposition of carbohydrates in the grains and ultimately increasing the grain yield during maturity stage (Matsushima *et al.*, 1971 Tanaka, 1972).

Root respiration was higher in MSD than Flooded treatment at neck node differentiation stage only (Fig.4). MSD might be due to better aeration during neck node differentiation stage and root system associated with higher mobility and absorption of inorganic N in soil solution which increased the uptake of nutrient and contributed to favorable growth attributes which in turn had resulted on higher yield attributes (Palachamy *et al.*, 1989).

In addition, respiration rate of EMSD20 or EMSD10 in both years showed the same trend and lower than MSD treatments. During this stage oxygen can be supplied through the root and root becomes more active. Root activity parameters (root respiration) in drained condition (MSD and EMSD20 or EMSD10) tended to be higher than those in Flooded (though insignificant) at the maturity stage (Fig.4) in our experiment and this result was agreed with previous report (Osaki *et al.*, 2001).

EMSD20 and MSD treatments the yield and yield components were not statistically significant; it means prolonged drained field condition of one year data had no adverse effect on yield and yield components under unfertile soil. Mori *et al.*, 2009 mentioned that EMSD reduces the gain number than MSD under fertile soil in Shonai area but this research mentioned that prolonged drained (EMSD20) did not affect the growth and yield of rice under unfertile soil. Fertile and unfertile soil under different water management might be not same. Therefore, this study should be required further research for understanding the mechanism.

Conclusion

This research indicates that the drained field conditions (MSD) in North East Japan did not decrease N accumulation/uptake and induced higher root physiological activity by enhancing root respiration and xylem exudation rate during drainage period.

In addition, this research suggests that timing and duration of drainage might not be affected rice growth though several years' data should be needed for more confirmation.

References

Arashi, K.(1996) Chapter 74. Irrigation and drainage. In Y. Togari and T. Matsuo eds., Rice Culture 3. Sakura Shoten, Tokyo. 191-204 (in Japanese).

Bloom, AJ.(1992) Root respiration associated with ammonium and nitrate absorption and assimilation by barley. Plant Physiology, 99, 1294-1301.

Botwright Acuna, T.L.,Latte, H.R. and L.J. Wade.(2008) Genotypic and environment interactions for grain yield of upland rice backcross lines in diverse hydrological environment. Field Crops Research, 108(2): 117-125.

Bremner, J.M. and Mulvaney, C.S.(1982) Nitrogen-Total. In: Method of Soil Analysis. Part2. Chemical and Microbiological Properties (2nd ed.). pp.595-624.

Goto, Y., Nitta, Y. and Nakamura, S.(2000) High yield in MSD. Association of Agruculutral Extension of Japan. Crops1 (Rice).p.98.

Hayashi, M., Hashizume, A., Shinohara, S. and Igarashi, G.(1960) Studies on the influence of water-percolation in rice plants during ripening period in ill-drained paddy field. Proceedings of the Crop Science Society of Japan. 29: 43-46 (in Japanese with English summary).

Hirasawa, T., Araki, T., Matsuda, E. and Ishihara, K.(1983) On exudation rate from the base of the leaf blade in rice plants. Japanese Journal of Crop Science. 52: 574-581 (In Japanese).

Iida, S., Shinmura, Y., Uemori, A. and Kuzuna, K.(1990) Influence of irrigation management at the middle growing stage on rice plant growth and yield. Japanese Journal of Crop Science. 59: 413-418 (in Japanese with English abstract).

IRRI (International Rice Research Institute).(2005) World ricestatistics. (http://beta.irri.org/index.php/Social-Sciences-Division/SSD-Database/).

Japan Metrological Agency.(2009-2010)

Kamoshita, A., Rodriguez, A., Yamauchi and Wade, L.(2004) Genotypic variation in response of rain fed lowland to prolonged drought and rewatering Plant Production Science, 7(4): 406-420.

Kawata, S. and Katano, M.(1977) Effect of water management of paddy fields on the direction of crown root growth and the lateral root formation of rice plants. Japanese Journal of Crop Science. 46: 543-557 (in Japanese with English summary).

Keeney, D.R., and Nelson, D.W.(1982) Nitrogen-inorganic forms. In: Methods of Soil Analysis. Agronomy Monograph 9, Part 2 (2nd ed.). American Society of Agronomy, Madison, Wisconsin.pp. 643-698.

Koyama, T., Miyasaka, A. and Eguchi, K.(1962) Studies on water management in the ill-drained paddy field. VII. The effect of the surface drainage on the photosynthetic activity in the rice plant. Proceedings of the Crop Science Society of Japan. 30: 143-145 (in Japanese with English summary).

Lee, C., Tsuno, Y., Nakano, J. and Yamaguchi, T.(1994) Ecophysiological studies on the drought resistance of soybean. II. Effect of soil water deficit on leaf wilting and changes in photosynthesis and bleeding influenced by re-watering. Japanese Journal of Crop Science, 63, 113-119.

Maclean, JL., Dawe, D., Hardy, B. and Hettel, GP.(2007) Rice almanac. Los Baños (Philippines): International Rice Research Institute. 253 pp.

Matsushima, M.(1971) Analysis of developmental factors determining yield and yield prediction in lowland rice. Bulletin of the Natural Institute of Agricultural Sciences Series. A5, 271 (in Japanese, with English abstract).

Mizoguchi, K., Odawara, K. and Matsue, Y.(1992) Effect of different water management of mid-season drainage on yield and growth of rice. Bulletin of the Kyushi Branch of Crop Science Society of Japan. 59: 32-35 (In Japanese).

Mori, S. and Fujii, H. (2007) Effect of different starting time of midsummer drainage on the number of spikelets in rice plant. The East and Southeast Asia Federation of Soil Science Societies 8, 223.

Morita, S. and Abe, J.(2002) Diurnal and phonological changes of bleeding rate in lowland rice plants. Japanese Journal of Crop Science, 66,195-201 (in Japanese).

Morita, S., Okamoto, M., Abe, J. and Yamagishi, J.(2000) Bleeding rate of field-grown maize with reference to root system development. Japanese Journal of Crop Science, 69, 80-85 (in Japanese).

Osaki, M., Shinano, T., Kaneda, T., Yamada, S. and Nakamura, T.(2001) Ontogenetic changes of photosynthetic and dark respiration rates in relation to nitrogen content in individual leaves of field crops. Photosynthetica, 39, 205-213.

Palachamy, A., Sundar Singh, S.D., Rajagopal, A. Ramiah, S. and Paramasivam, P.(1989) Effect of Irrigation regimes and nitrogen levels on rice varieties under transplanted condition. Madras Agricultural Journal. 76 (9): 498-506.

San-Oh, Y., Mano, Y., Ookawa, T. and Hirasawa, T.(2004) Comparison of dry matter production and associated characteristics between direct-sown and transplanted rice plants in a submerged paddy field and relationships to planting patterns. Field Crops Research. 87: 43-58.

Stoop, W. A., Uphoff, N. and Kassam, A.(2002) A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farm systems for resource-poor farmers. Agricultural Systems, 71: 249-274.

Tanaka, A.(1972) Studies on the characteristics of physiological functions of the leaf at a definite position on a stem of the rice plant: accumulation of carbohydrate in the leaf at a definite position. Journal of Science Soil Manure 29, 291–294.

Yamada, N. and Ota, Y.(1961) Effect of water percolation on physiological activity of rice root. Proceedings of the Crop Science Society of Japan. 29: 404-408 (in Japanese with English summary).

Yamaguchi, T., Tsuno, Y., Nakano, J. and Mano, R.(1995) Analysis of factors concerning bleeding rate from the basal part of stem in rice plants. Japanese Journal of Crop Science. 64: 703-708.

Yoshida, S.(1981) Fundamentals of Rice Crop Science. International Rice Research Institute, Manila, Philippines.

Zhang, X., Zhang, H. and Forde, BG.(1994) Experimental technology of plant physiology, concerning bleeding rate from the basal part of stem in rice plants. Japanese Journal of Crop Science. Special Research Bulletin Oriental Press, Mie, Japan, 1-149.

東北地方の水田で水稲生育初期の水管理が水稲根の活性、窒素吸収および収量に与える影響

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要 約

水管理が水稲根の活性、窒素吸収、収量に及ぼす影響を検討するために2年間の圃場試験を実施した。試験区は早期中干し（2009年は6月15日～7月5日、2010年は6月14日～6月24日）、慣行中干し（2009年は6月25日～7月5日、2010年は6月21日～7月1日）及び常時湛水（5～6cmの湛水）の3区である。最高分げつ期やそれよりやや早い時期には、水稲根の呼吸速度は慣行中干しで早期中干し、常時湛水より高い傾向が認められた。分げつ盛期と登熟期の溢液速度も慣行中干しで早期中干し、常時湛水より大きくなった。玄米収量も慣行中干しで大きな値となり、中干し期間の長さは影響が認められなかった。

キーワード：水稲根の生理的活性、慣行中干し、早期中干し、呼吸速度、溢液速度