Jurnal
Teknologi

Full Paper

Comparison of Irrigation Requirements between Transplanting Cultivation and Direct-seeding Cultivation in Large-sized Paddy Fields with Groundwater Level Control Systems

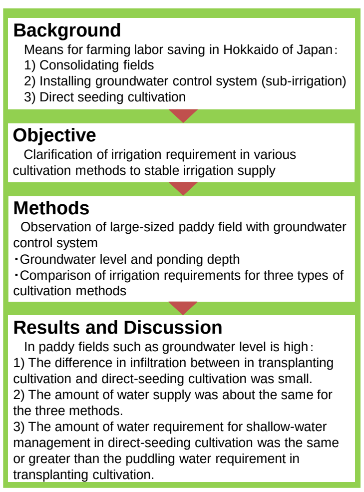
KOSHIYAMA Naoko*, SAKAI Miki, ITO Nobuo, NAKAMURA Kazumasa

Civil Engineering Research Institute for Cold Region, PWRI, Japan

Article history
Received
15 July 2015
Received in revised form
2 August 2015
Accepted
26 August 2015

*Corresponding author
koshiyama-n@ceri.go.jp

Graphical abstract



Abstract

In direct-seeding cultivation of rice, it is possible to save working time for growing and transplanting seedlings. In Hokkaido, where the management area of one farm is larger than that of other parts of Japan, the area of direct-seeding cultivation in large-sized paddy fields with groundwater level control systems has been increasing. Irrigation requirements increase in some cases of direct-seeding compared with the transplanting cultivation. To disseminate direct-seeding in an area it is necessary that the increases in irrigation requirements be within the permissible range of the irrigation of the area. The authors compared three cultivation methods: direct-seeding in non-puddled submerged paddy fields, direct-seeding in well-drained paddy fields, and transplanting cultivation, by using a large-sized block paddy field with the groundwater level control system facilities in Moseushi Town of Hokkaido. The following were clarified: 1) The difference in infiltration was small between the transplanting and direct-seeding cultivation methods. 2) The water supply volume, which is the sum of the irrigation requirement and the effective rainfall, of the three methods had very few differences in the period from the initial water intake and the re-submerging of the field because the groundwater level in the vicinity of the field was comparatively high and the infiltration was small. 3) The quantity of water intake during the period of shallow water management in direct-seeding cultivation is comparable to the puddling water requirement in transplanting cultivation.

Keywords: Large-sized paddy field, groundwater control system, irrigation requirements, transplanting cultivation, direct-seeding cultivation

1.0 INTRODUCTION

In recent years, the number of farm households has been decreasing and the aging of farmers has been progressing in Japan. It is feared that Japan's ability to produce food will continue to decline. The Japanese government's Basic Plan on Food, Agriculture and Rural Areas [1] promotes an agricultural policy of highly profitable farm management through agricultural land development, such as through the consolidation of small farmland plots and the improvement of farmland for cultivating diverse crops.

Hokkaido is the northernmost island of the four major islands of Japan. According to the Annual Statistics of Agriculture, Forestry and Fishery [2], Hokkaido had 1,148,000ha of arable land, about 25% of the Japan's total arable land, as of 2014. Hokkaido has 223,400ha of paddy fields, about 9% of all paddy field area in Japan. The management area per farm household in Hokkaido averages 23.4ha, which is about 15 times as large as elsewhere in Japan. Even though Hokkaido is a major agricultural area in Japan, the number of farm households has been decreasing and measures to consolidate farmland into large-scale farmland have been urgently needed. It is said that a family-run farm becomes short of workers when the management area exceeds 20ha [3]. It is predicted that in ten years it will be necessary to expand the management area per farm household to at least 50ha in part of the paddy rice cultivation area of Hokkaido. This is because the number of farmers will decrease as a result of aging and for other reasons and the farmland will be consolidated by the few remaining farm households [4]. The farms in the major paddy rice cultivation areas in Hokkaido have been making efforts to raise farm productivity by consolidating fields and developing groundwater level control systems. The farmers also have been introducing direct-seeding cultivation and promoting cultivation rotation of paddy rice and other crops.

Direct-seeding cultivation is advantageous in that work for raising seedlings is not necessary and work periods can be distributed by using the differences in cropping seasons of transplanting cultivation and direct-seeding cultivation. The vigorous growth of weeds caused by the unevenness of the surface of the field and instability in yields has been pointed out as problems with direct-seeding cultivation [5]. In recent years, many of the problems have been overcome through the development of technologies for grading, the dissemination of laser level bulldozers and the development of herbicides suitable for direct-seeding cultivation. Direct-seeding cultivation accounts for only 1.3% of paddy rice cultivation. However, the rate increased eightfold in the 10 years ending in 2013. It is estimated that the rate will further increase [6].

Wider dissemination of direct-seeding cultivation will require a stable supply of irrigation water. To secure a stable supply of irrigation water, it is necessary to clarify the characteristics of irrigation water demand for diverse cultivation methods. It is necessary to do surveys at farms that employ direct-seeding cultivation with various field conditions. The amount of irrigation water, interval of water intake, and water intake rate for each growing period should be clarified, and such factors should be analyzed in comparison with those of transplanting cultivation.

Based on a three-year-survey done at a large paddy field with a sub-irrigation system, the present study compared the irrigation requirements for three cultivation methods: direct-seeding cultivation in non-puddled submerged paddy fields, transplanting culture and direct-seeding cultivation in well-drained paddy fields.

The cultivation methods investigated in this study were defined as follows. In direct-seeding cultivation in non-puddled submerged paddy fields (DS), seeding is done after the ponding of a field that has been tilled but not puddled. Shallow-water management is done after seeding. In shallow-water management, the groundwater level is raised to wet the field surface several times until seedling growth has stabilized. In direct-seeding cultivation in well-drained paddy fields (DW), dry rice seeds are sowed after tilling, and shallow-water management is conducted. In transplanting cultivation (TC), seedlings are planted in the field after puddling. Water management after transplanting or after shallow-water management is done in the same way in all three methods.

2.0 MEASUREMENT METHOD

2.1 Outline of the field

The survey was done at a parcel of paddy field in Moseushi Town, Hokkaido. Readjustment and development of large-scale fields had been done in this area under government-operated projects since 2008. The groundwater level control system shown in Figure 1 was developed during this period. The branch line pipes are connected to the intake facility of the field (irrigation control unit). Irrigation water intake can be done as 1) surface irrigation, 2) sub-irrigation and 3) a combination of 1) and 2) by using (i.e., installing and removing) the bulkhead in the irrigation control unit. Surface or underground drainage is done through the

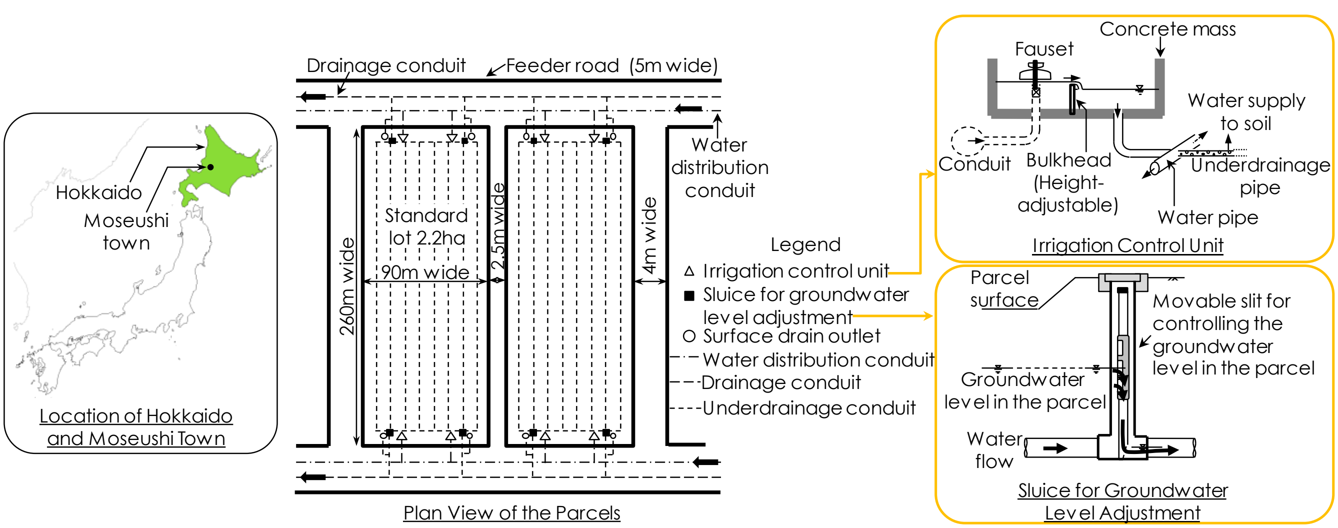


Figure 1 Irrigation and drainage system for parcels

underground branch drainage channel to the open-ditch drainage canal in the vicinity.

Figure 2 is a schematic of the surveyed field. In the surveyed field, rice cultivation was done by the three cultivation methods from 2011 to 2013 as shown in Table 1. The selection of irrigation method and the adjustment of water intake rate for irrigation were determined and implemented by the farmers.

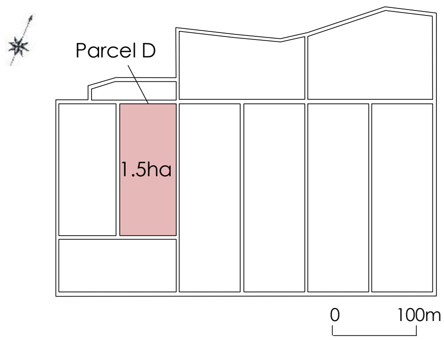


Figure 2 Location of the parcel for study

Table 1 History of cultivation method

Year	Cultivation method	With or without puddling
2011	Direct-seeding cultivation in submerged paddy fields (DS)	Without
2012	Transplanting cultivation (TC)	With
2013	Direct-seeding cultivation in well-drained paddy fields (DW)	With

2.2 Survey Items and Method

To clarify the characteristics of the groundwater level changes that occur as a result of the water management of the field, the ponding depth level and the groundwater level were observed. The observation points are shown in Figure 3. The ground water level and the ponding depth level were observed at 4 points each. The water level of the four irrigation control units was observed to determine the water intake duration and the water intake method. The interval of water level measurement was 10 minutes. The groundwater level and the ponding depth level were converted to elevation values using the average value of the four observation points. The groundwater level gauge was buried 1m below the field surface. Weather observation was done near the field. Precipitation, air temperature, relative humidity, sunshine hours, wind direction and wind velocity were measured every 10 minutes.

2.3 Method for Estimating the Irrigation Requirement

The structure of the irrigation control unit of the field was not suitable for installing a flow meter for measuring the water intake. The irrigation requirement of the field was obtained by adding the product of the change in the groundwater level and the porosity of the soil to the amount of change in the ponding depth level. The porosity of the soil was obtained by using the data for the rainy period after release of ponding water and by dividing the precipitation (mm) by groundwater level increase (mm).

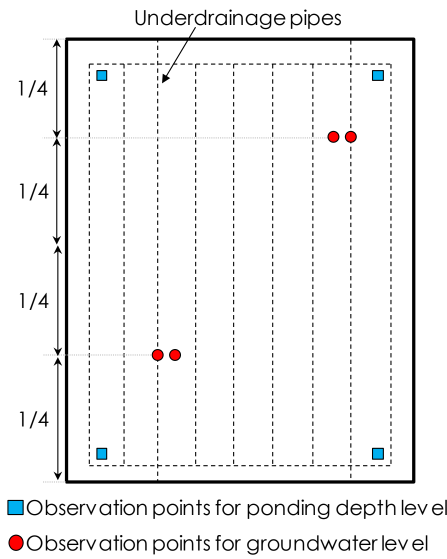


Figure 3 Location of observation equipment installation

3.0 RESULTS AND DISCUSSION

3.1 Water Management of the Field

Figure 4 shows the changes in the groundwater level and the ponding depth in the surveyed field in 2011, 2012 and 2013. The water management done by the farmers is noted in the figure. The main growth stages of each year are shown in Table 2.

In DS, seeding was done after the initial water intake and shallow-water management. Sub-irrigation was done during the period from the initial water intake to the end of the first ponding water release after the mid-summer drainage, and surface irrigation or sub-irrigation was done after that. In TC, the field was managed as a submerged field during the period from transplanting after puddling and water intake to ponding water release, except for the mid-summer drainage period. Even though surface irrigation and the sub-irrigation were used simultaneously in the mid June, water intake was from underground during other periods. In DW, the initial water intake was done after seeding, and shallow-water management was done after that. The farmers mainly used sub-irrigation. The frequency of surface irrigation was low in each of the 3 years. The day of ponding water release was about 2 weeks earlier in the year of TC than those in the years of the other cultivation methods. The farmer released the ponding water earlier than the ponding water release in the other two years, because early rice plant growth

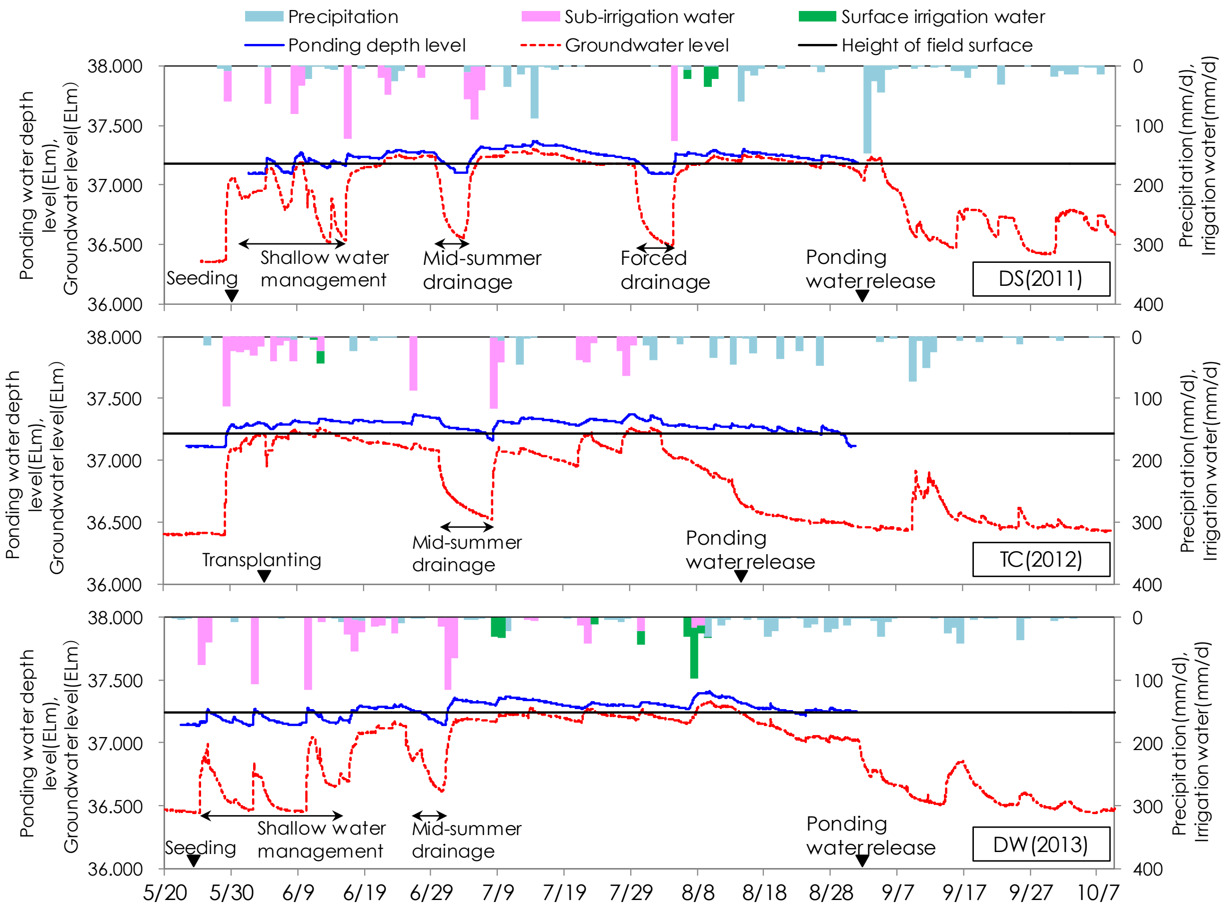


Figure 4 Temporal changes in the water level of ponding depth and groundwater

allowed for this. The purpose of the earlier water release was to secure the soil bearing capacity for fields where drainage of the ponding water became difficult because of puddling.

Table 2 Growth period

Year	2011	2012	2013
Cultivation method	DS	TC	DW
Sowing	5/30	(4/28)	5/24
Transplanting	-	6/4	-
Rooting	6/15	-	-
Panicle formation stage	7/8	7/2	7/12
Heading date	8/8	7/29	8/6
Maturing stage	9/20	9/10	9/27
Harvesting	10/13	9/28	10/9

3.2 Differences in Changes in Ponding Depth Level and Groundwater Level with Versus Without Puddling

In the TC in Figure 4, the ponding depth level and the groundwater level tend to differ greatly during the ponding periods. During these periods of great difference in the two water levels, open percolation occurs in the layers below the plow sole layer. For the mid-summer drainage period, the groundwater level decreased quickly after a relief well was opened and the ponding water was lost in DS and in DW. In TC, the ponding water level quickly decreased immediately after the relief well was opened and then slowly decreased after that, as shown in the shallow curve. The number of days for mid-summer drainage was 5 days for DS and for DW, and 8 days for TC. The days necessary for drying the field differed by cultivation method. The difference in the days necessary for drying is from the difference in the infiltration capacity of the plow sole, which is high in non-puddled direct- seeding cultivation and small in transplanting cultivation with puddling.

3.3 Infiltration Capacity

It is thought that the ponding depth level and the groundwater level change according to the infiltration capacity of the field. Table 3 shows the infiltration capacities. These values were obtained for the period when the ponding depth level and the groundwater level differed greatly. Based on the changes, the infiltration capacity was obtained for the plow sole layer and the layers below that layer. The values for the plow sole layer varied slightly, and the values for the layers below that layer were small compared with the amount of intake. In light of the above discussion, the changes in infiltration capacity by cultivation method can be regarded as small in the surveyed field.

3.4 Amount of Water Supply

The irrigation requirement in paddy rice cultivation depends on the water requirement rate, the effective rainfall and the water necessary for cultivation management. The sum of effective rainfall and irrigation requirement for each cultivation method for the period from the first day of water intake to the day of ponding water release was obtained as the amount of water supply of each year. Table 4 shows the amount of water supply for each year. The amount of water supplied for DS was 1.1 times that for TC, and that for DW was 1.3 times that for TC.

To clarify the irrigation requirements for each type of cultivation, the water intake period for the three types of cultivation was classified based on the water management work for the field and the growth stage of paddy rice, as shown in Table 5. The reason for dividing the irrigation period into that before and that after the mid-summer drainage period was that the permeability of the soil increases after the mid-summer drainage. Water supply for each year is broken down in Figure 5. The amount of water supply for the field during 1st period was about the same in each year. The sum of the irrigation requirement for the initial intake and that for the period for shallow-water management in DS (1-1 + 1-2) was about the same as the irrigation requirement during the puddling period of TC. (1-1). The irrigation requirement in the same period in DW (1-2) exceeded the irrigation requirement of the other two methods. It was reported that the low groundwater level in the surrounding areas was a factor in the difference in irrigation requirement during the initial period depending on the cultivation method [7]. The groundwater level of the surrounding areas of the surveyed field was high and the infiltration was small, which was thought to be the reason for the very small differences in water supply during 1st period among the three cultivation methods.

In 2nd period, the water supply during DS was 1.1 times that of transplant cultivation, and that of DW was 1.5 times that of TC. The irrigation requirement for re-submerging after mid-summer drainage in the three cultivation methods was from 150mm to 195mm, which was a smaller difference than the differences between the irrigation requirements for re-submerging after mid-summer drainage found in other cases [8]. Based on the above discussion, it can be said that the sum of water supply during the period from the initial water intake to the re-submerging after mid-summer drainage is about the same in all three cultivation methods.

Table 3 Field Infiltration capacity of each cultivation method

Cultivation method	Year	Infiltration capacity (mm/d)	
		Plow sole layer	Layers below the plow sole
DS	2011	4.3	1.9
TC	2012	4.9	0.9
DW	2013	4.5	1.2

Table 4 Amount of supply water

Cultiv tion method	DW	TC	DS
Year	2011	2012	2013
Total irrigation requirement(mm)	1029	790	805
Effective rainfall(mm)	209	148	207
Supply water(mm)	1239	938	1013

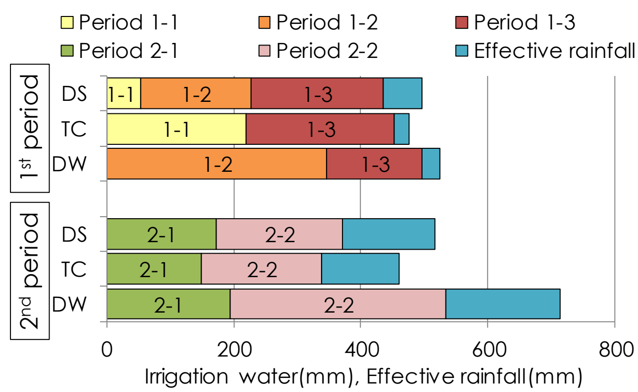


Figure 5 Components of supply water

Figure 6 shows the water intake rate and the precipitation in the three cultivation methods. When the water intake rate in 1st Period is examined for each cultivation method, the water intake rate during the shallow-water management period of direct-seeding cultivation occasionally greatly exceeded the water intake rate during the puddling and planting periods of transplanting cultivation. In DS, forced drainage was done at the end of July. The amount of intake for the re-submerging in DS was the factor that resulted in a greater amount of water supply in this cultivation method in 2nd period than the amount of water supply in TC in the same period. In the year when DW was done, the effective rainfall was scant from the middle of July to early August. It was possible that the irrigation requirement increased because infiltration increased as the result of drying of the field. The greater amount of effective rainfall than that of other years during the period in early August from the last day of irrigation to the drainage of ponding water was a factor that contributed to the increase in the water supply. Based on the above, under the condition with a relatively high groundwater level such as that of the surveyed field, it can be said that cultivation method has little influence on the amount of water supply.

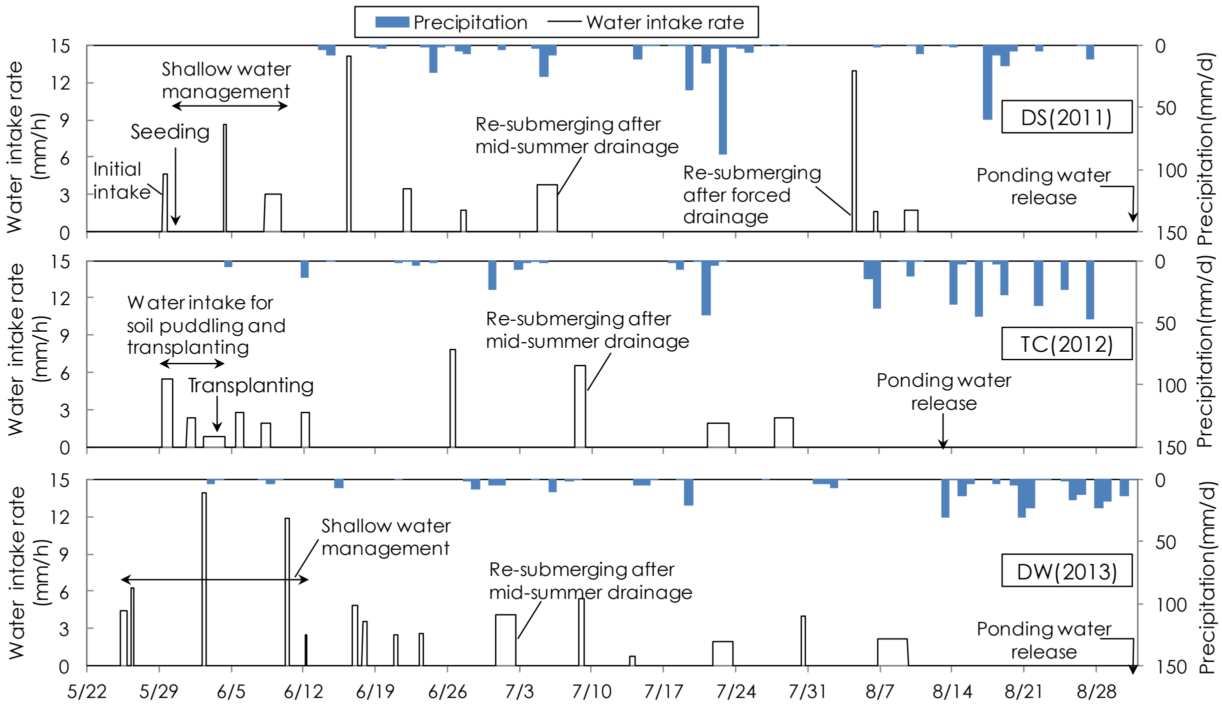


Figure 6 Water intake rate of each cultivation method

4.0 CONCLUSION

By using a parcel of paddy field in Moseushi Town, Hokkaido, the irrigation requirement in direct-seeding cultivation in a non-puddled submerged paddy field (DS), transplanting cultivation (TC) and direct-seeding cultivation in a well-drained paddy field (DW) were compared. The comparison clarified the following.

1) In transplanting cultivation and direct-seeding cultivation, the tendency in the changes in the ponding depth level and groundwater level differed depending on whether or not puddling was conducted; however, the difference in infiltration between the two methods was small.

2) The sum of water supply during the period from the initial water intake to the re-submerging after mid-summer drainage was about the same in all three cultivation methods. The difference in the amount of water supply by cultivation method during the period from the re-submerging to the drainage of ponding water was mainly formed by the rainfall conditions, and the influence of the cultivation method on the amount of water supply was not very great.

3) The amount of water requirement during the period of shallow-water management in direct-seeding cultivation was about the same or greater than the puddling water requirement in transplanting cultivation.

The influences of the degree of rainfall and drought of each year on the water requirement need to be clarified as issues of future studies. Water distribution management is expected to be tailored to the water requirement that is characteristic of each cultivation method. It is also expected that by providing farmers with information on the water requirement characteristics of each cultivation method, the farmers will be able to realize efficient water management based on the information provided.

Acknowledgement

The authors would like to express gratitude to the farmers in Moseushi Town, to the Land Improvement Center of Moseushi Town and to the Sapporo Development and Construction Department of the Hokkaido Regional Development Bureau for their assistance and cooperation in this study.

References

[1] Ministry of Agriculture, Forestry and Fisheries. Food, Agriculture and Rural Areas Basic Plan. [Online]. From: http://www.maff.go.jp/j/keikaku/k_aratana/pdf/1_27 keikaku.pdf. [Accessed on 13 July 2015].

[2] Ministry of Agriculture, Forestry and Fisheries. Agriculture and forestry fisheries statistics. [Online]. From: http://www.maff.go.jp/j/tokei/ [Accessed on 13 July 2015].

[3] Nihei, T. 1991. The Structure of Works in Rice Production and the Scale Limit in Hokkaido. *Research Material of the Hokkaido Agricultural Experiment Station*. 43: 1-18.

[4] Hosoyama, T. 2013. The Future Scale and Its Regionality of a Large-scale Farmhouse in the Hokkaido Paddy Field Zone. *Hokunou*. 80(4): 416-420.

[5] Makiyama, M. and Yamaji, E. 1998. The Subjects of Direct Sowing of Riceplant and its Possibilities for introducing to Large-sized Paddy Fields. *Journal of the Agricultural Engineering Society*. 66(10): 3-8.

[6] Tanaka, T. 2014. Progress in Direct-seeding Cultivation Technology for Paddy Rice in Hokkaido, Introduction. *Hokunou*. 81(4): 6-7.

[7] Komamura, M. Nakamura, T., Iida, A. and Nakagawa, Y. 1998. Farm Land Cosolidation at Direct Seeding Culture of Paddy Rice on Well-drained Paddy Field. *Journal of the Agricultural Engineering Society*. 62(10): 25-31.

[8] Sakata, S., Horino, H. and Mitsuno, T. 2001. Case Study on Lot Scale Water Use for Direct Seeding Culture in Paddy Field. Irrigation. *Drainage and Rural Engineering Journal*. 212: 17-22.