REDUCING FIELD PERMEABILITY AND WATER INPUT WITH SURFACE COMPACTION IN DRY SEEDED RICE FIELD

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Abstract

For development of a water-saving dry seeded rice production method (DSR), observations of water consumption of a DSR with and without compaction of the dry paddy field were conducted to clarify the water use reduction effects of soil compaction. Saturated hydraulic conductivity decreased to 4.9×10^{-5} cm s^{-1} by soil compaction with a Cambridge-roller in the field with compaction (CO). Water requirements decreased to 7 mm d^{-1}, which is lower than the value of 21 mm d^{-1} obtained for a Non-compacted field (NC). Amounts of irrigation water used for the growing season in CO were 1255 mm, which was 62% of water used for NC. Results show that preparation of a low-permeability layer near the field surface is effective to conserve irrigation water, thereby increasing water productivity. This DSR method with compaction is useful for coping with irrigation water supply variation that might occur with climate change.

Key words: dry seeded rice with compaction, hydraulic conductivity, water requirement, water productivity.

INTRODUCTION

Dry seeded rice production (DSR) systems are necessary for Japanese agriculture to reduce labor and production costs related to rice cultivation. Recently, reduction of rice production costs is necessary for Japanese rice farmers to compete with imported low-cost rice. The traditional puddled and transplanted rice production system (TPR) accounts for over 95% of Japanese rice production. The method requires puddling, raising of young rice plants, and their transplantation, which entail much labor and higher costs. TPR has generally higher production costs. Therefore, changing cultivating methods from TPR to DSR is expected to be necessary at some point.

The former DSR methods could not be conducted in highly permeable paddy rice fields because the former DSR methods could not prevent water seepage or deep percolation. In these paddy rice fields, farmers had to use TPR with puddling to cope with water seepage. Mainly for that reason, farmers in Japan have been reluctant or unable to adopt DSR in such paddy rice fields.

Recently, we developed a new DSR method that includes compaction of dry paddy fields to prevent water seepage and deep percolation. This new method is expected to replace traditional planting methods with DSR (OTANI ET AL., 2013).

Reportedly, DSR can conserve more irrigation water used for rice cultivation than TPR can (KUMAR AND LADHA, 2011). Some parts of Japan need efficient water usage to accommodate temporary water shortages that occur during the rice transplanting season. In addition, the possibility of water shortages deriving from climate change has been increasing, thereby threatening rice production sustainability. As in other countries, water shortages pose serious risks to food security. Therefore, enhancing the water productivity of rice is crucially important.

From these perspectives, new methods that use little irrigation water and less labor input for rice production must be sought. Observations of water consumption at DSR with and without compaction of dry paddy fields were conducted to clarify the effects of water use reduction through soil compaction.

MATERIALS AND METHODS

1) Site description

Experiments were conducted during the growing season in 2015 at rice paddy fields (38°09', 141°54') in Miyagi prefecture, Japan. Two test plots were set (Fig. 1): a 2.2 ha rice paddy field cultivated using DSR with compaction (CO), and a 0.3 ha rice paddy field cultivated using DSR with no compaction (NC). The soil properties and the values of saturated hydraulic conductivity in the subsoil are presented in Fig. 2. The topsoil of the experiment site was light clay. The plastic limit value and liquid limit value of topsoil were, respectively, 35.9% and 63.8%.

The subsoil, which affects deep percolation, was mostly in an aerobic condition, with saturated hydraulic conductivity of 1.7×10^{-3} cm s^{-1}, 1.4×10^{-3} cm s^{-1}, 5.9×10^{-4} cm s^{-1}, respectively, at 40 cm below in CO, 60 cm below in CO, and 60 cm below in NC.

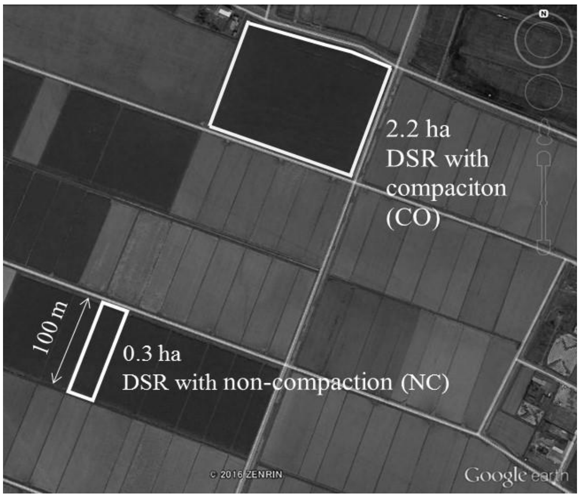

Fig. 1. – Locations of test plots (Added to Google Earth)

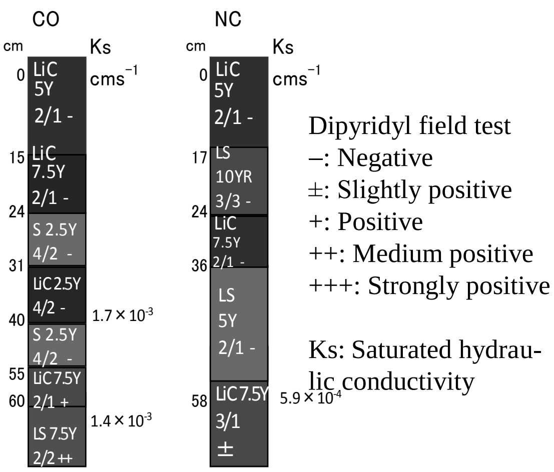

Fig. 2. – Profile description of CO and NC

2) Field management

Field management conducted in both CO and NC is presented Tab. 1 and Fig. 3. CO was tilled with a chisel plow and was compacted using a Cambridge-roller before seeding. Weight of the Cambridge-roller was 3700 kg with 5.3 m working width. Rice was seeded using a grain drill seeder. After seeding, the field surface was compacted again with the Cambridge-roller. Each compaction practice was counted one time for the entire field, compacted with one direction of working. CO was compacted once before seeding and twice after seeding: it was compacted three times, in all.

Actually, NC was tilled with a rotary cultivator before seeding. Seeds were sown by a seeder with an attached reverse rotary cultivator used simultaneously to break soil clods. In this seeding method, the NC field was not compacted in the entire field as with CO: only a part of the soil near seeds was compacted with a small and light roller attached with each seeder individually. Both plots were flooded after standing of rice seedlings. Thereafter, herbicides were applied in both plots. Flooding continued to mid-September in CO. In contrast, NC remained flooded except for about two weeks from July 2 through July 14.

3) Data collection

a) Soil hardness in the field

Using a digital cone penetrometer (DIK-5531; Daiki Rika Kogyo Co. Ltd.), soil hardness of the field profile was measured vertically from the field surface after compaction in CO or after seeding in NC. A top angle of the cone was 30°with 2 cm^2 section area.

b) Soil moisture content

Soil samples from CO were collected at depths of 0–5 cm and of 5–10 cm with a 100 ml stainless steel sampling tube to confirm soil moisture conditions under soil compaction working. Six soil samples were collected from each depth in CO. Soil moisture contents were measured from these samples drying at 105°C over 24 h.

c) Saturated hydraulic conductivity

The Cambridge-roller breaks up clods of soil by a protuberance at the outer circumference of the roller. It compacts the seedbed by the weight of the roller. As a result of compaction, about 0–5 cm in the seedbed becomes soft. The underlying 5 cm of soil texture turns to hard pan with reduced permeability to water. Therefore, undisturbed soils were sampled from 5–10 cm in seedbed with 100 ml stainless steel sampling tube for saturated water permeability tests to confirm the reduction of permeability by compaction. Samples were collected from 10 points in CO and 3 points in NC.

d) Water requirement

Water levels of both plots were measured using the water level meter (S&DL mini; OYO Corp.) to record the water requirement: consumption of water in the plot in a day. The water requirement consists of vertical or deep percolation to subsoil, lateral percolation or seepage through a levee, evaporation, and transpiration. Water level meters were set at two points in CO and at one point in NC. The data were recorded to a data logger at intervals of one hour.

e) Irrigation water applied

The amount of irrigation water supplied to NC was measured using a water flow meter (SA065GMS; Aichi Tokei Denki Corp.) set at the water inlet in NC. The water level meter (UIZ-WLR; Uizin) was set to measure the irrigation water input to CO at an open irrigation channel connected to CO. The amount of irrigation water for CO was calculated using the Manning Formula with water level data at the irrigation channel and the average gradient of the channel. The irrigation water was expressed in depth of millimeters to be divided observed water volumes by the area of each plot. The supplied irrigation water was measured during the pre-establishment period and during the rice growing season in both plots. The irrigation water was needed during the pre-establishment period to promote germination under dry climate conditions and to prevent formation of a soil crust that hinders seedling emergence.

f) Grain yield

The yield of brown rice in the whole plot with over 1.9 mm thickness was measured in both plots. The grain yield with rice-husks was calculated conveniently by dividing the brown rice yield with a 0.8 ripening rate and a 0.8 rice-husk rate.

g) Weather data

Rainfall data were collected from AMeDAS, operated by Japan Meteorological Agency, observed at the nearest point to our study site, where was about 1.8km far from it.

a) Compaction in CO b) Seeding in CO c) Seeding in NC

Fig. 3. – Working practice in CO and NC

Tab. 1. – Working practice in CO and NC

a) CO

Date	Working practice	Equipment
16-Mar	Tillage	Chisel plow Kongskilde HSF250 Tractor FENDT 415 vario(103 kW)
9-Apr	Compaction	Cambridge-roller DALBO MAXROLL530* Tractor Kubota M135A (99 kW)
	Seeding	Grain-drill AMAZONE D9-30 Tractor FENDT 415 vario (103 kW)
28-May	Flooding	

*Weight: 3700 kg, Working width: 5.3 m

b) NC

Date	Working practice	Equipment
28-Mar	Tillage	Rotary cultivator Kubota RM220Z Tractor Kubota MZ65 (48 kW)
11-May	Seeding	Reverse rotary cultivator Nipro BUR2010U Seeder Agritecno Yazaki TDR-2CE Tractor Kubota MZ65 (48 kW)
26-May	Flooding	

RESULTS

1) Soil water contents under compaction work

Soil water contents after compaction work are portrayed in Fig. 4. Soil water contents of 0–5 cm in CO were 37.5%. Soil water contents in 5–10 cm were higher than those of 0–5 cm. Compaction working was conducted without soil adhering to the surface of the Cambridge-roller under such soil water conditions.

2) Soil hardness

Fig. 5 shows soil hardness in both plots. The hardest layer was observed at 5 cm below the field surface in CO. NC did not have such a hard layer in 0–15 cm.

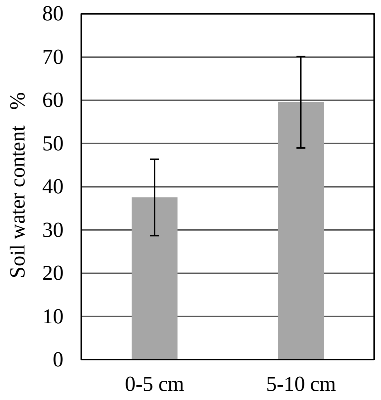

Fig. 4. – Soil water content at compaction working

3) Saturated hydraulic conductivity

Fig. 6 shows the saturated hydraulic conductivity in a logarithmic value of 5–10 cm of both plots. The average values of saturated hydraulic conductivity in CO and NC were -4.31 and -1.76, which were respectively equal to 4.9×10^{-5} cm s^{-1} and 1.7×10^{-2} cm s^{-1} in real value. The value of saturated hydraulic conductivity that is equivalent to our target value of water requirement 20 mm d^{-1} was 2.3×10^{-5} cm s^{-1}. The value of saturated hydraulic conductivity in NC was significantly higher (1.7×10^{-2} cm s^{-1}) than that value in CO of 4.9×10^{-5} cm s^{-1} and our target value.

4) Water requirement and irrigation water applied

The water requirements in CO and NC were 7 mm d^{-1} and 22 mm d^{-1}; that of NC was three times greater than that of CO (Fig. 7). The amounts of irrigation water inputted to both plots to promote an emergence of rice seedling are shown in Fig. 8. Before emergence, 209 mm of irrigation water was applied to CO to prevent soil crust formation on the field surface. In NC, 96 mm irrigation water was used before emergence. Cumulative irrigation water in the whole rice growing season before maturity is shown in Fig. 8. In CO with lower saturated hydraulic conductivity at the field surface than NC (Fig. 6), the amount of irrigation water during the whole season was 1225 mm, which was about 60% of 2019 mm in NC.

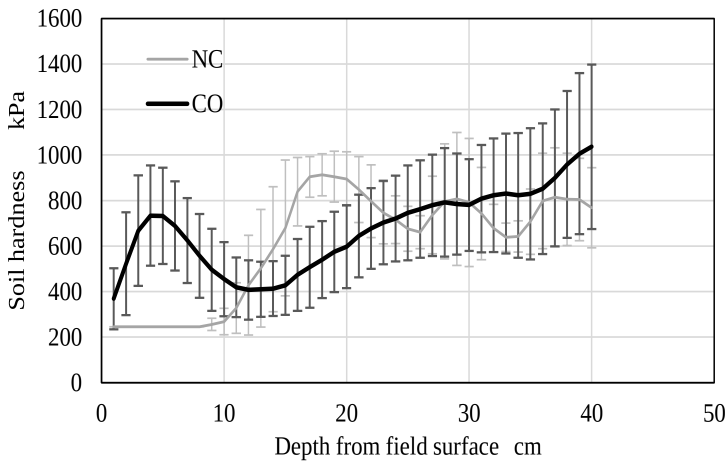

Fig. 5. – Soil hardness of field profile

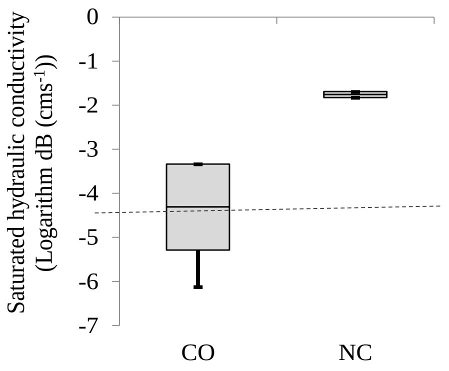

Fig. 6. – Saturated hydraulic conductivity
*Broken line signifies our target value of -4.6: water requirement 20 mm d^{-1}: 2.3×10^{-5} cm s^{-1}

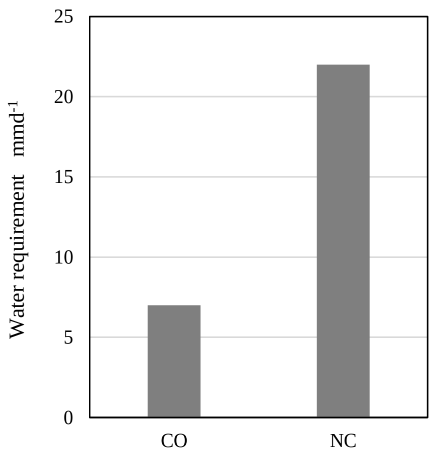

Fig. 7. – Water requirement

DISCUSSION

1) Reduction of permeability with soil compaction.

Regarding soil water condition under soil compaction, KANMURI ET AL. (2015) reported that soil permeability tends to decrease concomitantly with increased soil moisture at compaction working. For compaction with a Cambridge-roller, compaction will be impossible in high soil moisture conditions on field surfaces because of adherence of high-water-content soil to the roller. In this study, water contents of surface soil (0–5 cm) in the CO were 37.5% (Fig. 4), which is nearly equal to the soil plastic limit value of 35.9%, allowing compaction with a roller. Soil moisture under 5 cm from the field surface was 59.6%, which was slightly lower than the value of the soil liquid limit of 63.8%. That was a sufficient soil water condition to reduce soil permeability. Conducting compaction work under high soil water conditions is important to reduce the DSR field permeability.

2) Saturated hydraulic conductivity

When the value of the saturated hydraulic conductivity was calculated from the value of water consumption in both plots investigated in this study, CO and NC were 8.1×10^{-6} cm s^{-1} and 2.5×10^{-5} cm s^{-1}, respectively. The value of CO was similar to the observed value of 4.9×10^{-5} cm s^{-1} (Fig. 6), which was apparently derived from the low permeability layer formed by compaction. The corn index of the layer measured the saturated hydraulic conductivity was the highest of the field profile according to Fig. 5. At that layer, soil density of the layer was enhanced by compaction with increasing of cone index. As the result, the saturated hydraulic conductivity seemed to decrease enough to reduce the water consumption.

The value of NC was lower than the observed value of 1.7×10^{-2} cm s^{-1}. In this case, because no layer existed to reduce deep percolation at the field surface, it was regarded as affected directly by in-situ permeability in subsoil.

3) Saving irrigation water and increasing water productivity

The amount of water use during the growing season in CO was 1046 mm. That for NC was 1923 mm. The total value including flushing water used for emergence of rice plants in CO was estimated as 1225 mm, which was 62% of the NC value of 2019 mm. Compaction working in DSR can conserve about 40% of irrigation water. In the field conditions of high-permeability at the subsoil layer such as our test fields, making a low-permeability layer near the field surface is expected to be quite effective for irrigation water conservation.

From the viewpoint of demand for irrigation water, puddling practices for transplanting of rice are not conducted in DSR. Therefore irrigation water for puddling can be eliminated from DSR calculations. LIU ET AL. (2015) reported that DSR used 15.3% less water than transplanted flooded rice. Based on these results, DSR can decentralize the peak period of irrigation water use by farmers at the beginning of the rice growing and transplanting season.

The grain yield of CO was 7.9 t ha^{-1}, which is higher than that of NC 6.2 t ha^{-1} (Tab. 2). The prevailing aerobic conditions during the period without irrigation water might lose nitrogen from the field in NC, which is regarded as one factor contributing to lower grain yield than that of CO.

Water productivity in CO was 0.5 kg m^{-3}, which is 190% higher than NC of 0.26 kg m^{-3}, which resulted from the greater amount of water used in NC than in CO. KATO ET AL. (2009) reported water productivity measured in Japan as a value from 0.45 to 0.58 by some varieties with DSR cultivation under flooded conditions after seedling establishment. Our value of water productivity is similar to that value. However, the water productivity decreases concomitantly with the increase of the water input in NC. Therefore, reduction of deep percolation and seepage is needed. In addition to enhanced water productivity, irrigation water should be saved without decreasing the grain yield. CABANGON ET AL. (2002) pointed out that although DSR was able to conserve irrigation water, the lower yield of DSR than TPR presents an important consideration for farmers conducting DSR. The control of permeability in DSR fields with field surface compaction is expected to be useful to avoid low yields caused by failure of weed control and by runoff of nitrogen.

Saving irrigation water can provide increased water production in areas where irrigation water is short or limited. In other areas, it is considered that the DSR method with conservation of irrigation water enhances the rice cultivation area.

Tab. 2. – Yield and water productivity.

	brown rice yield	grain yield	irrigation	total water	IWP	WP
	t ha^{-1}	t ha^{-1}	mm	mm	kg m^{-3}	kg m^{-3}
CO	5.1	7.9	1255	1590	0.63	0.50
NC	4.0	6.2	2019	2354	0.31	0.26

*IWP: Water productivity for irrigation water
*WP: Water productivity for total water

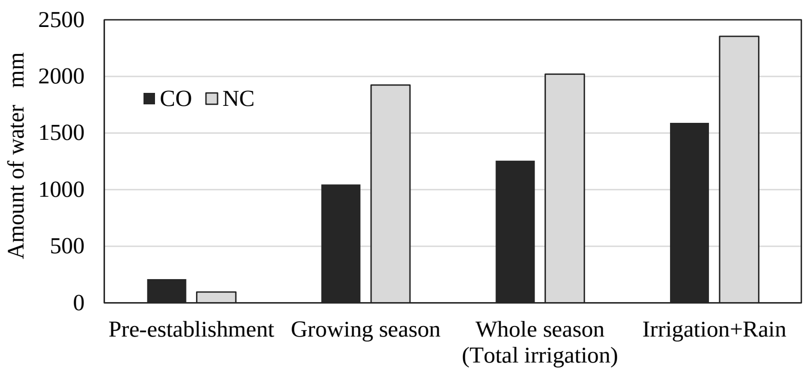

Fig. 8. – Amount of water used in each season

CONCLUSIONS

Effects of water saving on DSR with compaction were revealed by investigating the characteristics of paddy rice fields and amounts of irrigation water in fields with or without compaction working in DSR fields. Saturated hydraulic conductivity decreased to 4.9×10^{-5} cm s^{-1} by compacting soil with a Cambridge-roller in the CO plot. Water requirements decreased to 7 mm d^{-1}, which is lower than the Non-compacted plot value of 21 mm d^{-1}. The amount of irrigation water used for the growing season in CO was about 1255 mm, which was 62% of that in NC. The water productivity in CO increased in 67% compared with NC. Results show that field surface compaction reduces the amount of irrigation water, which increases water productivity. This DSR cultivation method is useful for coping with the variation of supply in irrigation water during an era of climate change.

ACKNOWLEDGEMENT

This research was conducted as a research project of "Advanced technology development for reproduce of food production area" with financial assistance by Japan Reconstruction Agency and Ministry of Agriculture, Forestry and Fisheries.

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