Characterization of the hydraulic property of the plow sole under double-cropped paddy fields in southern Japan

Keiko Nakano[A], Hideo Kubotera[B] and Yoshitaka Hara[A]

[A] Lowland Crop Rotation Research Team(Kyushu Region),National Agricultural Research Center for Kyushu Okinawa Region,496 Izumi, Chikugo, Fukuoka 833-0041, Japan, Email nakak@affrc.go.jp
[B] Sustainable Soil Management Research Team, National Agricultural Research Center for Kyushu Okinawa Region 2421 Suya, Koshi, Kumamoto 861-1192, Japan

Abstract
The saturated hydraulic conductivity of plow soles in paddy fields appears to increase when the fields are used for double-cropping, due to the creation of macropores during the upland growing season. Since these macropores cannot act as a route for water and solute transport in the unsaturated state, the degree of hydraulic conductivity of the plow sole, excluding macropores, is the key to ensure successful cultivation of upland crops. However, such hydraulic conductivity has been rarely determined for paddy fields. Near-saturated hydraulic conductivities were measured by using a tension disk infiltrometer with supply pressure heads (h) ranging from 0 to –12 cm. The hydraulic conductivities at h = 0 cm in double-cropped fields were greater than those in single-cropped rice fields, due to the presence of macropores. In fine-textured soil areas found near the lower reaches of rivers, hydraulic conductivities at h < 0 cm in double-cropped fields were greater than those in single-cropped rice fields, suggesting that the cropping system employed affects the hydraulic property while unsaturated during the upland growing season. In coarse-textured soil areas found near the middle reaches of rivers, the near-saturated hydraulic conductivities in double-cropped fields were no different with those in single-cropped rice fields.

Key Words
Soil structure, unsaturated hydraulic conductivity, drainage, ponding water.

Introduction
The hydraulic properties of near-saturated soil are very important for water and solute transport processes. In southern Japan, the double cropping is employed on many rice paddy fields. One of the essential functions of paddy fields is to pond water; this function is usually a result of the very low hydraulic conductivity of the plow sole and/or due to puddling of the topsoil. When using paddy fields for upland planting, the saturated hydraulic conductivity of the plow sole tends to increase due to the creation of macropores caused by root penetration, resulting in the soil drying out down to the plow sole (Yoshida *et al*. 1997). This high-saturated hydraulic conductivity has the effect of preventing injury by excess moisture in winter wheat in southern Japan, which experiences high rainfall during the growing season. Repeated and regular planting of upland crops tends to create fields suitable for double cropping, which need to have the opposing functions of both ponding and draining water. However, a lack of concern about the unsaturated state of paddy fields had led to no numerical evidence having been collected. The tension disk infiltrometer is an effective tool for studying the hydraulic properties under near-saturated conditions in the field (Perroux and White 1988; Ankeny *et al*. 1988; Angulo-Jaramillo *et al*. 2000). The objective of this study was to determine the differences in the near-saturated hydraulic conductivity of the plow sole between double-cropped fields and single-cropped rice fields.

Methods
Study areas and fields
The study region encompassed adjoining plains known as the Chikugo Plain, the Saga Plain, and the Shiroishi Plain in northern Kyushu, Japan. Many farmers in this region engage in double-cropping. Fields are usually planted with rice or soybean from June to October, followed by winter wheat from November to May. On the basis of soil maps of Japan, 11 areas were selected for the study area. Gray Lowland soil was distributed widely in the study region, enabling the selection of multiple study areas. Although the distribution of the other soil groups (Andosol and Brown Lowland soil) was rare, only a study area was selected for each group. Gray Lowland soil and Brown Lowland soil correspond to Hydragric Stagnic Anthrosols in the World Reference Base for Soil Resources. Two or three double-cropped fields or single-cropped rice fields were selected from each study area (Table 1).

Table 1. Summary of selected study fields.

Cropping system	Area name	Soil group on Japanese soil maps
Double cropping	Shiroishi	Gray Lowland soil
(paddy rice/soybean – wheat)	Kawazoe	Gray Lowland soil
	Yanagawa	Gray Lowland soil
	Oki	Gray Lowland soil
	Takeo	Gray Lowland soil
	Nabeshima	Gray Lowland soil
	tanushimaru	Gray Lowland soil
	Yasutake	Brown Lowland soil
	Amagi	Andosol
	Yanagawa	Gray Lowland soil
Single cropping	Oki	Gray Lowland soil
(paddy rice)	Kinryu	Gray Lowland soil
	Yasutake	Brown Lowland soil

Measurements

Infiltration measurements using a tension disk infiltrometer were conducted at three supply pressure heads, *h*, of –12, –3, and 0 cm, applied successively at the same position from low to high pressure to give a dry to wet sequence. If no water infiltrated at *h*= –12 cm for 10 min, the minimum *h* were increased by 1 cm until water infiltration occurred. Measurement was performed at 2–3 spots in each field. The instrument was set on the plow sole, which was judged according to soil hardness and root distribution. Steady-state infiltration rates were measured, and the hydraulic conductivity was calculated by using the method described by Ankeny *et al*. (1991). Measurements were carried out in June 2007 and May 2008. Particle size distribution was measured by bulk soil sampling of the plow sole.

Results and discussion

Study area classification according to soil texture

Soils in Shiroishi, Kawazoe, Yanagawa and Oki had a fine texture due to their clay content exceeding 30 %. In Amagi, although the clay content exceeded 30 %, the sand content was also above 40 %, giving the soil a coarse texture. The sand content was above 40% in Takeo, Nabeshima, Kinryu, Tanushimaru and Yasutake; moreover, the coarse sand content was above 10 % in these areas, except in Takeo. As shown in Figure1, fine-textured soils were located around the lower reaches of rivers, while coarse-textured soils were found in the middle reaches. Soil texture in the study region was likely to depend on the location. We have therefore classified the study areas into two groups: the lower reaches and the middle reaches; we have discussed the characteristics of near saturated hydraulic conductivity accordingly.

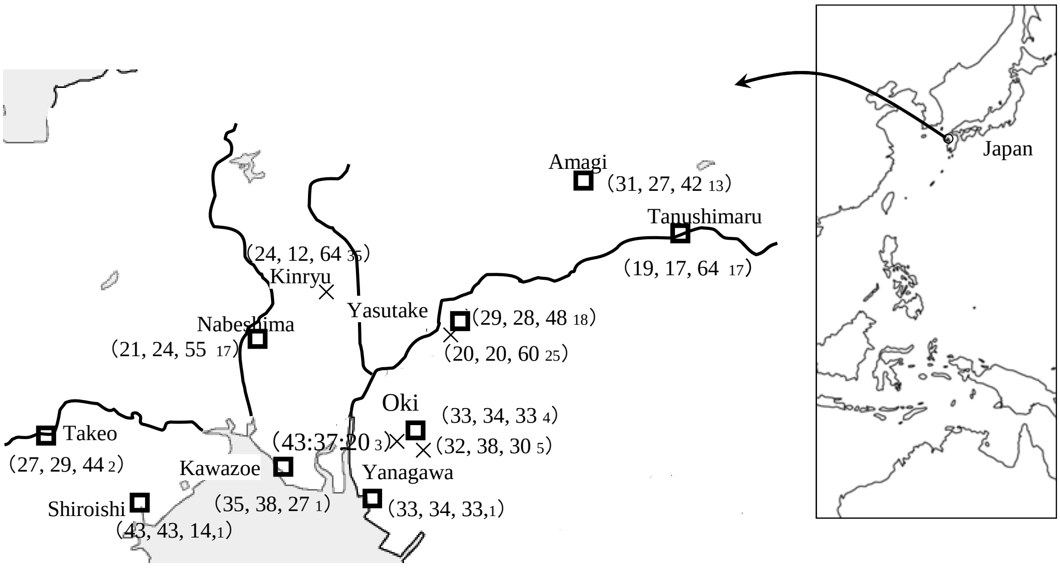

Figure 1. Spatial distribution of the study areas and their soil textures (clay, silt, sand coarse sand %) . Areas labelled with □ were under double-cropping, and areas labelled with × were under single rice-cropping.

The hydraulic conductivities of the plow sole at h = 0 cm

The average hydraulic conductivity in each area is shown in Figure 2. These values at h = 0 cm in double-cropped fields were in the order of 10^{-3} cm s^{-1}; overall, it was greater than the corresponding value in single-cropped rice fields. This high hydraulic conductivity is likely to be attributable to macropores because of a steep decrease with increased supply tension.

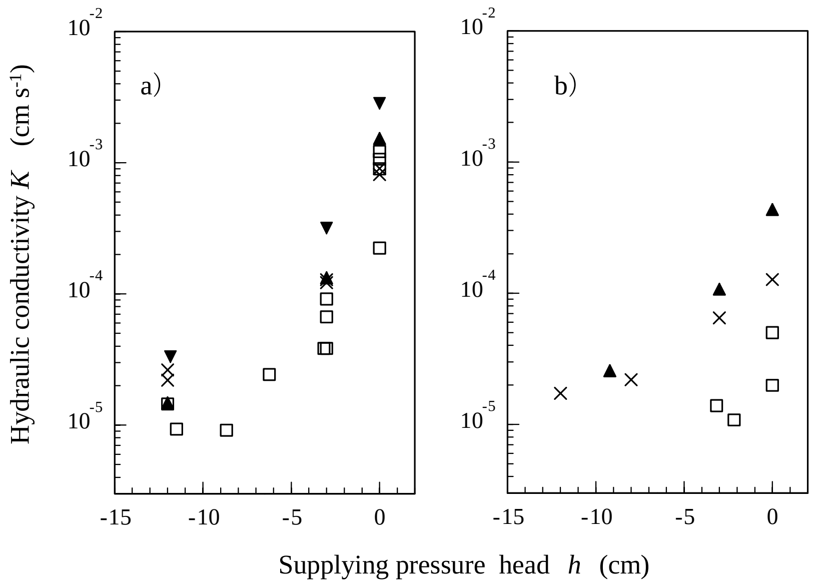

Figure 2. Near-saturated hydraulic conductivity in the plow sole of a) double-cropped fields and b) single-cropped rice fields.
×Gray Lowland soil around the middle reaches of rivers; □Gray Lowland soil around the lower reaches of rivers; ▼Andsol; ▲Brown Lowland soil

The hydraulic conductivities of the plow sole under supplying pressure head, especially h = –12 cm

Hydraulic conductivities of the plow sole at h = –12 cm in single-cropped rice fields in lower reaches (Oki and Yanagawa) were markedly lower than those in double-cropped fields (Oki, Yanagawa, Shiroishi and Kawazoe), as shown in Figure 2. They were in fact below the measurement limit of the tension disk infiltrometer. In fields with fine-textured soil, the effect of macropores on the permeability of the plow sole under the single rice cropping system was lower than under the double-cropping system. In the middle reaches, there was no difference in the hydraulic conductivity of the plow sole at h = –12 cm between the double-cropped fields (Kinryu, Tanushimaru, Takeo and Yasutake) and the single-cropped fields (Nabeshima and Yasutake). The value was in the order of 10^{-5} cm s^{-1}. These results indicated that the cropping system in coarse-textured soil fields would not significantly affect the hydraulic conductivity under h < 0 cm, i.e. the permeability of the plow sole during upland cropping.

Management according to cropping system, based on the near-saturated hydraulic conductivity of the plow sole

In double-cropped fields, fertilizers may promptly flow out from the root zone following heavy rain during upland growing season owing to the presence of macropores in the plow sole. For ponding water on the field during rice planting, double-cropped fields need to be managed to limit infiltration, irrespective of the permeability of the plow sole, akin to that caused by puddling of the topsoil or a high water table due to water filling the ditches in the surrounding of the fields.

Conclusion

The near-saturated hydraulic conductivity of the plow sole in single-cropped rice fields and double-cropped fields was determined by using a tension disk infiltrometer. Macropores significantly affected the saturated hydraulic conductivity of the plow sole in double-cropped field. In areas around the lower reaches of rivers, the effect of macropores was seen up to h = –12 cm. The choice of the cropping system and its continuous use are likely to lead to the development of a specific structure of the plow sole and affect water and solute transport during upland growing season, especially in fine-textured soil.

References

Angulo-Jaramillo R, Vandervaere JP, Roulier S, Thony JL, Gaudet JP, Vauclin M (2000) Field measurement of soil surface hydraulic properties by dis and ring infiltrometers: A review and recent developments. *Soil and Tillage Research* **55**, 1-29.

Ankeny MD, Kaspar TC, Horton R (1988) Design for an automated tension infiltrometer. *Soil Science Society of America Journal* **52**, 893-896.

Ankeny MD, Ahmaed M, Kaspar TC, Horton R (1991) Simple field method for determining unsaturated hydraulic conductivity. *Soil Science Society of American Journal* **55**, 467-470.

Perroux KM, White I (1988) Design for disc permeameters. *Soil Science Society of America Journal* **52**, 1205-1215.

Yoshida S, Itoh K, Adachi K (1997) Improvement of drainage in clayey rotational filed by introducing winter crops after conversion from paddy. *Soil Physical Conditions and Plant Growth, Japan* **76**, 3-12 (in Japanese with English Abstract).