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Non-Excavation Subsurface Irrigation and Drainage Systemin the Reclaimed Lowland to be Cultivated with Upland-Field Crops

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Abstract: Although previously the reclaimed land has been developed and used mainly for paddy field in Korea, there is a need to improve the reclaimed land to be cultivated for highland-field crop, due to the necessity for smooth management of grain supply and demand to cope with the changes of international and domestic agricultural environment, and higher farming income from highland-field crops than rice. However, it is difficult to cultivate highland-field crops in the reclaimed land, because it is mostly located in lowland, containing high salinity soil with a difficulty of drainage due to the characteristics of fine grained soil which is a major component of the reclaimed land. In addition, there is a big problem of re-salinization of root zone soil caused by the capillary rise of saline groundwater during the dry season.

In this study, seepage analysis to draw high-capacity drainage system was conducted by each type of subsurface drainage system, and subsoil breaking and no-excavation subsurface drainage system were proposed to be utilized for the improvement of reclaimed land at low-cost to cultivate highland-field crops. Following results were acquired through pilot construction in the field.

(1) Reclaimed soil of Korea, which is mostly impermeable ($k < 1*10^{-4}$ cm/s), requires the introduction of (i) subsurface drain and (ii) subsoil breaking method, to improve the land to be cultivated for highland-field crop.

(2) In order to array the appropriate spacing (3-10 m) by the soil type, it is necessary to develop and introduce cost-effective non-excavation subsurface drainage system installation method.

(3) The introduction of subsurface irrigation and drainage system is necessary to clean drain system and to prevent re-salinization.

(4) As a result of the pilot construction of cost-effective non-excavation subsurface irrigation and drainage system, it was confirmed that workability was improved due to the construction of non-excavation method, and construction cost was lower (75%) and subsurface drain and desalinization performance was far superior (over 150%) with 5 m intervals in parallel with subsoil breaking method than that of existing method with 10 m intervals.

(5) It was proved that subsoil breaking and subsurface irrigation and drain system were efficient to clean the drain system using underground irrigation water as well as prevent re-salinization. And also it was confirmed that the system made the desalinization of soil from 10-15 ds/m to 2-5 ds/m within a year under the condition of natural rainfall possible.

As the result of the crop cultivation on the pilot reclaimed land desalinized by subsoil breaking and subsurface irrigation and drain system, it was found that crop growth without any damage by moisture during wet season was shown in good status, and it led to conclusion that the system is highly effective for the development of reclaimed land.

Key words: subsoil breaking, subsurface irrigation and drainage, subsurface horizontal filter system, non-excavation system

1. Introduction

Korea has been utilizing the reclaimed low land for paddy field to produce mainly rice as staple food, but nowadays it is required to develop the reclaimed land to cultivate upland crops for income improvement, control of cereal supply and demand.

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Generally the reclaimed land is located at a lowland area with high salinity and fine-grained soil. Fine-grained soil causes a difficulty in subsurface drainage that leads to the poor cultivation of upland crops. In order to cultivate the upland crops in the reclaimed farmland, subsurface drain facilities have been installed, but it could not be actively implemented due to the high construction cost and low desalination effects [1]. In addition, there is another challenge that reclaimed low land, even if upland crop could be cultivated after desalination, may be re-salinized due to capillary rise of saline water under the ground during dry season [2].

The purpose of this study is to develop subsoil breaking method and low cost non-excavation subsurface drainage system to improve subsurface drainage and desalination in the reclaimed land. The efficiency of the low cost non-excavation subsurface irrigation and drainage system has been confirmed through the test construction.

2. Materials and Methods

2.1 The Necessity for Development of Subsoil Breaking and Drain Construction Method

According to the calculation using Van Schilfgaarde and Hooghoudt equations in the basic design, optimum spacing of culvert is highly correlated with the permeability coefficient of the soil, which is shown in Fig. 1 [3].

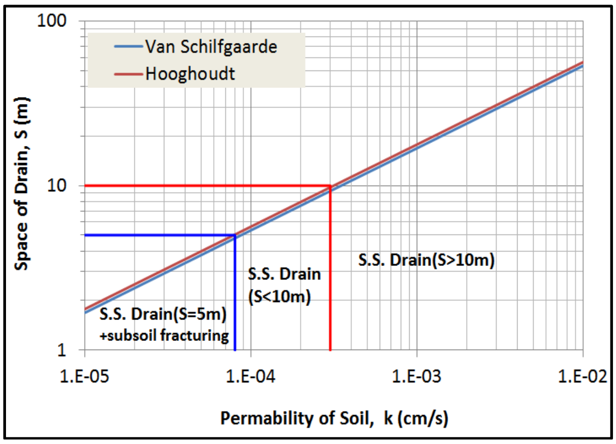


Fig. 1 Permeability coefficient and spacing of culvert (formal theoretical model).

If the permeability coefficient (k) of the soil is less than $3*10^{-4}$ cm/s, the spacing of culvert should be less than 10 m, and if k = $1*10^{-4}$ cm/s, the spacing of culvert should be less than 5 m. If the coefficient of permeability is equal or less than $1*10^{-4}$ cm/s, it may be efficient to improve the permeability of the soil by breaking subsoil [4].

Low and wet paddy field in Korea usually has a coefficient of permeability less than $1*10^{-4}$ cm/s, but the culverts have been constructed with the spacing more than 10 m due to economic issues for which the culverts could not to be functioned properly [1].

In order to solve these problems, it is required to develop subsoil breaking and the low cost & high efficient non-excavation subsurface drainage construction methods suitable for the reclaimed soil in Korea.

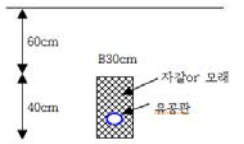
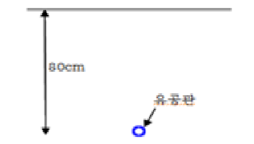
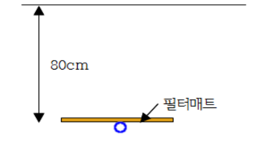
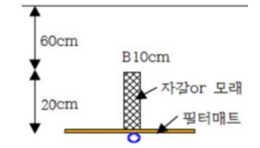
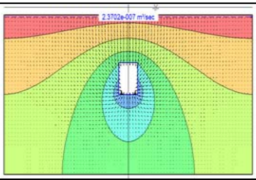
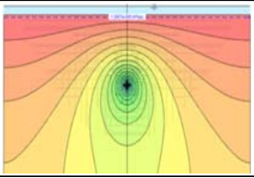
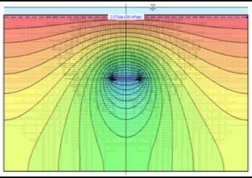
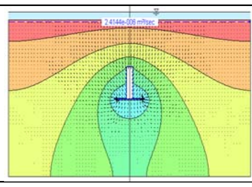
2.2 Introduction of Low Cost & Highly Efficient Subsurface Drainage System

2.2.1 Evaluation on the Performance of Subsurface Drainage System by Culvert Types

As shown in Table 1, numerical seepage analysis were conducted to check the performance of subsurface drainage system by four types of culverts, such as: (1) the existing trench perforated drain pipe + gravel improved culvert: (2) non-excavation perforated drain (50 mm) (3) perforated drain (50 mm) + 50 cm non-excavation horizontal drain mat (4) perforated drain (50 mm) + 50 cm wide horizontal mat + non-excavation gravel improved culvert. As a result, subsurface drainage discharge from soil to culvert per meter was in order of (4) > (1) > (3) > (2).

However, (2), (3) and (4) are 1/3 times cheaper than (1). If (1) is installed at 10m interval, and (2), (3), (4) are installed at 5m interval, the subsurface drainage per unit area is(4) > (3) > (2) > (1), but the construction cost is (1) > (4) > (3) > (2). In other words, (3) and (4) havehigher performances (1.75 times) and lower construction cost (67%) than (1), which means that these culvert construction methods are low in cost and highly efficient.

Table 1 Drainage effects of subsurface drainage.

Type of culvert	(1) Excavated culvert (gravel B30*H40 cm)	(2) Non-excavation culvert (50 mm perforated pipe)	(3) Non-excavation culvert 2 (50 mm perforated pipe + filter mat B50 cm)	(4) Non-excavation culvert 3 (perforated pipe + filter mat + sand B10 cm)
				
Shape of subsurface drain				
Discharge of drainage water (m^3/s/m)	$2.37*10^{-6}$	$1.29*10^{-6}$	$2.17*10^{-6}$	$2.41*10^{-6}$
Remark (%)	100	54	92	102
Installation space (m)	10	5	5	5
Discharge of subsurfacedrainage water per unit area (mm/d)	20.5 (100%)	22.3 (109%)	35.8 (175%)	41.6 (209%)
Construction cost (million Won)	45 (100%)	20 (44%)	25 (56%)	30 (67%)

2.2.2 The Necessity for Optimization and Test Constructions of Subsurface Culvert

When the permeability coefficient (k) of the soil is less than $3*10^{-4}$ cm/s, the spacing of culvert should be less than 10 m and when the k = $1*10^{-4}$ cm/s, the spacing of culvert should be less than 5 m. However, due to economic problems, it was forced to be over 10 m.

Number (3) (50 mm perforated pipe + 50 cm horizontal mat) and (4) (wrinkle perforated pipe + 50 cm horizontal mat + rice husks improved non-excavation culvert) constructionmethods can be used to resolve the problems in association with their lower construction cost (67%) and higher drainage performances (175%).

However, the calculation of drainage performance obtained through theoretical numerical analysis needs to be verified in the field. Therefore, test construction of number (1) and (2) for verifying their drainage performance were carried out.

In addition, since the permeability coefficient of the simulation site was less than $1*10^{-4}$ cm/s, the subsoil breaking was also carried out.

2.3 Subsurface Irrigation and Drainage System to Prevent Re-Salinization

2.3.1 Re-Salinization Characteristics in Dry Season

As shown in Fig. 2, the soil salinity repeatedly changed after the installation of the subsurface culverts. Soil salinity decreased in the wet season and rose again in the dry season. This phenomenon was caused by capillary rise of brine water. Hence, capillary rise during dry season should be prevented.

2.3.2 Subsurface Irrigation System for Preventing Re-salinization in Dry Season

As shown in Fig. 3, capillary rise in dry season can be blocked by artificially forming freshwater layer above the saline water [5]. To confirm this method, test construction was carried out.

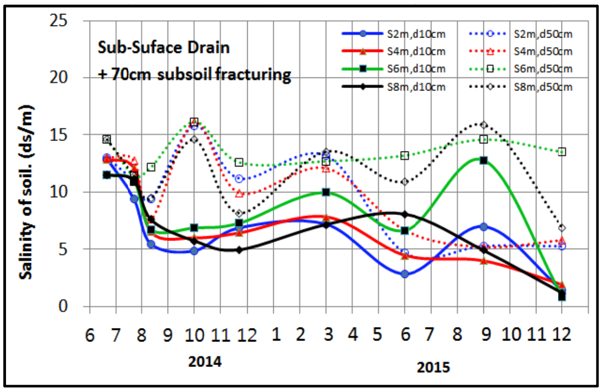


Fig. 2 **Changes in soil salinity of reclaimed land during wet and dry seasons.**

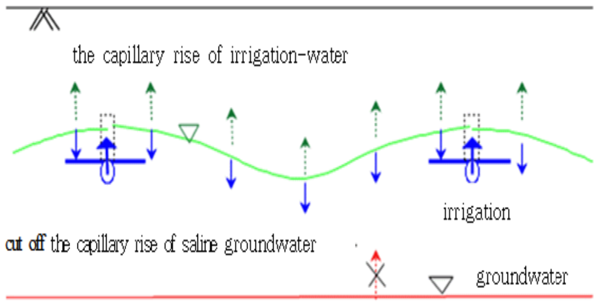


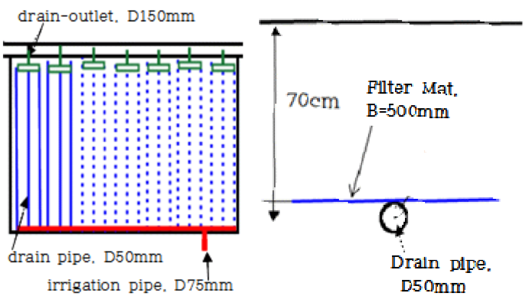
Fig. 3 **Schematic diagram of re-salinization prevention through subsurface irrigation system in dry season.**

3. Layout of Test Site

3.1 Test Construction of Non-Excavation Subsurface Irrigation and Drainage System

3.1.1 Plan and Cross Section of Test Construction

As shown in Fig. 4, test construction of subsurface irrigation and drainage system was carried out by using non-excavation single pipe method (0.3 ha). The culvert was constructed by 50 mm perforated pipe and 500 mm horizontal mat with 5 m spacing.



(a) (b)

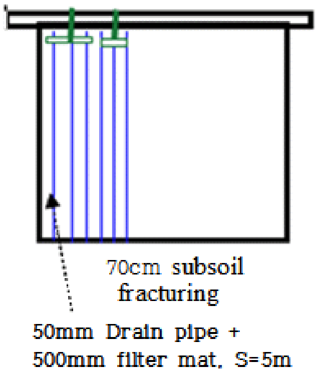
Fig. 4 **Plan and cross section of non-excavation subsurface irrigation and drainage system: (a) plan of subsurface irrigation & drainage culvert; (b) cross section of non-excavation culvert.**

3.1.2 Test Construction of Non-Excavation Single Pipe Subsurface Culvert

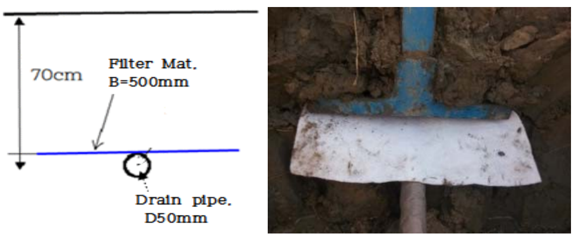
Fig. 5 shows the test construction of subsurface irrigation and drainage culvert using non-excavation single pipe in 0.3 ha area.

3.2 Subsoil Breaking

After the installation of the subsurface culvert as shown in Fig. 6, subsoil with the depth of 0.7 m was crushed by using a backhoe breaker. After subsoil breaking, the soil was completely crushed and the water penetrated evenly into the ground. Almost all the water penetrated into the ground immediately after the rainfall.



(a) Plan of Culvert



(b) Cross Section of Culvert

(c) Construction of Non-Excavation Culvert

Fig. 5 **Test construction of subsurface irrigation and drainage using non-excavation single pipe method.**

Fig. 6 Subsoil breaking using a backhoe.

4. Results and Discussion

4.1 Effects of Rainfall Penetration and Subsurface Drainage

As shown in Fig. 7, the surface water in the *no ss block* has not been discharged for more than 20 days after rainfall, but a block with culvert and crushed subsoil in the *ss drain block* has been dried immediately within a day by infiltration after rainfall.

4.2 Continuity of Subsurface Drainage in Three Years after Construction of Subsurface Culvert and Subsoil Breaking

As shown in Fig. 8, in three years after construction of subsurface culvert and subsoil breaking, it can be seen that subsurface drainage can effectively drain the water even without surface water drainage after rainfall of 100 mm/day. Subsoil breaking improves the soil structure and soil permeability.

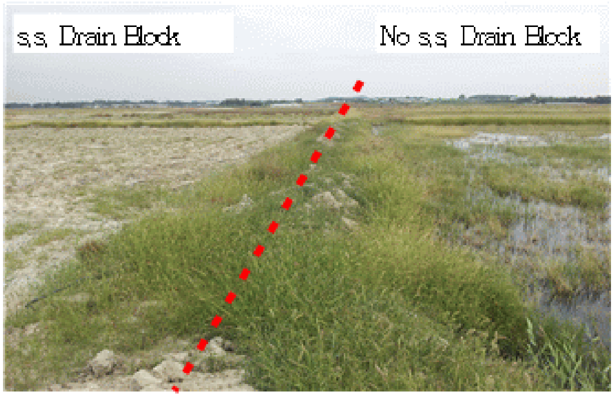


Fig. 7 Effects of subsurface culvert and subsoil breaking.

(a) Vegetation and subsurface drainage statusin the non-excavation culvert block

(b) drainage status of culvert drain

Fig. 8 Condition of subsurface drainage after 100 mm/day rain (3 years after construction).

4.3 The Effects of Expediting Desalination and Preventing Re-salinizationby Subsurface Irrigation and Drainage System

As shown in Fig. 9, the untreated block showed almost no desalination for 2 years. However, the salinity in block with drainage culvert (No I+D System) decreased from the initial salinity of 12 ds/m to 4.2 ds/m in 2 years. The salinity of soil tends to decrease in wet season and increase in dry season.

Non-excavation subsurface irrigation and drainage system (+backhoe breaking) was desalinated up to 2-5 ds/m in the first year and the salinity continuously decreased until the end of experiment period without re-salinization.

Through this experiment, it was confirmed that the subsurface irrigation and drainage system has a great effect of preventing re-salinization.

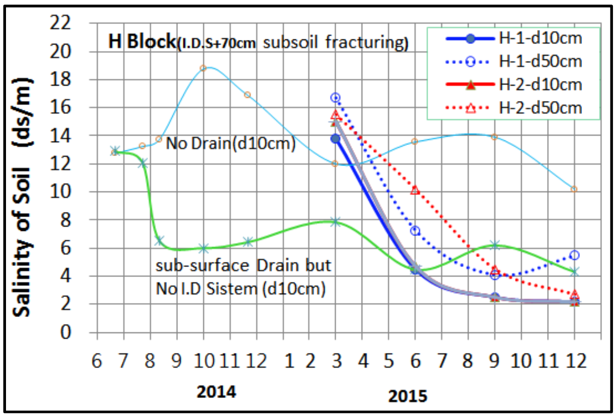


Fig. 9 Effects of expediting desalination and preventing re-salinizationby subsurface irrigation & drainage system and subsoil breaking.

4.4 Vegetation Changes after Desalination

Vegetation changes after desalination for 1 to 2 years is shown in Fig. 10. It shows that the untreated block was overgrown by halophytes vegetation, while the block with non-excavation culvert (+backhoe breaking) was overgrown by common vegetation.

It is confirmed that the area with subsurface irrigation and drainage culvert is well drained and the soil moisture is suitable for cultivation of upland crops.

(a) untreated block (halophytes)

(b) block with subsurface culvert + subsoil breaking
(common vegetation)

Fig. 10 Vegetation status after 100 mm/day rainfall.

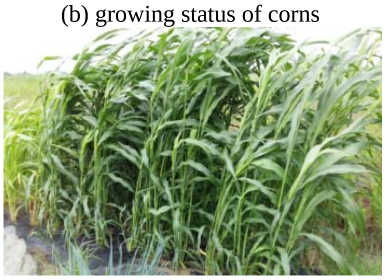
4.5 Crops Cultivation in 2 Years after Culvert Construction and Subsoil Breaking

The block over 2 years after construction of subsurface irrigation and drainage system and subsoil breaking had a salinity of 1-4 ds/m and was overgrown by crops as shown in Fig. 11.

It was confirmed that the construction of subsurface culverts in appropriate intervals with subsoil breaking can improve the soil structure even in impermeable reclaimed land and subsurface drainage which expedite desalination and prevent re-salinization to cultivate upland crops.

(a) growing status of kidney beans

(b) growing status of corns



(c) growing status of sorghum

(d) growing status of green onion

Fig. 11 Growing status of upland crops in 3 years after test construction.

5. Conclusion

In order to convert the reclaimed land to highland crop field, the disadvantages of subsurface culvert were re-analyzed, and construction of non-excavation irrigation & drainage system with subsoil breaking were proposed. The study resulted in conclusions as follows:

(1) Reclaimed land in Korea, in which soil is mostly impermeable ($k < 1*10^{-4}$ cm/s), requires the introduction of (i) appropriate interval (less than 10 m) of subsurface drainage system and (ii) subsoil breaking method, to improve the land to be cultivated for upland crops.

(2) In order to array the appropriate spacing (3-10 m) by the soil type, it is necessary to develop and introduce cost-effective non-excavation subsurface drainage system installation method.

(3) The introduction of subsurface irrigation and drainage system is necessary to clean drain system and to prevent re-salinization.

(4) As a result of the pilot construction of cost-effective non-excavation subsurface irrigation and drainage system, it was confirmed that workability was improved due to the construction of non-excavation method, and construction cost was lower (75%) and subsurface drain and desalinization performance was far superior (over 150%) with 5 m intervals in parallel with subsoil breaking method than that of existing method with 10 m intervals.

(5) It was proved that subsoil breaking and subsurface irrigation and drain system were efficient to clean the drain system using underground irrigation water as well as prevent re-salinization. And also it was confirmed that the system made the desalinization of soil from 10-15 ds/m to 2-5 ds/m within a year under the condition of natural rainfall possible.

As the result of the crop cultivation on the pilot reclaimed land desalinized by subsoil breaking and subsurface irrigation and drain system, it was found that crop growth without any damage by moisture during wet season was shown in good status, and it led to conclusion that the system is highly effective for the development of reclaimed land.

Acknowlegement

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