Evaluation of Subsurface Drainage System for Excess Rainfall : Design on Subsurface Drainage in Paddy Fields (II)

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Abstract

The performance of the subsurface drainage system was examined and evaluated for the crop diversification, the rice and the non-rice farming, in a paddy field.

The subsurface drainage system is designed and installed with the design drainage rate of 20-30 mm/d, about 1 mm/h, to remove excess topsoil water for rice farming, usually having a 10 m spacing.

The same system in the non-rice farming field converted from rice farming is expected to have a ten times subsurface drainage discharge, 10 mm/h, and to remove excess rainfall which corresponds to the design rate of the surface drainage for non-rice farming.

Introduction

In the drainage design of the paddy fields for the crop diversification, the subsurface drainage system design for such items as a lateral drain spacing, a drain depth, a drain diameter, envelope materials, the combination system with mole drains and a mole drain spacing are usually carried out for rice farming, that is drainage for mid-summer drying up and for harvesting. Employing the design drainage rate of 20-30 mm/d, about 1 mm/h, to remove excess topsoil water, the systems are designed and installed, most popularly having a 10 m spacing extending 7 m up to 15 m, a 50 mm diameter up to 75 mm, a 70-90 cm drain depth backfilled with rice husks and/or gravel[1,2].

There is, however, no design concept of the subsurface drainage for non-rice farming, though it is recognized that drainage conditions must be improved to grow the non-rice crops in paddy fields. The paddy field for the crop diversification is defined here the field where non-rice crops grow compatibly with rice.

For non-rice farming, it is necessary for the drainage system to remove surface water ponding on a field caused by excess rainfall. Thus, farm drain ditches are designed and installed along the fields with higher drainage rate of about 7-10 mm/h[3]. On the fields, however, it is out of designing whether the rate is actually drained to the ditches or not, while the ditches have their capacity for the rate of 7-10 mm/h.

In this paper, it is attempted to estimate the capacity of a subsurface drainage system for the excess rainfall and to evaluate the performance of the system in non-rice farming field converted from rice farming.

Design Drainage rates[4)]

The field drainage for the crop diversification is classified into following three cases according to field conditions of rice or non-rice farming: (1) surface drainage of excess rainfall and (2) subsurface drainage of excess topsoil water for mid-summer drying up and for harvesting in a rice farming field, and (3) drainage of excess rainfall in a non-rice farming field.

In a non-rice farming field, the excess rainfall is removed through the surface and the subsurface drainage systems. Then it is difficult to separate two drainage components and how to share a design drainage rate with two systems quantitatively. Thus the concept that the excess rainfall is removed through the subsurface drainage system is acceptable to field drainage design having the objective of "no water-logging".

The design drainage rates for three cases are determined as follows.

1. Surface drainage for rice farming

The drainage rate (D_1) is commonly derived from one day rainfall of 10 year return period. The rate is, for example in Osaka, about 3 mm/h based on that the rainfall is 150 mm and the runoff ratio is 40-50%.

2. Subsurface drainage for rice farming

The drainage rate (D_2) is 20-30 mm/day, about 1 mm/h, which is a peak drainage discharge that enables to remove the excess topsoil water of 7-10 mm within one day long, 24 hrs.

3. Subsurface drainage of excess rainfall for non-rice farming

As the design drainage rate of subsurface drainage for non-rice farming, the rate (D_3) of surface drainage design is employed which is commonly derived from 4 hours rainfall of 10 year return period. The rate is, for example in Osaka, about 8 mm/h based on that the rainfall is 75 mm and the runoff ratio is 40-50%.

4. Drainage capacity of the subsurface drainage system

The drainage capacity is defined here a drainage intensity of a subsurface drainage system with a given drain spacing and drainage conditions such as the hydraulic conductivity and topsoil thickness.

Performance of Subsurface Drainage System

The drainage capacity of a subsurface drainage system which is designed and installed for rice farming with the drainage rate of D_2 will be evaluated for the non rice-farming converted from rice farming.

Figure 1 shows a flow pattern in the shallow permeable topsoil overlying the impermeable plowsole layer in a paddy. In a trench, pipe envelopes such as rice husks and/or gravel are backfilled up to the topsoil to reduce the head loss for the downward flow of the water. Therefore, a drain depth below the plowsole can be neglected in the consideration on drain spacing. By using *Dupit-Forchheimer* assumptions, the drain

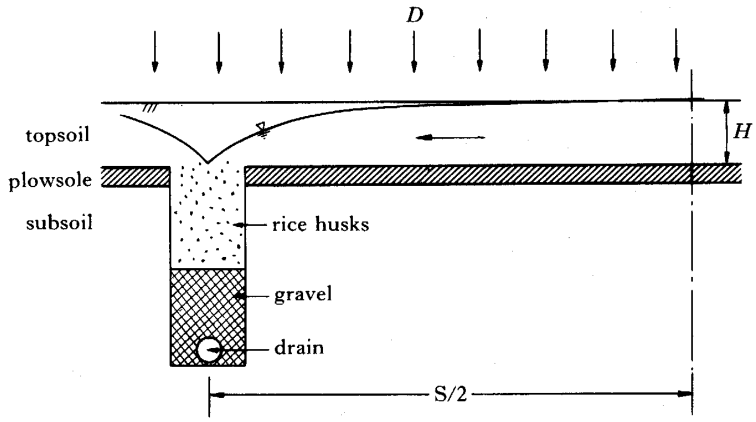

Fig. 1 Flow pattern in shallow topsoil

spacing is written as follows[2,5],

$$S=2H\sqrt{86.4\frac{k}{D}} \quad (1)$$

The drainage rate D which is the drainage capacity of the system having a drain spacing of S is rewritten from Eq. (1) as follows,

$$D=86.4\left(\frac{2H}{S}\right)^2 k \quad (2)$$

where S: drain spacing in m, D: design drainage rate in mm/h, H: topsoil thickness in cm, k: hydraulic conductivity in cm/s and 86.4: a constant for conversion of time unit.

A drainage capacity of the identical subsurface drainage system under the field condition of non-rice farming is estimated by using Eq. (2) and design data of D, H, k for rice farming. Then a value of the hydraulic conductivity, k, is evaluated to be ten times higher at least than that of rice farming field, because macro-pores and fissures develop in the topsoil through cultivation and drying. Consequently, the drainage capacity is estimated at 200-300 mm/d, 8-12 mm/h, assuming that D is 20-30 mm/d, k is ten times higher, and S and H do not vary from non-rice farming to rice farming.

The drainage capacity of 8-12 mm/h equals to the design drainage rate D_3 of surface drainage of excess rainfall for non-rice farming. The subsurface drainage system is evaluated to be performable to remove the excess rainfall in the non-rice farming field.

Drainage Testing

1. Methods

An evaluation of the performance of subsurface drainage systems was carried out through drainage tests[6] at an experimental plot and 11 actual paddy fields in Hyogo Prefecture. The subsurface drainage systems and their drainage capacities are shown in Table 1. At three fields in Hayashidani and Yosida districts, the combination drainage system of the lateral and the mole drains were employed.

The drainage capacity of every subsurface drainage system except Nomura Field was estimated in following ways: At rice farming fields, under the initial condition that there is no ponding surface water after draining it out through a spill way, the drainage

Table 1. The drainage systems and estimated subsurface drainage capacities.

Field Name	Farming	Plot Size	Drain Spaicing	Envelope Material	Drainage Capacity
		m m	m		mm/h
Nomura	Non-rice	100×30	13.5	Gravel/Rice Husk	11.0
Hayashidani	Non-rice	76×38	38 +3*	Rice Husk	10.4
Yoshida No. 1	Non-rice	70×30	12.5+3	Gravel/Rice Husk	3.7
Yoshida No. 2	Rice	70×30	12.5+3	Gravel/Rice Husk	3.1
Sadamori No. 1	Rice	50×30	8	Gravel/Rice Husk	0.2
Sadamori No. 2	Rice	60×27	8	Gravel/Rice Husk	0.3
Goyu	Rice	100×30	10	Gravel/Rice Husk	1.0
Hata No. 1	Rice	57×15	15	Gravel/Rice Husk	0.5
Hata No. 2	Rice	63×17	17	Gravel/Rice Husk	0.5
Abara No. 1	Rice	75×40	10	Gravel/Rice Husk	1.5
Abara No. 2	Rice	75×40	10	Gravel/Rice Husk	1.3
Hudai No. 7	Non-rice	10× 8	8	Rice Husk	12.0

*) Combination Drainage system of lateral drains and mole drains which drain spacings are 38 m and 3 m respectively.

discharges, q in mm/h, were observed with time t in hours, after opening an outlet of subsurface drains. From the hydrograph of q to t, adjusted initial discharge was estimated as the drainage capacity of the system. At non-rice farming fields, after closing the outlet and supplying irrigation water into the field up to the initial condition mentioned above, the observation was carried out and the drainage capacity was estimated.

At Nomura Field where a self recorded flow meter and rain gauge were installed, also the subsurface drainage ratios were calculated. Every observed hydrograph except those that the peak discharge is less than 1 mm/h in Nomura Field are shown in Fig. 2.

2. *The subsurface drainage capacity*

Every fields under the non-rice farming, Nomura, Hayashidani and Hudai No. 7 Fields except Yoshida No. 2 Field has the drainage capacity over 10 mm/h, which seem to be performable to remove the excess rainfall. In Yoshida No. 2 Field, it is required to employ drains having larger diameter such as 75 mm at least judging from the recession

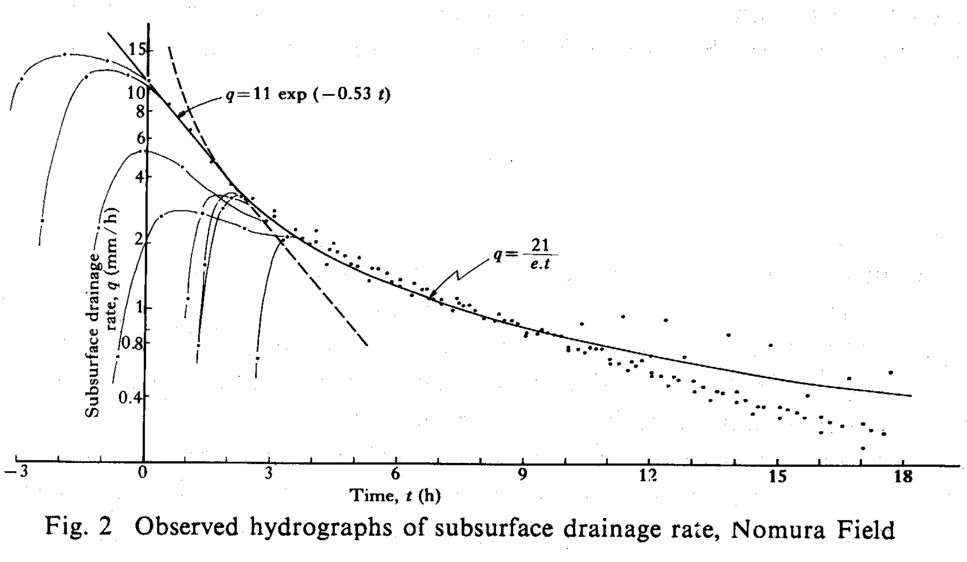

Fig. 2 Observed hydrographs of subsurface drainage rate, Nomura Field

Table 2. Subsurface drainage ratio, Nomura Field, Hyogo Pref.

No.	Rainfall			Subsurface Drainage			ARI**
	Term	Total Rainfall	Peak Intensity	Total Discharge	Drainage Ratio*	Peak Discharge	
	1982	mm	mm/h	mm	%	mm/h	days
1	Jun. 13-14	20.5	3.0	0.6	2.8	0.0	9
2	Jun. 19-20	20.0	9.5	0.1	0.0	0.0	4
3	Jul. 13-19	77.5	13.0	31.2	40.4	3.2	18
4	Jul. 24-26	36.5	3.5	16.2	44.5	1.0	4
5	Jul. 29	9.5	6.0	1.2	12.3	0.1	2
6	Aug. 1-2	162.5	20.0	125.9	77.5	14.1	2
7	Aug. 8-11	36.5	20.5	7.5	20.5	1.1	5
8	Aug. 16-20	36.0	6.5	6.0	16.7	0.8	4
9	Aug. 27-29	30.5	5.0	1.0	5.1	0.1	6
10	Sep. 9-13	133.5	10.3	105.6	79.1	3.0	10
11	Sep. 19-21	59.5	7.0	52.4	88.1	3.3	5
12	Sep. 26-26	69.5	8.0	58.9	84.7	5.2	1
13	Oct. 1-2	11.5	2.0	3.2	27.7	0.1	4
14	Oct. 19	26.0	4.0	3.9	15.0	0.3	15
15	Oct. 31-1	17.0	6.0	2.5	14.4	0.2	11
16	Nov. 5-11	44.5	3.0	31.5	70.9	0.9	3
17	Nov. 15-16	10.5	3.5	8.8	83.8	0.3	3
18	Nov. 22-23	6.5	3.0	3.4	53.0	0.1	5
19	Nov. 29-30	71.5	26.5	62.6	87.6	11.4	5

*) Drainage Ratio: Total (Drainage) Discharge/Total Rainfall (%)

* *) ARI: Antecedent non-rainfall index in days

characteristics of the hydrograph.

In Nomura Field, as shown in Fig. 2, the capacity is estimated at 11 mm/h through analyses of the observed hydrographs. On the hydrographs where peak discharge is less than 11 mm/h, the topsoil did not saturated with rainfall. On those having the peak discharge larger than 11 mm/h, Nos. 6 and 19 in Table 2, water-logging seems to have been occurring for 2 or 3 hours. Then the drainage ratios of them are high as much as 77.5 and 87.6%. It is the subsurface drainage system that removes the heavy rainfall, not the surface drainage.

3. *Subsurface drainage ratio to rainfall*

The drainage ratio depends on a storage capacity of a field, mainly of soils. In Table 2, the storage capacity is showed by ARI, a number of days of the antecedent non-rainfall. The drainage capacity and the total drainage discharge of the subsurface drainage system depend on the storage capacity, and also those of the surface drainage system depend on those of subsurface drainage system. The subsurface drainage system will has higher performance for removing excess rainfall than the surface system, provided the subsurface system installed as designed.

In an installation of drains, it is most important to backfill the envelope materials up to the topsoil as shown in Fig. 1. Many failures of the suystem are caused by less envelop materials[7].

References

1) The Ministry of Agriculture, Forestry and Fisheries (MAFF), Bureau of Agricultural Structure Improvement (BASI). (1979). Planning and Design Standards of Subsurface Drainage Project. 66p. (*in Japanese*)
2) MURASHIMA, K. and OGINO, Y. (1992). Comparative Study on Steady and Non-Steady State Formulae of Subsurface Drain Spacing -Design on Subsurface Drainage in Paddies (I)-. *Bull. Univ. Osaka Pref.*, **44**, 41-48.
3) MAFF, BASI. (1977). Planning and Design Standards of Agricultural Land Consolidation Project. 80p. (*in Japanese*)
4) OGINO, Y. and MURASHIMA, K. (1992). Conceptual Model of Large-Size Paddy Plot and Drainage System for Crop Diversification. *Jour. JSIDRE*, **60 (8)**, 21-26. (*in Japanese*)
5) OGINO, Y. and MURASHIMA, K. (1985). Theoretical Investigation for a Pipe Drainage Design -Design of Pipe Drainage for Multipurpose Paddy Fields (I)-. *Trans. JSIDRE*, **119**, 1-6. (*in Japanese*)
6) MURASHIMA, K. and OGINO, Y. (1985). Design of Pipe Drainage Using the Modification Coefficient (α) -Design of Pipe Drainage for Multipurpose Paddy Fields (III) -. *Trans. JSIDRE*, **119**, 13-20. (*in Japanese*)
7) MURASHIMA, K. and OGINO, Y. (1992). Operation and Maintenance of Subsurface drains for Diversified Cropping in Paddy. *Jour. JSIDRE*, **60 (1)**, 13-18. (*in Japanese*)