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Master of Workshop: Ms. Le Thi Thanh Hue (TLU) and Prof. K. Hiramatsu (Gifu U)

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Analysis of the strength of rock foundations for the safety of dams

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SUMMARY

In the present paper, the direct shear of rock masses was analyzed with a set of plaster model tests and a finite element analysis for the safety of dams. The plaster model tests simulated the direct shear tests which are actually carried out for in-situ rock masses in order to obtain the shear strength of dam foundations. Failures progressively occurred throughout the process of the tests. The cracking patterns depended upon the normal stress range; and therefore, the strength appeared in different ways according to the normal stress range. In the cases with macroscopic discontinuities, the strength of the discontinuities affected the shear strength much more than the strength of the material itself. Such strength was explained properly with the theoretical strength of the materials, including the weak planes. In the finite element analysis, the appearance and propagation of cracks were accurately obtained. As the next step, further progress in the stress analysis of direct shear is desired.

Introduction

Engineers who are engaged in the work of agricultural dams in Japan have recently encountered two new phenomena: the first is the appearance of damage to dams after their long-time use, and the second is severe damage to dams occurring after well-known huge earthquakes. Great efforts have of course been made to counteract these problems; however, there are many difficulties which cannot be treated sufficiently with the existing knowledge and techniques. Moreover, such difficulties are not always new. What is necessary for engineers now is not only to break new grounds, but also to make up for the problems which have remained unsolved for years. One of these problems is identifying the mechanisms of the direct shear of the materials, including rock masses.

The shear strength of the rock foundations of large dams was recognized after the famous Malpasset Dam Break in 1959. Since then, in-situ tests (International Society for Rock Mechanics (1974)) have been carried out at many dam sites to measure the shear strength of rock masses. Certainly, the resultant resistance has been measured and the results of such tests have been available for use in the design of dams.

However, the mechanisms of shear failure have not been explained, particularly according to the fundamental Mohr's theory. To understand the strength that appears in the shearing process, the process must be solved theoretically. This is also important for interpreting the cause of failures in actual cases.

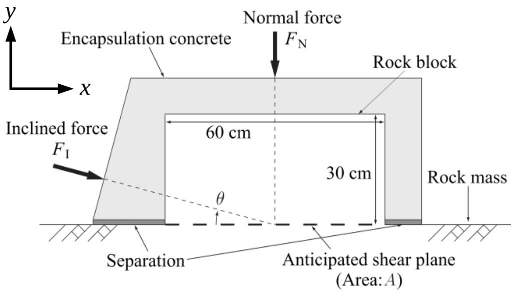
This paper reports the results of experiments which were carried out to clarify the failure mechanisms and the results of the numerical analysis simulating the experiments.

Problems

Figure 1 shows diagrams of the in-situ tests used to obtain the strength of rock foundations. Firstly, a block is shaped for loading, and an inclined force is imposed on it incrementally under the desired constant normal force. Then, the block is forced to separate from the rock foundation. The resultant maximum tangential force per unit area, namely, the shear stress, on the base of the block which is treated as the anticipated shear plane, is regarded as the shear strength of the rock mass under consideration.

A failure like that in the above-mentioned tests, where the shear of a particular plane is forced, is called direct shear. With such a failure, the shear strength is related to the normal force per unit area, namely, the normal stress, and the relation is treated as a linear function which is known as the famous Coulomb's criterion.

On the other hand, it is also widely known that the normal stress and the shear stress on a plane in an arbitrary direction are both represented on Mohr's circle. After a set of material tests, some circles at failure are obtained; their envelope represents a failure criterion of the material. Since the failure occurs as shear under compression, such an envelope should correspond to



Normal stress σ and shear stress τ are given as

$\sigma = (F_N + F_I \sin\theta) / A, \quad \tau = F_I \cos\theta / A$

on the anticipated shear plane. The maximum value for τ and the corresponding value for σ are used to determine the strength. Initial normal stress σ_n is given as

$\sigma_n = F_N / A$.

After performing the test several times, all of the results are arranged into Coulomb's criterion.

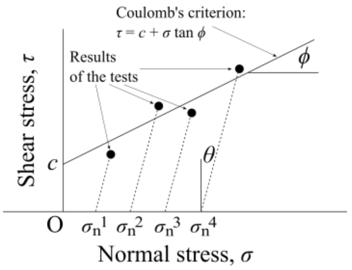


Fig. 1 Schematic diagram of the in-situ rock shear tests.

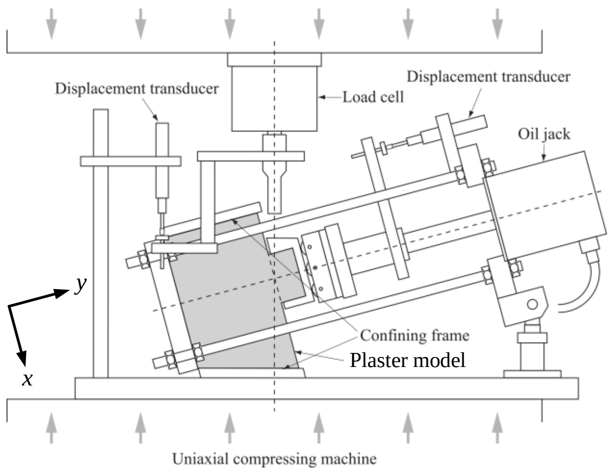
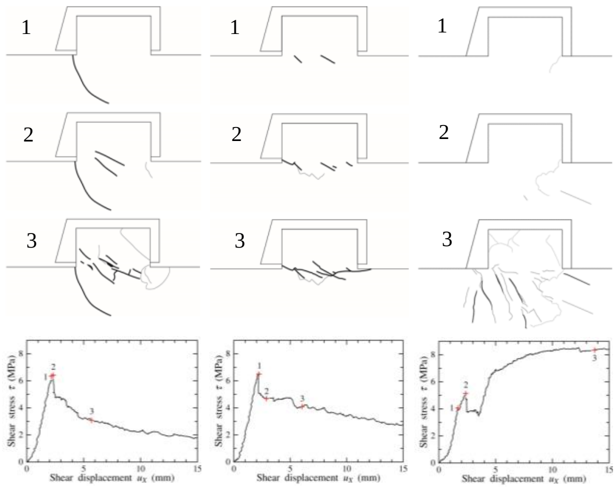


Fig. 2 Brief description of the set-up of the model tests. The plaster model is shown in gray. The block part to be sheared is set as being inclined.



σ_N = 0.625 MPa σ_N = 1.25 MPa σ_N = 7.5 MPa

(a) (b) (c)

Fig. 3 Crack sequences observed in three cases of the plaster model tests.

Coulomb's criterion of the material, if both of them are appropriate for the material under consideration. However, it is known that Mohr's envelopes for rocks and rock masses are curvilinear (Hoek (1983)).

In addition, Mohr's envelopes show failure planes in a particular direction at any failure. Such failure planes offer good interpretations in cases under simple pressure, like in triaxial tests, which are often performed for geomaterials. However, such good interpretations cannot be obtained in cases of direct shear where the shear of a particular plane is forced because the directions of the simple compressional stress, namely, principal stress, are unknown. In-situ rock shear tests are conducted under exactly such conditions.

Plaster Model Tests

To simulate the in-situ rock shear tests, a set of plaster model tests was carried out. Each plaster model had a block part, to be loaded, and was shaped into a flat form in order to observe cracks throughout the loading process. The models were set to be inclined and adjusted to the loading apparatuses in each case for actual operations (**Fig. 2**).

Figure 3 shows the crack sequences observed in three test cases. All of the cases were divided among these three typical cases. The first type, shown in **Fig. 3**(a), was obtained under lower normal stress. Firstly, a tensile crack initiated and propagated forming a curved path. Then, a few small cracks appeared at the center of the block base, marking the peak of the shear stress, namely, the shear strength, at the same time. Those small cracks were diagonal to the block base. The second type, shown in **Fig. 3**(b), was obtained under middle normal stress. The features of the cracking process and the appearance of strength are almost the same as those of the first type, except that the tensile crack did not appear for this type. The third type, shown in **Fig. 3**(c), was obtained under higher normal stress. The deep zone seemed to be highly

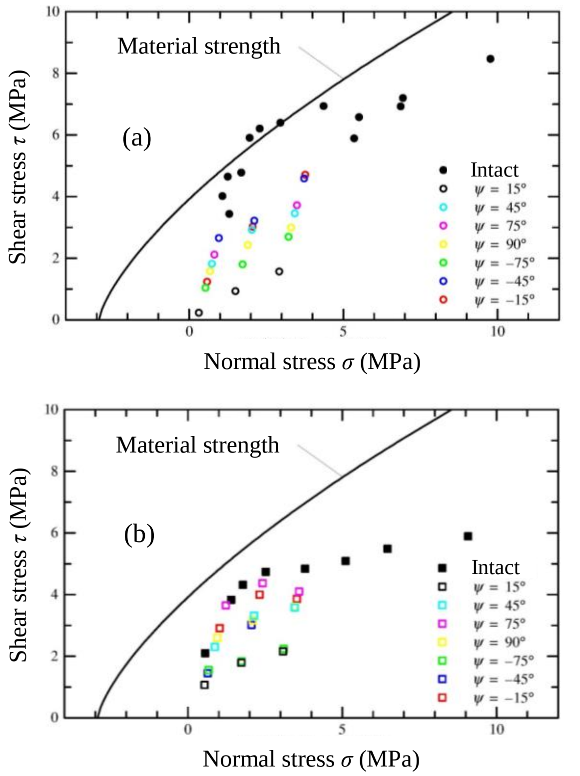


Fig. 4 Shear strength: (a) Results of the model tests; (b) Results of the computation.

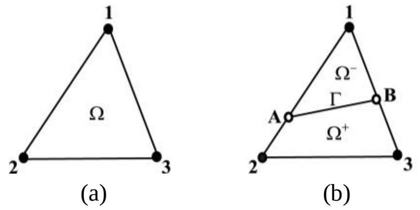


Fig. 5 Finite elements to simulate cracks: (a) An ordinary triangular element; (b) An enhanced element including an interface Γ (Bolzon (2001)).

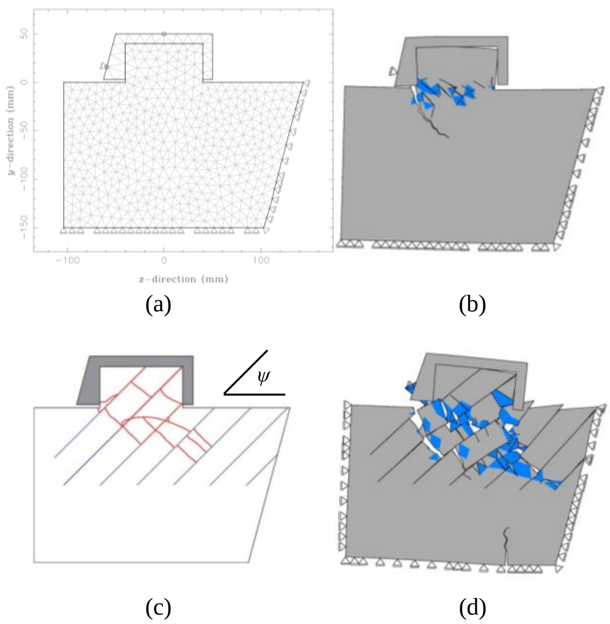


Fig. 6 Results of the finite element analysis: (a) Discretization for the intact model. The normal force was imposed on the node enclosed with a circle. The inclined force was imposed on the node marked with a circle and a triangle, as the incremental displacement; (b) Results for the intact model, σ_N = 0.625 MPa, whose results for the actual experiment are shown in **Fig. 3**(b); (c) Cracks on the actual layered model, ψ = 45°; (d) Results for the same case as (c).

compressed and widely crushed. Even after being severely crushed, the block seemed to be pressed and rubbed strongly against the foundation part.

Figure 4(a) shows the strength obtained in all the cases. The black points are for the ordinary intact models. The features of the distribution of those points are represented in the figure corresponding to the above-mentioned three types. Only the results of the second type belong to Mohr's envelope which was obtained by the other material tests as the material strength. The strength for the third type seems to correspond to that of the crushed material.

The second type was also reported in past research done on concrete structures (Kaneko et al. (1993)), and seems to be similar to the common damage found on actual structures or grounds. Tensile cracks, like those of the first type, are occasionally observed at actual dam sites. The results of the third type seem to be similar to actual crush zones.

The other points in color in **Fig. 4**(a) show the results for the models which had layered discontinuities, like those shown in **Fig. 6**(c). The strength of the discontinuities affected the shear strength much more than the strength of the material itself. Such strength can be properly explained by the theoretical strength of the materials, including the weak planes (Jaeger and Cook (1976)).

Numerical Analysis

As mentioned above, the fundamental theory of the failure of rocks and rock masses is essentially related to the stress in the materials. However, it is exceedingly difficult to obtain such stress values for actual materials. Therefore, another stress analysis is necessary to explain the failure mechanisms in the above-mentioned experiments.

In this study, an analysis of the crack initiation and propagation by the finite element method is performed. At present, the analysis cannot be completed satisfactorily; however, the numerical computation is able to realize a good simulation of the crack initiation and propagation in the actual experiments.

To simulate the cracks, enhanced finite elements, each of which includes an interface (Bolzon (2001)), were adopted, as seen in **Fig. 5**. Initially, the incremental computation was started with ordinary finite elements for every case, and the elements whose stress values reached the material strength were replaced with enhanced elements. The simple contact analysis was done on the interfaces in the enhanced elements, and also on the outer boundary and the initial discontinuities if given. **Figure 6**(a) presents a discretized model of the intact plaster model.

Figure 6(b) shows one of the results of the finite element analysis for the plaster model. The crack distribution is similar to the corresponding actual results shown in **Fig. 4**. Furthermore, **Fig. 6**(d) shows one of the results for the layered model and corresponds to the actual results shown in **Fig. 6**(c). They are also similar to each other.

Figure 4(b) shows the strength obtained through the finite element analysis. Compared with **Fig. 4**(a), the strength of the intact models was entirely computed as the lower value; however, the shape of the row of points is similar to that in **Fig. 4**(a). On the other hand, the strength for the layered models seems to be similar to that in **Fig. 4**(a). It is desirable that details on the procedure for the crack appearance and crushed material be improved. Thereafter, as the next step, the stress analysis itself should be enhanced by an examination of the obtained stress values.

Conclusions

From the results of plaster model tests, which simulate the direct shear tests for in-situ rock masses, the following conclusions can be drawn.

- Failures occurred progressively throughout the process of the tests, and it was found that the cracking patterns depended upon the normal stress range. The strength appeared in different ways according to the normal stress range.
- The strength of the discontinuities affected the shear strength much more than the strength of the material itself. Such strength was accurately explained by the theoretical strength of the materials, including the weak planes.

Furthermore, a finite element analysis for the appearance of cracks and their propagation was developed for the simulation of the plaster model tests. As a result, the appearance of cracks and their propagation, as well as the stress relaxation caused by them, were obtained correctly. In the next step, further progress is needed for a stress analysis of the direct shear.

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DISCHARGED FLOW FROM THE EFFLUENCES OF A THERMAL POWER PLANT

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ABSTRACT

Prediction of the transport of effluent discharged from the outfalls of thermal power plants to coastal waters is an important task in coastal environment and related areas, not only to operation and design of the plant but also to living systems due to changes in water temperature. In this study, the hydrodynamic characteristics of water flow and heat transport in a tidal flat of Vietnam were studied using a numerical hydrodynamic heat transport model. The model was calibrated with observed data and it well reproduced water level, salinity and seawater temperature. We found that the tidal currents and winds play an important role in the dynamics of water temperature in the tidal flat area.

INTRODUCTION

This study was carried out for effluents of the Cam Pha thermal (coal-fired) power station, which is located on the shore of Bai Tu Long Bay, northern Vietnam (**Fig. 1**). The power station consists of three plants, two existing ones (CP1, CP2 with outfalls O1, O2 respectively) and one (CP3, with influent I3 and outfall O3) to be constructed. The plants will be using seawater from the bay for cooling purposes. Based on thermal specifications for these plants, there is a need to conduct a research on how thermal effluents affect the ambient water on the bay and on the influent of CP3 in order to fix its location. There is a number of operating scenarios; however, we here considered only the case when all plants are working together.

METHOD AND MODEL SETTING

The transport equation for salinity or temperature is of the form:

$$\frac{1}{\rho}\frac{\partial(\rho S)}{\partial t} = \frac{\partial}{\partial x_j}\left(D_i \frac{\partial S}{\partial x_j}\right) + SS \qquad (1)$$

in which S – is the concentration of salinity or temperature; D_i - the dispersion coefficient in the i-direction, which is dependent on grid size and the computing time step, and SS - the source/sink term. The dispersion of salinity and temperature is assumed to be proportional to the effective eddy viscosity with the factor of proportionality being $1/\sigma_T$, the dispersion factor; σ_T is the Prandtl/Schmidt number. Values of σ_T greater than one imply that diffusive transport is weaker for salt/temperature than for momentum.

In this study, MIKE 3 model (DHI, 2003), a modeling tool, was newly set up for the study area. The model consists of two main modules: a hydrodynamic module and an advection-dispersion module. The bathymetry data were constructed based on a local map with some modification to the shoreline because of land reclamation activities taking place in the area.

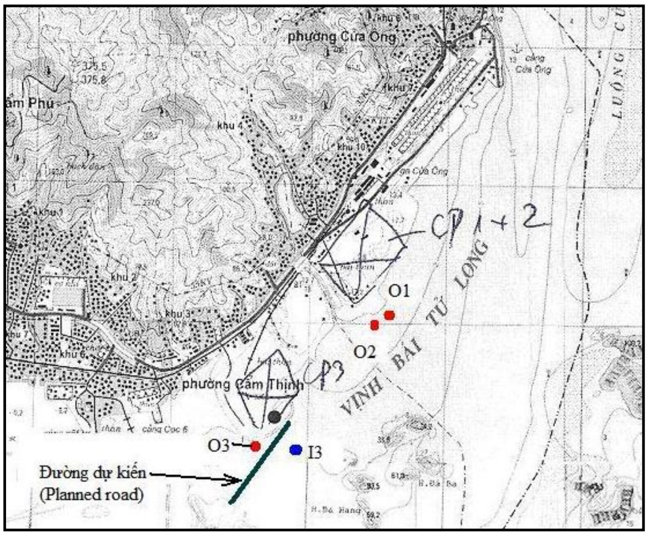

Fig. 1 Map showing location of the study area

A 3-D finite-difference grid was developed to adequately discretize the model domain. One of the objectives for grid development is to sufficiently discretize the model domain while minimizing the total number of model cells (Don et al., 2007). The area of interest is approximately 7.0 x 6.0 km^2 and is covered with a 3-D grid. The sizes of each cell are Δx = 50 m, Δy = 50 m. The vertical direction, z, is divided into 5 layers with Δz = 1 m interval. The 2-D grid contains 17324 cells: n_x = 142, n_y = 122, where n_i denotes the number of cells in the i direction.

The information on u_i at each time step is provided by the hydrodynamic module and is assumed constant during each time integration of the advection dispersion equation. The advection-dispersion equation is solved at each time step following the time integration of the hydrodynamic equations. The turbulence is modeled in terms of an eddy viscosity and a bed shear stress. The eddy viscosity can dynamically be specified by means of the mixed *k-ε/Smagorinsky* formulation with a standard *k-ε* model in the vertical and a Smagorinsky formulation in the horizontal (Don et al., 2007; MIKE3, 2001).

RESULTS AND DISCUSSION

Calibration of the model focusing on choosing parameters was achieved through trial and error for water level, salinity and water temperature. **Figure 2** plots the computed sea water levels (lines) against the observed ones (dots). The simulated tidal levels have a good agreement with the observed ones. The errors (mean absolute error, relative mean square error, mean error) are approximately 1% of the water depth at this location, indicating that a good estimation has been obtained.

Figure 3 shows a comparison of computed salinity and the observed one. Overall, the computed salinity follows well the observed data. At low tides, salinity levels were over estimated due to the effects of air and water tempera-

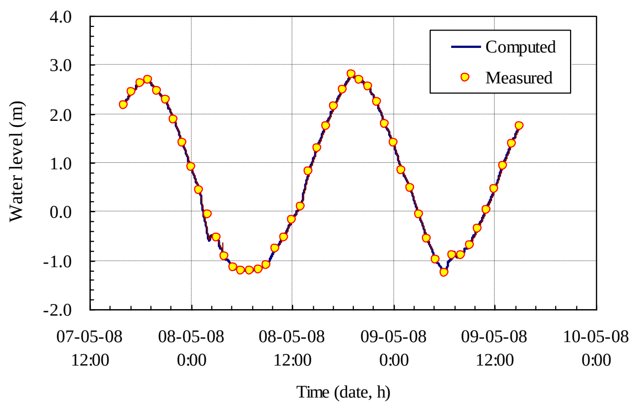

Fig. 2 Variation of computed seawater levels (lines) vs. the observed ones (dots)

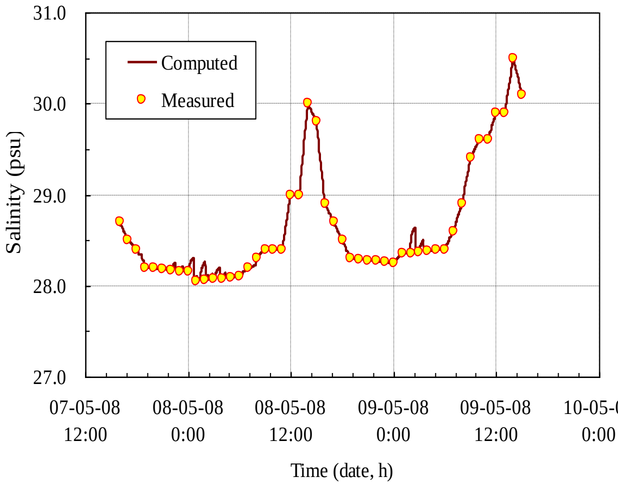

Fig. 3 Comparison of computed salinity (lines) and observed one (dots)

ture. Extremely low surface salinity occurred during web tides. Calibration of the model for water temperature however was not done because of there were no observed data as long as the plant is in operating conditions. From the above results, we newly found that the thermal plants will contribute small impacts to the seawater levels and salinity concentrations in the local bay.

Effect of winds

In the bay, winds are significant, which cause large variations in the water properties by advecting the waters on- and offshore, and strongly influence the direction of flow circulation. Therefore winds contribute great effects to the distribution of seawater temperature. The optimal conditions for input of this coastal water are NE and SW winds, which are driving forces for current waters to run up and along the shoreline.

The wind friction originates from the vertical shear term assuming a balance between the wind shear and the water shear at the surface:

$$\frac{\tau}{\rho} = \nu_T \frac{\partial u}{\partial z} = \frac{\rho_{air}}{\rho} C_w W^2 \tag{2}$$

where ρ_{air} is the density of air, W - the wind speed at 10 m above the sea surface, C_W - the wind drag (friction) coefficient = 0.0026 for moderate and strong winds, ρ is the density of water.

The effects of northeastern (NE) wind and southwestern (SW) winds to seawater temperature at I3 are plotted in **Fig.**

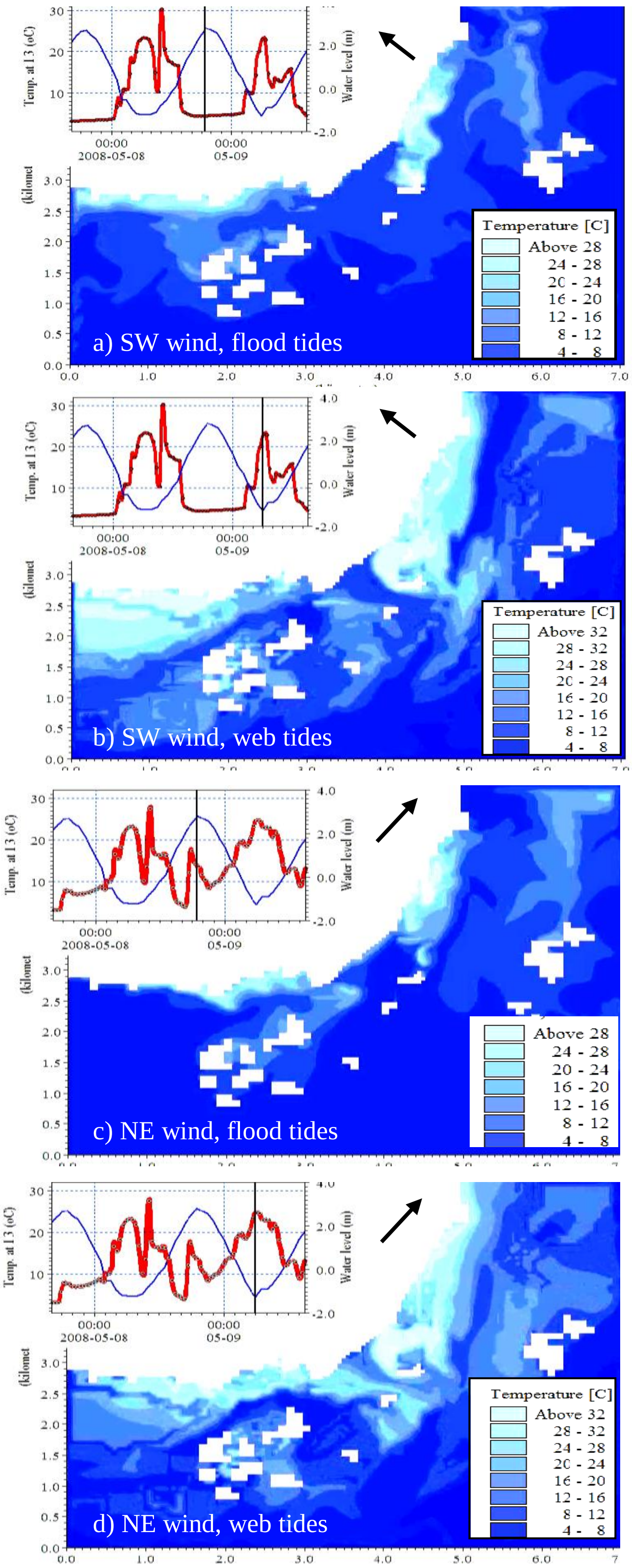

Fig. 4 Distribution of temperature in seawater in response to wind directions

4. When the southwestern wind is dominant, the effluents of O2+O1 will also make water temperature at the influent I3 (**Fig. 4a, b**) to increase by 15%. The "Thermal Flume and Mixing Zone" can be determined based on the size and spatial distribution of the thermal plume resulting from the outfall discharges. The size and spatial distribution of the mixing zone tend to vary considerably from time to time.

When the northeastern wind is dominant, the effluents of O2+O1 will induce more change in water temperature at the influent I3 (**Fig. 4c, d**). The cooling water flume from CP2+CP1 will tend to move to the southwestern part along the shore. This will induce water temperature at I3 to increase up to 35% , especially at low tides (Don, 2008).

CONCLUSIONS

In this study, the effects of thermal effluents in the ambient water on the bay and on the influent I3 were addressed using a numerical model that simulates the hydrodynamics of water flow and the dispersion-advection of density currents. We found that winds play an important role in spatial distribution of the water cooling flumes. SW winds will induce a higher water temperature in comparing to NE winds. The location of the effluent I3 (300m from O3) should be chosen so as to be less thermal influence from the effluent sources, while not being separated from the plant. However, it is recommended that such a location of I3 should be selected based on a more detail study in order to minimize the construction cost while also increasing the heat dispersion efficiency.

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A study for Water Stops Installed Outside of Galleries on Deformable Ground

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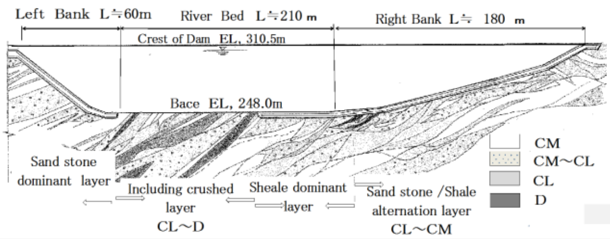
Abstract

In Japan, it is defined to construct a concrete gallery when construct a fill dam with a height of 30 meters or more. However, in softer foundation ground, deformation of the foundation may occur. At the joints of the galleries, deformation of the foundation ground concentrates on it and the risk of hydraulic destruction by Infiltration water around the joint will increases. Here, I will introduce a water stop made by new ideas, installed on the outer circumference of the gallery, developed to prevent Infiltration water.

Ⅰ Introduction

The foundation ground of the dam site is the Mesozoic sedimentary rock. The height of dam is 62.5 m. And sectional view of the foundation ground of the dam and the rock classification of the ground are shown in Figure 1. This rock classification was applied to this dam by arranging the standard rock classification used in Japan. On the left bank side of the riverbed part of this dam site, there is a large deformability part fractured by the fault. The maximum width was 90 meters.



Fig−1 Rock classification longitudinal section

The deformation coefficient of the foundation ground corresponding to this rock classification is as shown in

Table 1 Deformation coefficient of rock

geological name	deformation coefficient (kg/cm2)		
	rock classification	range	design number
Shimanto layer	D	260～920	610
	CL	1,100～4,800	2,400
	CL～CM	2,000～13,300	5,700
	CM以上	5,000～21,800	12,700

The deformation of foundation ground due to embankment weight was analyzed by finite element method.[1] The analysis model is shown in Fig.2. The analysis method adds embankment weights divided into nine stages.[2]

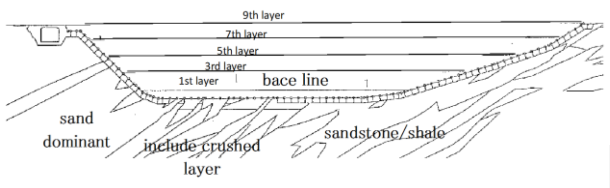


Fig 2 Deformation analysis model

Figure 3 shows the deformation of the foundation ground due to the analysis results. As a result, a subsidence as much as 30 cm was predicted on the left bank side.

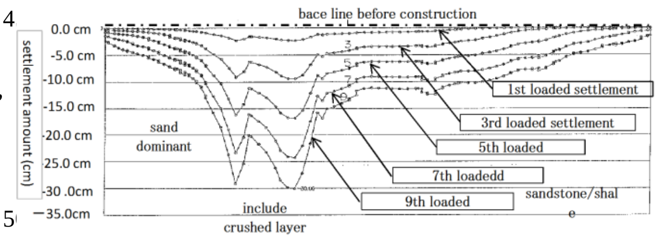


Fig 3 Result of deformation analysis

From this result, the establishment policy of the gallery was decided as follows. ① It was judged that the amount of deformation was large on the left bank riverbed. As a result, it was judged that it was difficult to install gallery on the dam axis center line. Therefore, as shown in Fig. 4, 5 the audit aisle arrangement of the riverbed was placed on the downstream side of the water impermeable zone.

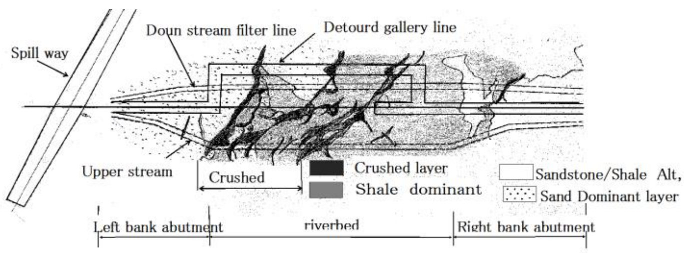


Fig. 4 riverbed department gallery layout map

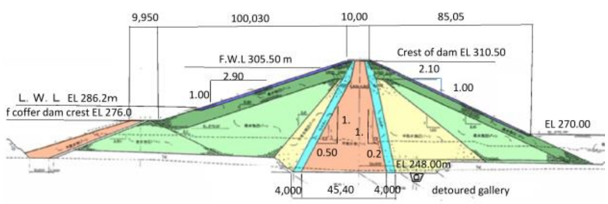
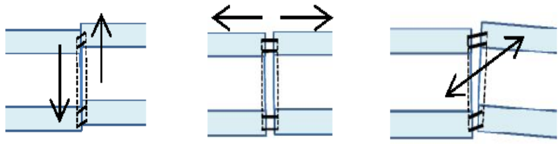


Fig. 5 Standard sectional of dam body

Ⅱ Problem of gallery joint caused by deformation of foundation ground

Gallery have been established since the 1980s for safety management and future repair. However, if the deformation of the foundation ground is large, the ground deformation concentrates on the joint of the gallery. As shown in Fig. 6, the deformation shape of the joint is openings, gaps, and its composite shape.



fig－6 Joint deformation overview

In this dam, FEM analysis including joint elements was performed to estimate the gallery joint deformation. As a result of the analysis, it became clear that the gallery deforms greatly toward the deformable ground. The analysis result is shown in Fig-7. At the lower left abut, it was predicted that a maximum opening of 10 mm would occur outside the gallery joint. Also, opening of several mm was predicted for several joints.

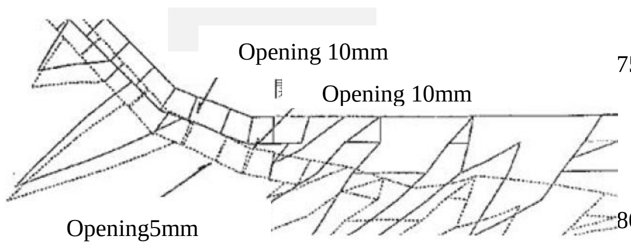


Fig. 7 Diagram of gallery joint deformation analysis

Ⅲ Gallery joints structures

Figure-7 shows a typical gallery joint structure[3]Various ideas are made at the gallery joint for the purpose of preventing water leakage towards inside of the gallery and dealing with local deformation etc.

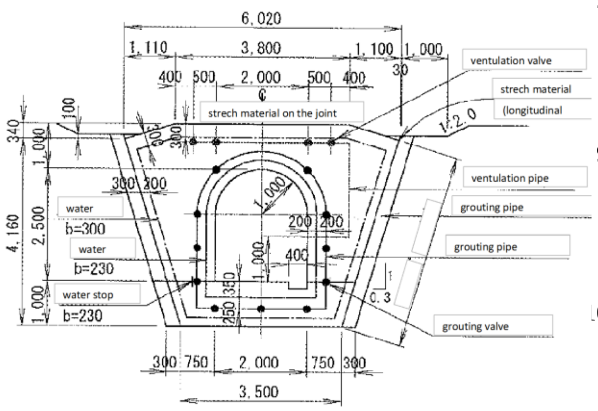


Fig. 8 Diagram of gallery joint detail

① water stop; double water stop structure inside and outside. Strong against high pressure water pressure.

② Joint grouting: After completion of the embankment construction works, mortar grouting is performed between double water stop preventing the water stop deformation due to water pressure.

However, when the deformation becomes large, in the portion indicated by the arrow shown in Fig. 9, a gap is generated outside the outer water stop, and it is impossible to deal with it from the inside of gallery. Then it will result in extremely dangerous situation in water shielding materials against upstream to downstream infiltration.

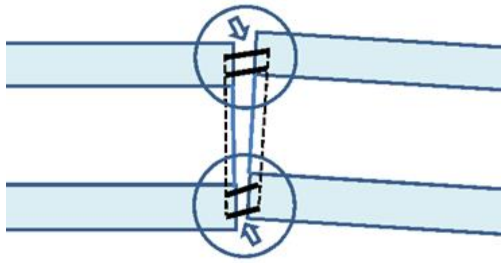


Fig. 9 Gap formed during joint deformation

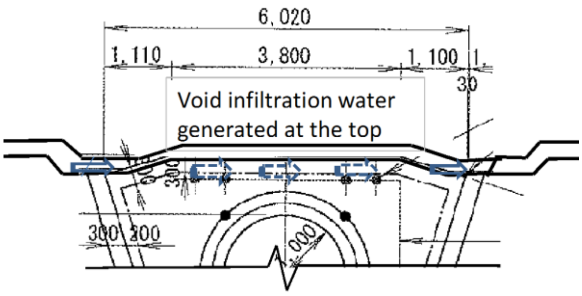


Fig.10 Opening formed between joints deformation on the top of the gallery joint

In the gallery bottom part, after the embankment construction, the main curtain grout and the water impermeable grout of the auxiliary curtain grout are constructed. However, if the joint dislocation or opening due to the base deformation occurred after the embankment construction work, voids occurred at the top edge and the foundation ground contact surface as shown in Fig-10. As a result, there is a greater risk of progressive destruction due to soil particle flow through the void made by opening deformation. In this way, the water-stop of the fill dam gallery constructed on great deformable foundation ground, is insufficient to deal with inundation only to the inside.

1. Development of water stop installed Outside of the gallery.

Against the above problem, we have developed water stop structure by new ideas as followings.

① It is necessary to have a new idea of a water stops that wraps the released space caused by displacement and opening .

②In addition, a buffering backup rubber (B = 500 t = 25 mm) for backing up the plastic deformation of the main water stops, was arranged outside of water stop.

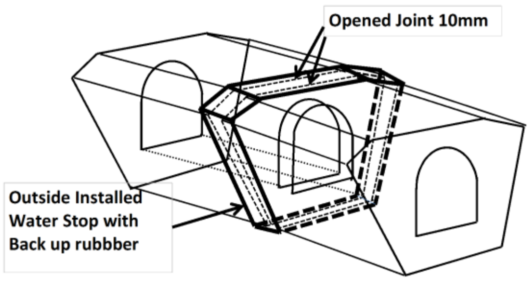


Fig. 11 Explanation of outside water stop structure

③ As shown in Fig. 12, construction was carried out with primary concrete preceded by side walls and bottom so as to absorb irregularities of the rock surface. The backup rubber and the outer water stop were set there, and the main body concrete was constructed.

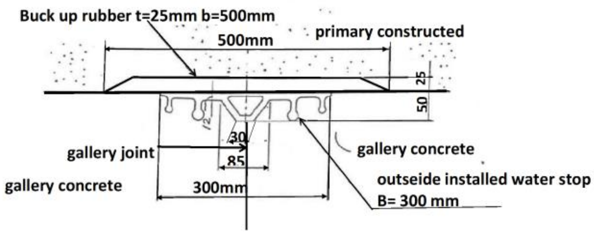


Fig. 12 Explanation of outside water stop detail

Since the outer water stop and the backup rubber are of two kinds of rubber structures, the connection surface was bonded with asphalt urethane rubber that is softer and slippery than these twe materials. These performances are as shown in Table 2.[4)]

Table 2 Outer Water Stop Material Performance

materia	back up rubber	asphalt uretan rubber	outline settled water stop	remarks
hardness	50	40	60-70	degree
expantion ratio	>350	420	>350	(%)
tensile stlength	>150	22	>150	kg／cm2
adhision strength		8		kg／cm2

As a result, the gallery joint structure shown in Fig. 13 was adopted for the five joints at left side bank with large displacement.

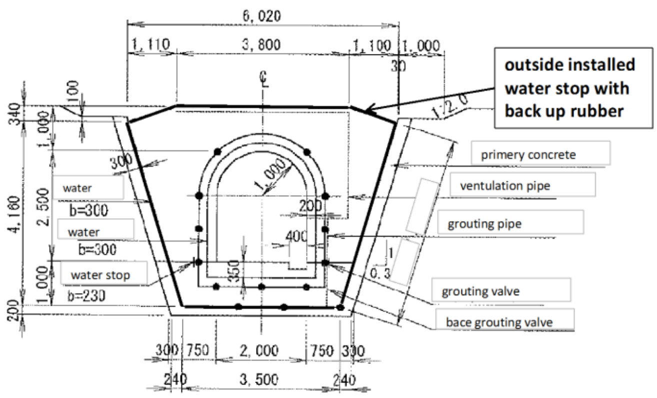


Fig.13 gallery Joint section with new type water stop

Ⅳ Performance check test

1. Pressure test

Performance confirmation against water pressure after completion of dam construction was carried out with the equipment shown in Fig.14。In the test, firstly, two pieces of the concrete device has been set in the state of a gap 45 mm, and being set in the state of opening 15 mm. Next, an assumed water pressure of 6 kg / cm 2 was applied from the inside, and it was confirmed that there was no decrease in internal pressure during the test period.

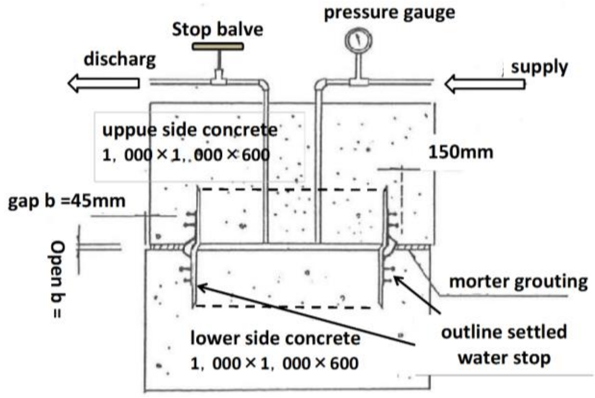


Fig.14 Outline of pressure test

2. Construction confirmation test

The construction site of this joint type is constructed at the inclined slope part. On the other hand, the water stop has many projections, and when vibrator work performed excessively the air separated from the concrete is likely to accumulate. We have already confirmed this in the indoor casting test. Then we conducted onsite tests so that construction could be carried out safely. As for the test the same scale of the gallery, two pieces of a 1 m section concrete block including a joint was constructed. In the field test, concrete was casted from the lower part. And in the construction of the top part, stopping the vibrator work, the water stop was turned up toward the center part and the separated air was eliminated. After that we added additional concrete, and finally we confirmed that we can push the water stop into the concrete by manual strike. Photo 1 shows that, after the test, the concrete block was cut with a concrete cutter, and it was confirmed that the protrusion of the water stop was surely being put into the concrete without air.

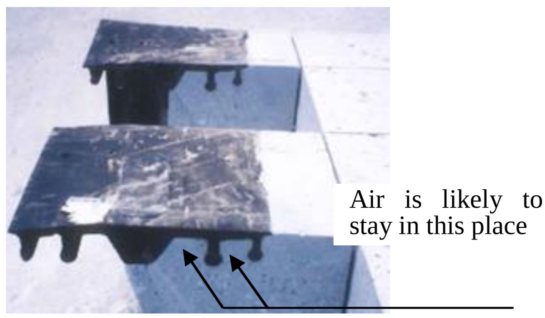


Photo 1 Casting test Specimen after cutting

Ⅴ Construction works and behavior monitoring

Measurement of gallery joint behavior, and observation against infiltration water along gallery joint were planned as follows. The opening and the gap of the joint of the gallery were monitored from the inside of gallery by many joint meter. On the top of gallery, pore pressure gauge was placed at upstream and downstream to observe infiltration water along the gallery joint.

Ⅵ Monitoring result

At the joints, where the deformation prediction has been done, predicted opening, and gap were occurred. The maximum opening was 7 mm in the width confirmed from inside of gallery. From this, it is assumed that at the outer circumference, the opening of the gallery is assumed to be 10 mm. And it was judged to be the same as the initial prediction. Water storage was started after the dam construction was completed, but in the internal observation, no leakage trace, nor free lime the joint was confirmed. In addition, no abnormality was found in the pore pressure gauge installed at the upstream and downstream of the top of the audit corridor. From these observation results, it was judged that the water stops installed outside of gallery is functioning normally.

About 10 years have passed since then, no abnormality is recognized. From this result, it is judged that the newly developed water stop contributes to the hydraulic safety of gallery joint of the dam constructed on the deformable ground.

Reference

1) Japanese Ministry of agriculture forestry fisheries, Design standards of Fill Dam PⅡ-149 ,

2) Same as above PⅡ-150 イ FEM analysis including gallery by joint elements.

3) Same as above PⅡ-150(4) Joint instruments and stop water treatment

4) ASTM D412 Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers─Tension

A Study on the Operation Procedure of South Nghe An Hydraulic System for Irrigation under Water Shortage Conditions

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SUMMARY

The South Nghe An hydraulic system has been upgraded with a new Nam Dan sluice to replace the old one to meet the irrigation requirement for 22,500 ha with the probability of 85%. The water is taken from the Lam River through Nam Dan sluice. However, in recent years, due to the effects of climate change and human activities, the water levels in Lam River tends to decrease considerably. This greatly affects the ability of taking irrigation water for agriculture.

In this paper, MIKE 11 model was applied to compute the abilities of taking water to the system and the hydraulic regime in the system with 12 water shortage scenarios (different flow regimes with minimum water levels of the Lam River at the upstream of the sluice below design water level). The computed results show that for some cases, both new Nam Dan sluice and the old one should be operated together in order to increase water taking ability to the system. Different operation options were computed corresponding to the scenarios to determine the appropriate operating procedures to increase the amount of water taken through the sluices to improve the irrigation water supply under water shortage conditions in the study area.

Introduction

South Nghe An Hydraulic System has one main sluice, the Nam Dan Sluice (old), built in 1936-1939 to take water from the Lam River for water supply and navigation in districts Nam Dan, Hung Nguyen, Nghi Loc, Vinh and Cua Lo town. The sluice has been working for quite long time (more than 70 years). Moreover, recently the cultivated area increases (from 18,000 ha to 22,500 ha) and the water requirement expanded for other sectors such as aquaculture and industry... So that the capacity of the old sluice could not be satisfied the water requirement of the region. Therefore, in 2008, a new Nam Dan sluice project was approved to replace the old one.

The new Nam Dan sluice was designed to supply water for the South Nghe An area. The designed water level of + 0.833m was calculated from water level data series (1960-2000) to ensure to supply water with frequency of 85%. However, currently hydrological data at Nam Dan station from 1995 to 2014 show that the water level of Lam River tends to decrease significantly. Fig. 1 shows the average water level for the years from 1995 to 2014. Fig. 2 shows the monthly minimum water levels in the dry season. The observed data show that from 2008 to 2014 the minimum water level decreased significantly, from + 50cm down to -20cm. This trend considerably

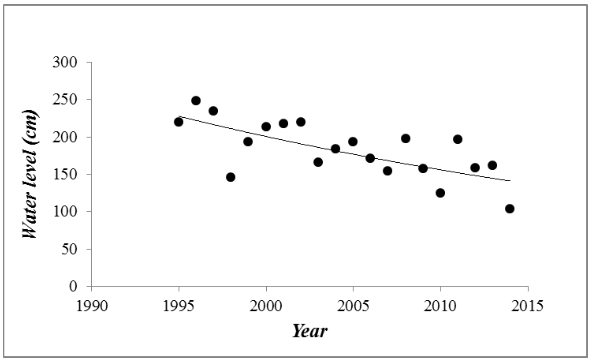

Fig.1 Average water level of the years from 1995-2014

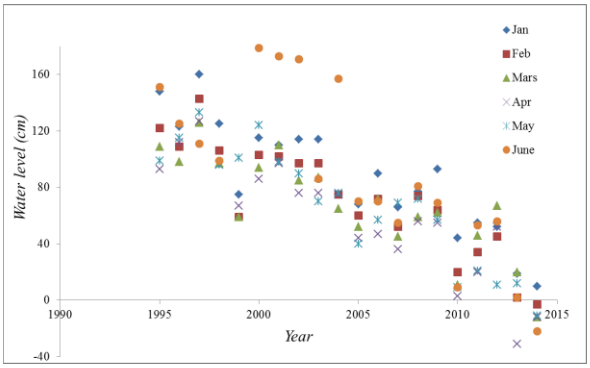

Fig. 2 Monthly minimum water level of the years from 1995-2014 in dry season

affects the water supply to the South Nghe An system.

Therefore, under the water shortage conditions in order to increase the capacity of taking water from the Lam River to the system, the old Nam Dan sluice is proposed to be operated together with the new one in case the new one cannot take enough water to the system.

In this paper, several scenarios of water shortages (when the upstream water level is smaller than the designed water level) with different operation options in the dry season (Winter-Spring crop) were simulated. From that, appropriate operations are recommended to increase the capacity of taking water to the irrigation system, in order to reduce water shortage situation in the region.

Method

In order to solve this problem, Mike11 model (DHI, 2007) was applied to calculate the hydraulic regime of Nam Nghe An irrigation system. The MIKE 11 model developed by DHI Water & Environment is a one-dimensional hydrodynamics, water quality and sediment transport model in river systems, canals with structures (dams, gates, pumps ...) reservoir and canal ans structure operations... This model is a very good tool to help decision makers for design, management and operation of hydraulic systems.

Hydraulic scheme of South Nghe An system

The South Nghe An irrigation system has the following head works: old Nam Dan and new Nam Dan sluices at the upstream (taking water from the Lam River) and Nghi Quang, Ben Thuy drainage sluices at downstream of Cam River and Vinh River. The old Nam Dan sluice has 4 gates with the width of b = 2.0m each and a navigation lock with the width of B = 5.0m, the inverts of the gates and lock is -1,30m. The new Nam Dan sluice is designed with 3 gates, with the width of b = 5m each and a navigation lock with the width of B = 7.0m, the inverts of the gates and lock is -1,40m. The system consists of 4 main canals (Thap, Gai, Cam and Khe Cai) and grade 1 canals with the length of 130 km. Inside the system, irrigation procedure is operated by pumping stations. Water is pumped from the main canals and grade 1 canals. The geometry data and the operation data of pumping stations of the system are provided by the South Nghe An Irrigation and Drainage Company. Fig. 3 illustrates the hydraulic scheme of South Nghe An Nam in Mike 11.

Upstream boundary is the water level Z (t) of Lam River at the upstream of the old and new Nam Dan sluice gates.

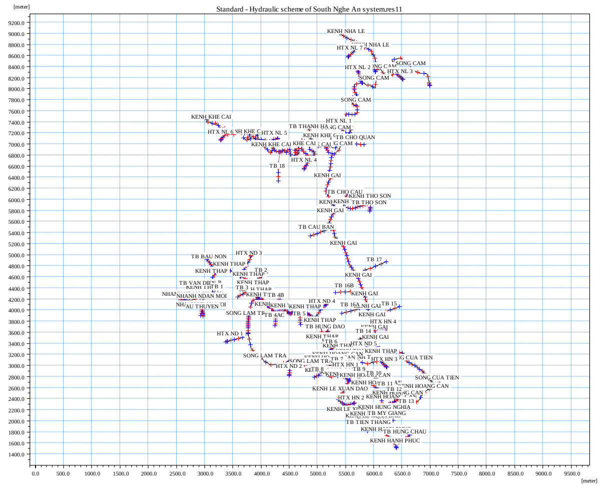

Fig.3 Hydraulic scheme of South Nghe An system

In dry season, Nghi Quang, Ben Thuy drainage sluices are closed (South Nghe An Irrigation Drainage Company, 2008). Therefore, for this study the downstream boundaries are closed boundaries. Other boundaries are internal boundaries at pumping stations in the system.

Model calibration and verification

The model was calibrated by adjusting roughness coefficients using observed data at some locations on the system from April 14, 2015 to April 21, 2015. Figure 4 shows that the measured and computed water levels at the upstream of the 4A pumping station are quite closed to each other. The difference between the computed and measured water levels ranges from 0 to 7cm. The Nash-Sutcliffe coefficient is 96%.

The calibrated parameter set is verified for the period 6th June 2015 to 16th June 2015. Fig. 5 shows the observed

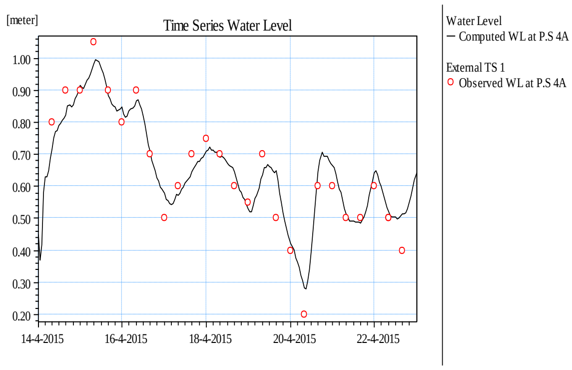

Fig.4 Computed and observed water levels at the 4A pumping station (model calibration)

and computed water level at the 4A pumping station. From the figure it can be seen that the computed water levels are closed to the observed ones with The Nash-Sutcliffe coefficient of 0.78.

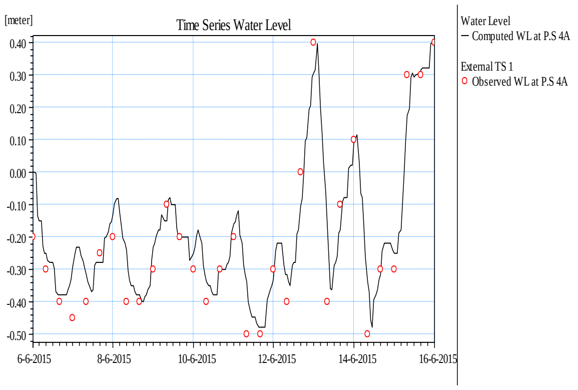

Fig.5 Computed and observed water levels at the 4A pumping station (model verification)

Scenarios and operation options

Operation procedure is considered under different conditions of water shortage. 12 scenarios were computed corresponding to the stage hydrographs of the Lam River at the location of the new Nam Dan sluice with the lowest water levels ≤ + 0.83m (design water level) (see Table 1).

For each scenario, there are the following operation options:

- Option 1 (O1): only the new Nam Dan sluice gates are opened (completely or partly open);
- Option 2 (O2): the new Nam Dan sluice gates and navigation lock are opened (applied when option 1 is not satisfied);
- Option 3 (O3): the new Nam Dan sluice gates and navigation lock are opened and combined with the old Nam Dan sluice gates (applied when option 2 is not satisfied);
- Option 4 (O4): Same as option 3 with a combination of alternating irrigation inside the system (applied when option 3 is not satisfied).

Table 1 Water shortage scenarios (water level at upstream of the new Nam Dan sluice)

Scenario	S1	S2	S3	S4	S5	S6
U/S WL (m)	0.83	0.73	0.63	0.53	0.43	0.33
Scenario	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
U/S WL (m)	0.23	0.13	0.03	-0.07	-0.17	-0.27

It is noted that Nam Dan sluice gate(s) are operated to take water to the system and Nam Dan gates are closed when water levels of the Lam River was lower than the water level of the Thap Canal (downstream of the gates).

Simulation time:

According to the local cultivation, there are 3 main crops in the area (winter-spring crop, summer-autumn crop and winter crop). Of which, winter-spring crop has most difficulties in terms of water source because it is in the dry season. Therefore, in this study, the simulation duration is the dry season of the winter-spring crop (December-May).

Result and Discussions

In the South Nghe An system, water is taken gravitationally from the Lam River through the Nam Dan sluice(s). Lam River's water level is affected by tides, especially in the dry season. The data show that the level fluctuation in water level from 45 cm to 160 cm, particularly, in dry season, the influence of the tide significantly affects to the ability of taking water through the Nam Dan sluices to the system.

Figure 6 shows the simulated stage hydrograph at some locations in the system corresponding to the scenario 1 and the operation option 1. The figure shows that in winter-spring crop duration, the water levels from in January (3rd - 23rd January) in the system are very low because this is highest water demand for land preparation and sowing. Therefore, this duration is most difficult time to ensure water requirement and is chosen to discuss for operation options in this paper.

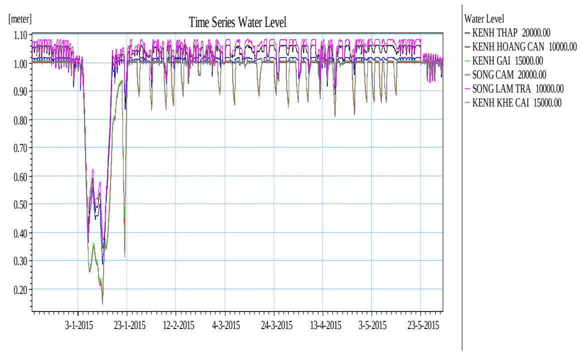

Fig.6 Stage hydrograph at some locations in the system (S1 - O1)

Table 2 shows the total water requirement of the system and the total water volume can be taken through the Nam Dan sluices under different scenarios and options. Total water demand for the period from 3/1 to 23/1 is 43.977 mil. m^3(Water resources engineering institute , 2017). The results show that though the discharge requirement of the system in this duration is not properly satisfied but for Scenarios S1 to S5, the new Nam Dan sluice can get enough the total volume to the system. For scenarios 6 and 7, it needs to open also the navigation lock to increase the capacity of taking water.

Table 2 The total volume of water taking through Nam Dan sluices with different scenarios and options in January (mil. m3)

	S1 - S5	S6	S7	S8
O 1	43.977	43.299	41.606	41.132
O 2	43.977	43.977	43.977	41.194
O 3	43.977	43.977	43.977	43.977
O 4	43.977	43.977	43.977	43.977
	S9	S10	S11	S12
O 1	39.482	37.591	35.519	33.085
O 2	40.718	39.878	38.618	34.518
O 3	43.063	41.216	39.229	34.894
O 4	43.958	42.484	39.978	35.408

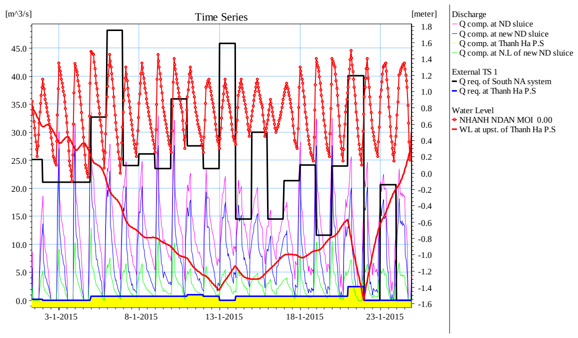

Fig.7 Computed stage and discharge hydrograph and discharge requirment of the system and Thanh Ha pumping station (S8 – O3)

For Scenario 8, when the water level in Lam River is very low, if only the new Nam Dan sluice gates and lock are operated, the total water volume cannot take enough water for this duration. Therefore, it is necessary to combine the old one to increase the amount of water taken into the system (operation options O3). The results show that for this case when two sluices operated together the total water volume taken to the system satisfied the water requirement for this duration. Fig. 7 illustrates the discharges flow to the system when both the sluices gates and locks are operated.

From Table 2, it also can be seen that for scenarios S9 to S12, even both sluices and navigation locks are operated, the total water volume is not satisfied the water requirement. And for these conditions, alternating irrigation method should be applied to reduce the effect of water shortage and regulate the requirement discharges.

Conclusion

In this paper, MIKE 11 model was applied to study operation procedures for Nam Nghe An irrigation system in water shortage conditions (water levels are lower than designed water level). 12 scenarios with different operating options were considered. The computed results show that, in order to improve the ability of taking water to the system in water shortage conditions in many cases it is necessary to operate both Nam Dan sluices combined with alternating irrigation method.

It is also recommended that in very serious water shortage conditions (for example for scenarios S9 - S12), besides applying the proposed operation procedure, some other solutions should be considered such as applying modern irrigation technology to save water, regularly maintaining the hydraulic system (canals, structures, pumping stations…), applying new crops with high drought tolerance, changing crop pattern.

Acknowledgement

All the data related to structures, canals, observed data and gates and pumping station operation data of South Nghe An hydraulic system were provided by the South Nghe An Irrigation Drainage Company. The authors gratefully acknowledge.

Reference

1) DHI (2007). MIKE11 software - A modeling system for rivers and channels
2) South Nghe An Irrigation Drainage Company (2008). Decision on supplementary operation procedures for the headwork sluices Nam Dan, Ben Thuy, Nghi Quang.
3) Vietnam standards (TCVN 8412:2010). Hydraulic structures – Guideline for setting operation procedure.
4) Water Resource Engineering Institute (2017), Water requirement computation for Nam Nghe An region.

How the water distribution pattern to paddy plots will change by an adjustment of weir height - trial simulation -

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SUMMARY

We need to satisfy three different purpose, maintaining productivity, conserving water quality, and reducing greenhouse emission simultaneously. Regulating water management is one of the promising way to achieve this goal. Thus, the objective of our research is to evaluate how the different water management method will influence on the productivity, water quality, and greenhouse emission. To achieve our goal we are conducting field measurements and numerical simulations at Vietnam. As of the first trial of our numerical simulation, we assumed a simple imaginary case. The results indicate that if we can properly set the weir height of the irrigation canal, homogeneous water distribution to each plot might be possible. Further combined research of field measurements and simulations are required.

Introduction

Generally, the highest priority of paddy field is rice productivity and quality. To achieve that purpose, efficient water resource use is important. In other words, saving irrigation water is required. On the other hand, paddy agriculture sometimes induces various environmental problems. Excessive drainage water, which contains various materials, contaminate the downstream water bodies including rivers, lakes, and oceans. And, a part of nitrogen fertilizer in soil goes to groundwater as nitrate, and induces groundwater contamination. Thus, water quality conservation of the downstream water bodies and groundwater is very important for safe drinking water and ecosystem conservation. Furthermore, a part of nitrogen in soil emits to the atmosphere as N_2O (nitrous oxide). CO_2 and CH_4 (methane) also emit to the atmosphere from soil when organic matter is decomposed. These gases are greenhouse gas and induce global warming. So, reducing greenhouse gas emission from paddy field is also required. Thus, we need to satisfy three different purpose, maintaining productivity, conserving water quality, and reducing greenhouse emission simultaneously. Regulating water management is one of the promising way to achieve this goal. Thus, the objective of our research is to evaluate how the different water management method will influence on the productivity, water quality, and greenhouse emission.

Material and Method

Research framework is shown in **Fig.1**. We set three different types of water management plots. The first is conventional management plot. The second is dry type management plot. And the third is wet-type management plot. Comparing these differently treated plots, we are going to clarify which is the optimum management method. One important characteristics of our research is considering a practical way to control water in paddy field; i.e. by only implementing a small weir of which height is different in canals, water regime of each plot will be regulated.

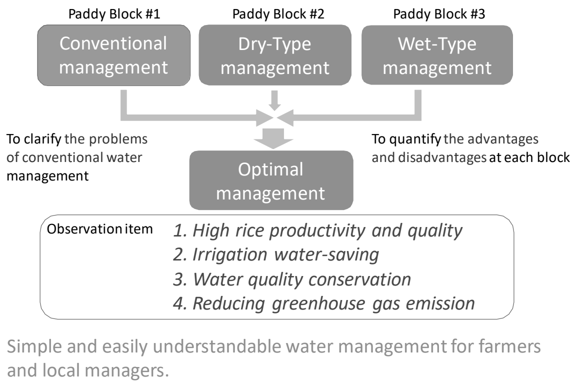

Fig.1 Research framework

Under the above-mentioned framework, we are now conducting field measurements such as water quantity and quality, groundwater levels, volumetric soil water, Eh of soil water, the amount of greenhouse gas (N_2O, CO_2, and CH_4) and rice productivity. Configuration of the study site is shown in **Fig.2**.

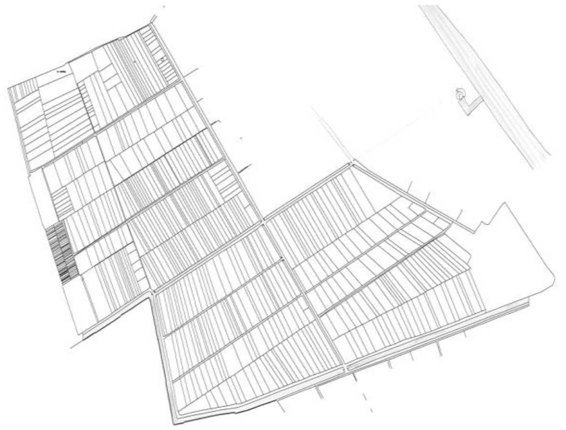

Fig.2 Outline of the study site

As a component of this research project, we attempted to simulate how the water distribution pattern to paddy plots will change by an adjustment of weir height of an irrigation canals. As of the first trial of our numerical simulation, we assumed a simple imaginary case shown in **Fig. 3**. In the setting, one straight canal of which slope is 1/0000 is lined along two plots of which sizes are 100m×30m. Through the three small inlets (ditches dug at levees of plots), irrigated water will flow into plots. Flowing pattern and the amount of water is regulated by the difference between the water level of upstream canal and that of downstream canal. By changing the water levels at the downstream of canal, how the water flow pattern in plots will change were evaluated.

The governing equation used for the simulation is 2 dimensional Saint Venant equations as follows.

$$\dot{H} + H_i u_i + H u_{i,i} = 0$$
$$\dot{u} + u_j u_{i,j} - \varepsilon\left(u_{j,i} + u_{i,j}\right)_{,j} + g\left(H + z\right)_{,i} + \frac{gn^2|u|}{H^{4/3}}u_i - \frac{K|W|W_i}{H} + fu_i = 0 \qquad (1)$$

Here, H: water depth, u: velocity, ε: kinematic viscosity, g: gravitational acceleration, n: roughness, W: wind velocity, f: Coriolis force. Calculation scheme is the finite element method with two step explicit method propose by Kawahara et al. (1978), and customized for flood simulation by Hai et al. (2008).

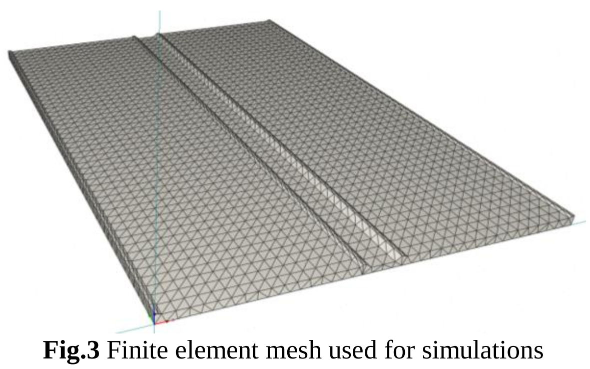

Fig.3 Finite element mesh used for simulations

Result and Discussion

Three different types of water level at the downstream of canal were set as boundary conditions for each simulation. The first condition was 0.3m lower than the bottom elevation of inlets of plots (case1). The second condition was 0.3m higher than the bottom elevation of inlets of plots (case2). And the third condition was periodical change of water levels between 0.3m lower than the bottom elevation of inlets to 0.3m higher than the bottom elevation of inlets (case3).

The simulation results indicate in case of case1, water distribution to plots are not homogeneous, since water level of the canal at the downstream is lower than the bottom elevation of outlet. On the other hand, in case of case2, irrigation water homogeneously spread out to the whole area of plots, but also some water were flowing back to the canal, since water level of the canal at the downstream is higher than the bottom elevation of outlet. In case of case3, the result indicate that if we can change the weir height according to the water levels of plots, we can properly manage the amount of water for irrigation. On the other hand, farmers usually don’t want to spend much time for water level management. So, it’s not practical to recommend the case3. More practical way might be to find the optimum height of weir to achieve three goals mentioned in the Material and Method. Thus, the next step is to construct a simulation model of actual case. And based on the model and observation, it is required to find the optimum way to manage the water.

Conclusion

Numerical simulation was conducted for the assessment of water distribution to plots. The results indicate that if we can properly set the weir height of the irrigation canal, homogeneous water distribution to each plot might be possible. Further combined research of field measurements and simulations are required.

Acknowledgement

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Research on cause of KE 2/20 REC dam failure in Vietnam from view point of hydraulic fracturing

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SUMMARY

Hydraulic fracturing is the propagation and development of cracks under the effect of water pressure. It is widely believed that hydraulic fracturing will occur in a fill dam when the stress in the dam is reduced to levels that are lower than the water pressure, a condition which allows for crack propagation in the dam body. The risk of hydraulic fracturing may increase when arching action occurs due to the differential displacements of the different materials in the dam body. The aim of this study is to explain the cause of a dam failure using the finite element method. A case study, KE 2/20 REC dam, investigates a dam that broke during the first reservoir filling at positions adjacent to the culvert. A build-up model is taken to simulate the stress-strain state in the dam body. This research reveals that the normal stresses around the culvert were reduced to levels much lower than the water pressure. This was due to the arching action that was associated with the effects of the culvert and the foundation. The findings suggest that the cause of the dam failure was related to the hydraulic fracturing phenomenon.

Introduction

Hydraulic fracturing has been identified as one of the possible causes leading to the concentrated leakage and failure of many fill dams especially at the first reservoir filling [2]-[3], [5]-[7], [9]-[10]. It is generally accepted that hydraulic fracturing will occur when the normal stress at any point is exceeded by the water pressure [6]-[7]. Previous studies revealed that hydraulic fracturing is closely related to the occurrence of arching action in the dam body. Arching action often occurs among different materials, such as between impervious cores and shoulders, culverts and fill soil or fill soil and foundations [2]-[3], [5]-[6], [10]. Under loading, materials with different elastic moduli can lead to differential displacements and then induce arching action. Due to this action, the stresses in fill dams can be reduced. Past researches indicated that an incident at the Hyttejuvet Dam during the initial filling of the reservoir was related to the hydraulic fracturing phenomenon [3], [5]. The arching effects in the clay core of this dam caused a reduction in the stresses to levels that were much lower than the water pressure. In such a situation, under water pressure, seepage can penetrate through the existing cracks in the dam and induce stress concentration at the crack tips. As the tensile strength of soil is very small, the cracks can easily propagate through the embankment, resulting in the failure of the dam. Similar incidents, also identified as coming from the hydraulic fracturing mechanism, occurred at Balderhead (England), Stockton (USA), Wister (USA), Viddalsvatn (Norway), and Teton (USA) Dams during the first reservoir filling [2].

In addition, arching action also occurs easily around culverts. Due to arching, the normal stresses on both sides of a culvert can be reduced to values that are much lower than the water pressure. According to field observations, past research concluded that hydraulic fracturing is the most probable cause of leakage along outlet conduits [6]. However, little attention has been paid to arching that was brought about by the effects of slopes excavated for the construction of culverts.

It is clear that dam failures due to hydraulic fracturing are actual potential risks. Therefore, much research in recent years has focused on predicting the risk of hydraulic fracturing in earth or rockfill dams. These studies can be divided into three groups [3], [10]. The first relies on cylindrical or spherical cavity expansion theories in elastic or elastic-plastic mechanics. The second is based on field or laboratory tests. The last uses theories of fracture mechanics combined with laboratory tests.

To predict hydraulic fracturing in fill dams or foundations, numerical analyses using the finite element method were often performed in past researches. The computed results of these analyses were compared with the results of in-situ or laboratory tests. The comparisons showed a good agreement. In this paper, therefore, a finite element procedure is applied to find the cause of a real dam failure as a case study.

A case study called KE2/20 REC dam failure in Vietnam was used for this study. This dam is located in Ha Tinh Province in Central Vietnam. The dam's initial purpose was to create a reservoir to supply irrigation water for farmland (about 30 hectares). Construction of the dam and reservoir were started in October 2006. After 2 years, the dam was completed and was put into operation in July 2008. The related structures consisted of the main dam (maximum height of 12.5 m), a saddle dam, a spillway (width of 11.2 m), and a culvert (design flow of 0.037 m3/s). After being in operation for just one year, the dam broke in June 2009 [1], [8].

Past research concluded that the dam broke due to the piping mechanism [8]. Even though the research somewhat explained the cause of the failure, it did not point out what happened before the seepage had formed. The current authors inferred that the dam failure may be related to the hydraulic fracturing phenomenon. The focus of this study, therefore, is to explain the cause of the dam failure under the hydraulic fracturing mechanism using a numerical analysis.

Description of the dam failure

Much research in recent years has focused on explaining dam failures due to concentrated leakage. Hydraulic fracturing is considered to be one potential cause of concentrated leakage especially at the first filling soon after the dam completion. The risk of hydraulic fracturing may become higher when the normal stresses in the dam are reduced by the arching effect and the level of the water in the reservoir rises. Past researches pointed out that dam failures were caused by hydraulic fracturing at Hyttejuvet, Balderhead, Stockton, Wister, and Teton Dams during the first impounding [2].

This research introduces a dam failure that will be used as a case study called KE2/20 REC dam. The dam is situated in Central Vietnam. It broke at the location of the culvert under completely normal conditions, without the incidence of an earthquake or rain, and with an approximately normal water level in the reservoir of +30.5 m [8].

Observations after the failure showed that a segment of the culvert had broken in the middle and that the water flow had then caused deep erosion in the foundation, approximately 8.5 m in length in the water flow direction and 3.5 m in depth. There was also no sign of seepage from the shoulder of the dam. At the same time, the broken segment and a part of the dam body close to the culvert were swept toward the downstream [1]. An actual image of the dam failure is given in Pictures 1.

Picture. 1 KE 2/20 REC dam failure

Results of in-situ surveys and experiments after the dam failure showed that the slope of the excavation on the left side of the culvert (looking from upstream to downstream) was rather steep. In reality, the observed slope was just 1:0.5 (vertical and horizontal directions, respectively), even less than seen in Pictures 1 and 2, even though the required design value was 1:1. Figure 1 shows a longitudinal section of the dam that was idealized from the design section and in-situ observations. According to the geological description, the culvert and the dam were erected on a firm foundation of cracked and weathered rock – a kind of argillaceous slate. The elastic modulus of the foundation was much higher than the value of the filled soil. The physical properties of the filled soil and the foundation, taken from previous studies on the dam, are listed in Table 1. In addition, in-situ tests on the filled soil after the dam failure revealed that the embankment had not been compacted carefully. The real relative compaction (90.4%) had not reached the required value (95%) [1].

Cross sections of the dam and the culvert are presented in Figs. 2 and 3, respectively. It can be seen that the culvert is a reinforced concrete circular conduit and was placed on a concrete foundation bed 0.4 m in depth. The physical parameters of the culvert materials are summarized in Table 1.

From the above descriptions, the current authors suspected that the cause of this dam accident might be related to the hydraulic fracturing mechanism. There may have been discontinuities in the filled soil adjacent to the culvert after the construction process. Moreover, due to the effect of the culvert's shape, arching action could have occurred on the left side of the dam. With the excavation of a steep slope and a considerable distinction in the elastic modulus between the embankment and the foundation, arching can become severe. During the first filling of the reservoir, the water pressure grew higher than the normal stresses on both sides of the pipe culvert; the stresses were reduced to a small value by the arching action. Under this condition, the discontinuities acted as the initial cracks that were extended and propagated by the water pressure. This process might have led to the dam failure.

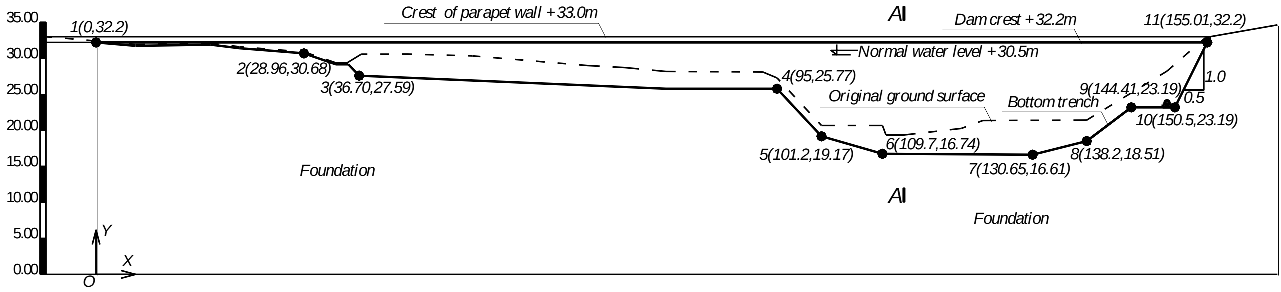

Fig. 1 Longitudinal section and data of nodal points on boundary in numerical model

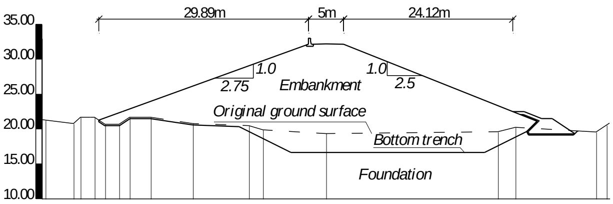

Fig. 2 Cross section of dam (A-A)

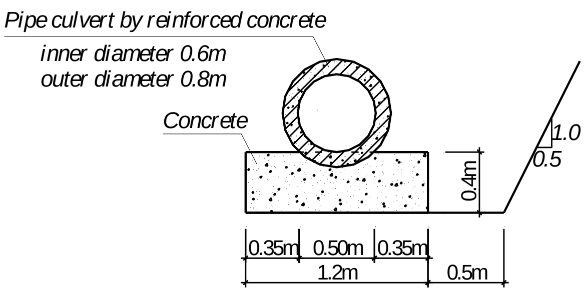

Fig. 3 Cross section of culvert

Numerical analysis

1. Purpose of numerical analysis

In recent years, numerical analyses using the finite element method have been widely applied in investigations of the stress-strain distribution and the seepage in dams. In previous studies on the hydraulic fracturing phenomenon in soil or the earth pressure on buried pipes, the finite element method was often used to yield numerical results. These results were then compared with the results of either in-situ observations or laboratory tests. The comparisons showed a good agreement [3], [4]. In this research, therefore, the authors set up a plane stress build-up analysis using the finite element method to simulate the stress-strain state in the dam. The build-up analysis allows for a better simulation of the influences during construction. The results of the analysis will show the distributions of stress and displacement in the dam, especially at positions adjacent to the conduit, to verify the arching effect.

Table 1 Material properties

a. Filled soil	
Total density (ρ):	2.018 Mg/m^3
Dry density (ρ_d):	1.673 Mg/m^3
Soil cohesion (c):	23.0 kPa
Angle of internal friction (φ):	16^{o}47'
Coefficient of permeability (k):	6.247×10-5 m/s
Elastic modulus (E):	16800 kPa
Poisson's ratio (v):	0.3
b. Reinforced concrete	
Total density (ρ):	2.45 Mg/m^3
Elastic modulus (E):	2.4×107kPa
Poisson's ratio (v):	0.2
c. Foundation	
Elastic modulus (E):	1.0×107kPa
Poisson's ratio (v):	0.25

2. Model description

A build-up analysis by FEM, using 12 successive layers of fill soil, is performed to analyze the deformation and stress in a longitudinal section of the dam which includes the cross section of the culvert as well. Even though the shape of the culvert is symmetric, the boundary conditions in this analysis are unsymmetrical due to the effects of the excavation. As a result, this analysis used the whole longitudinal section of the dam. In addition, the elastic modulus of the foundation is much higher than that of the embankment. Thus, for the sake of simplicity, this model just simulates the dam body. The coordinates of the 11 main nodal points on the boundary are shown in Fig. 1. The coordinates of the other nodal points were calculated from the coordinates of these main nodal points.

The finite element mesh, which consists of 641 elements and 2121 nodal points, is shown in Fig. 4. All the elements are eight-node quadratic quadrilateral elements, and the elements adjacent to the culvert have smaller dimensions than the others in order to improve the accuracy and the details of the stress distribution around the culvert. The model is also assumed to be restrained at the foundation. Theoretically, when these nodal points were fixed, the stress at these points was equal to zero. However, this did not simulate the actual stress state on the boundary. Therefore, to improve the accuracy of the model, the nodal points between the 9th and the 10th main nodal points (in Fig. 1) were set up to be free in the horizontal direction.

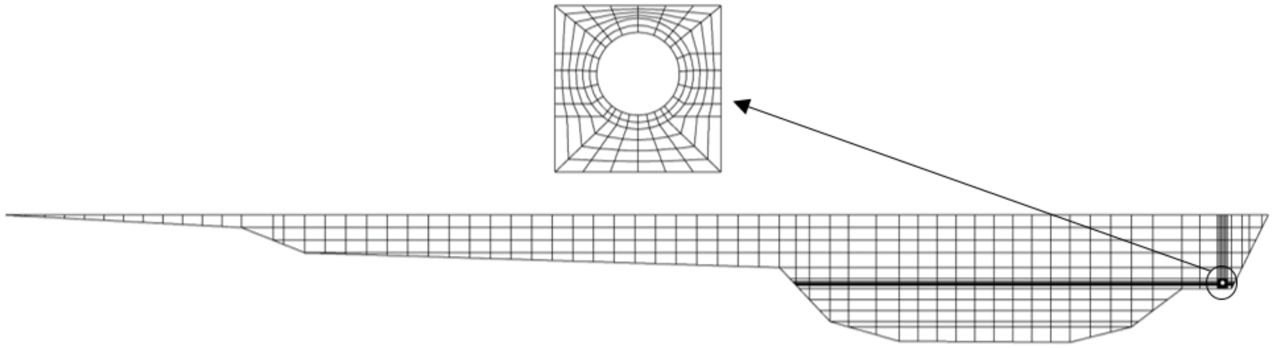

Fig. 4 Finite element mesh model

Results of numerical analysis

1. Distribution of displacement

Previous studies on dam failures or concentrated leakage due to hydraulic fracturing revealed that hydraulic fracturing occurs when the stresses in the dam body fall to levels that are lower than the water pressure. The risk of hydraulic fracturing might increase with the arching effect. Thus, a simple criterion for predicting the potential of hydraulic fracturing at any location in the dam body is to compare the normal stress with the water pressure at that point. This criterion was used here to explain the cause of the KE 2/20 REC dam failure.

The deformation mesh for the dam, magnified 10 times, is shown in Fig. 5. The maximum vertical displacement occurred around the mid-height of the embankment. This corresponds to some past researches using the build-up model [3], [6], [10]. The model used in this study might be consistent with the real dam conditions just one year after its completion, because the stress-strain state in a dam body can be significantly affected by the construction process, the consolidation condition, and the first filling of the reservoir.

The displacement distribution around the pipe culvert is also displayed in Fig. 5. It is seen that the vertical displacement of the fill soil columns on both sides of the pipe is higher than that in the column of the fill soil above the crown of the pipe. This is because the elastic moduli of the culvert material and the foundation were much higher than the elastic modulus of the fill soil. Therefore, differential displacements occurred under loading and induced arching action adjacent to the culvert. This result is verification of the above suspicions.

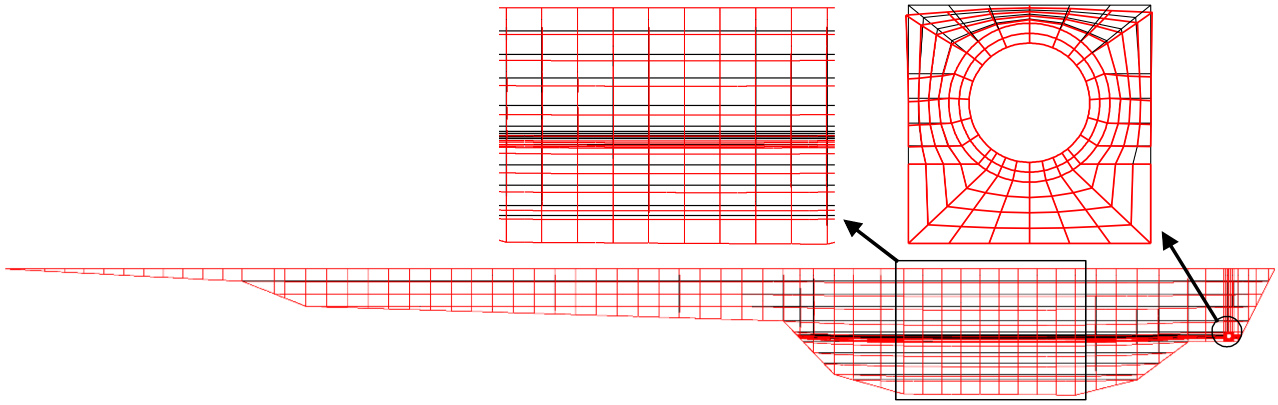

Fig. 5 Deformation mesh of analysis (scale factor = 10)

2. Distribution of stress around the culvert

As most stresses in soil are compressive stresses, for convenience, the sign for stresses in this research are positive for compression stresses and negative for tensile stresses. Figure 6 indicates the relationship of the normal stress (σ_θ) and the normal stress minus the water pressure (σ_θ - W) around the pipe culvert versus the theta angle (θ^o) with the sign convention of theta as in Fig. 7. The normal stresses on both sides of the culvert, especially at the bottom of the pipe, were clearly reduced and much lower than the stress at the top of the pipe. This might be due to the arching effect. These results are similar to those of past research that also addressed the cause of leakage along an outlet conduit underneath a low fill dam [6]. Moreover, the results from Fig. 6 show that all of the stresses were still compression stresses, although the normal stresses on both sides of the culvert were significantly reduced by the arching action. This is slightly inconsistent with the results of previous research [8].

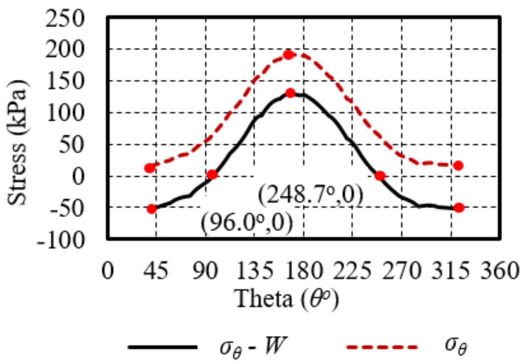

Fig. 6 Graph of stress around pipe culvert versus theta angle (θ^o)

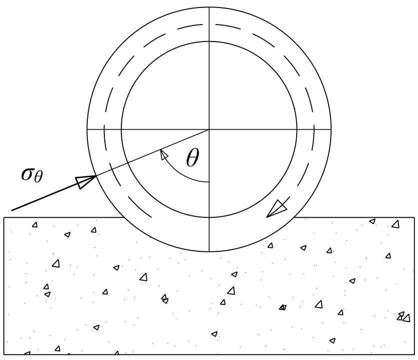

Fig. 7 Convention of theta angle (θ^o)

As detailed in Fig. 6, when the theta angle is smaller than 96.0^o and higher than 248.7^o, the normal stress is really exceeded by the water pressure. It can be concluded that hydraulic fracturing may have occurred in these regions. This coincides with the inferences of this early research. Moreover, the results from Fig. 6 also indicate that the normal stress distribution around the pipe culvert is unsymmetrical. The normal stress around the culvert was peak to maximum when the theta angle was equal to 167.3^o rather than 180^o. This might due to the effect of the excavation shape.

Discussions

The results of this study revealed that the cause of the dam failure may be related to the hydraulic fracturing phenomenon around the culvert. This also confirm the high risk of hydraulic fracturing adjacent to a conduit that can result in dam failure. The findings coincide with the conclusions of Ngambi et al. (1998). On the other hand, there are significant differences in the methodology and the results between this study and the previous research on the dam failure. Our analysis shows that the normal stresses on both sides of the culvert were reduced considerably by the arching effect. However, these stresses were still compression stresses (as in Fig. 6). Thus, there may have been no tensile cracks on the left side of the dam; this differs from the conclusions drawn in the previous research on the dam failure [8].

The results in this analysis confirmed that the stress-strain state around the culvert was affected remarkably by the shape of the culvert. In addition, the slope of the excavation also had an effect on the arching action. This research is thought to be the first study that elucidates the KE 2/20 REC dam failure under the viewpoint of hydraulic fracturing. It suggests that hydraulic fracturing may occur easily around the culvert in a dam body. Therefore, it is necessary to consider the risk of hydraulic fracturing in the design and construction processes of culverts underneath fill dams. Simultaneously, countermeasures to prevent the potential risk of hydraulic fracturing should be proposed.

Besides the positive aspects of this research, the contact behavior between the fill soil and the foundation or the concrete culvert, that have an elastic modulus that is much higher than the embankment's, has not been considered for the models employed in this analysis. This could lead to slight errors in the calculation at some local points. Future studies, therefore, will aim at using better models to simulate the stress-strain state of the case study. In addition, some countermeasures to reduce the risk of hydraulic fracturing adjacent to the culvert will proposed as well. Another numerical analysis will also be used to check the effectiveness of the countermeasures.

Conclusion

Base on the above study, the following conclusions can be made:

(1) Hydraulic fracturing can occur easily when the normal stresses on both sides of a culvert are reduced by the arching effect to be lower than the water pressure. This phenomenon may have been the original cause of the KE 2/20 REC dam failure before the dam was broken by piping mechanism.

(2) The culvert shape has a significant effect on initiating arching action. Moreover, an excavation with a high slope will contribute to even more serious arching. Therefore, a dam with the unreasonable culvert shape or high excavated slope might have high risk of hydraulic fracturing.

Dam failures due to hydraulic fracturing can lead to severe damage to the downstream areas. Therefore, measures against hydraulic fracturing are really important in terms of ensuring the safe working conditions of dams. The focus of future work will be to research other countermeasures for preventing hydraulic fracturing and the effects of an excavation slope on arching action.

Acknowledgement

The authors would like to acknowledge Prof. Dr. Nguyen Chien, Dr. Ho Sy Tam, and Ha Tinh of the Hydraulics Construction Consultant Joint Stock Company - Vietnam for providing valuable input data for this research.

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Characteristics of Denitrification in an Agricultural Drainage Channel

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SUMMARY

Denitrification is a part of purification process to remove nitrogen from ecological and environmental system in the nitrogen cycle, which is an essential phenomenon from a viewpoint of environmental sustainability. Though denitrification in tidal flat, the bottom mud of lakes and paddy field that are often in anoxic condition has been discussed frequently thus far, an agricultural drainage channel was unconsidered as a place of denitrification because of its abundant reaeration. In this study, we focus on the denitrification from an agricultural drainage channel, especially in non-irrigation period, because its discharge remarkably decreases during the period and then anoxic condition might occur for its rich organic matter on the channel bed. N_2O emission from the undisturbed cores of the bottom mud was measured in the laboratory by applying acetylene gas inhibition method. The results suggest the amount of nitric gas emission from the agricultural drainage channel is not negligible and sometimes not less than that from tidal flats.

Introduction

Since the invention of Haber-Bosch process a large amount of nitrogen compounds such as fertilizers has been produced and distributed in the natural and human environment. Some are consumed appropriately in the field, but excessive nitrogen left in the environment often induces various environmental problems, for example, eutrophication and various plankton blooms. In the nitrogen cycle most of nitrogen is taken from atmosphere by fixation including above mentioned Haber-Bosch process and it is finally released into atmosphere through a reduction process called denitrification. So the denitrification is essential to drive the nitrogen cycle and to purify the excessive nitrogen pollution in our environment.

A number of studies regarding the characteristics of denitrification are carried out for tidal flats, lakes and paddy fields, but there are few for lotic waters such as rivers and channels. It is because abundant oxygen due to reaeration in the lotic waters is considered to disturb the denitrification process. We, however, consider the nitrification might occur even in the agricultural drainage channel, because the reaeration reduces during the non-irrigation period and the bottom mud or sediment of the channel includes abundant organic matter due to excessive fertilizer and agricultural residues.

In this study we try to make the characteristics of denitrification from the channel clear and to prove how much the nitrification by the channel contributes to purify the water environment quantitatively.

Material and Method

Our investigation target is Ooe drainage channel flowing through Aichi prefecture, Japan. It is a concrete lining channel and so the bed is obviously flat by cement. However, fish pools that are 20m long reach deepened by approximately 0.5m compared with the adjacent reaches are installed for every 500m of the channel to preserve its aquatic ecosystem. In addition, several fish-nest blocks that are a kind of cavities on the sidewall are installed in the fish pools (Fig1). While the sediment that is rich in organic matter is flushed by the running water from and on the flat bed, it sinks and accumulates in the fish pool due to its slow velocity.

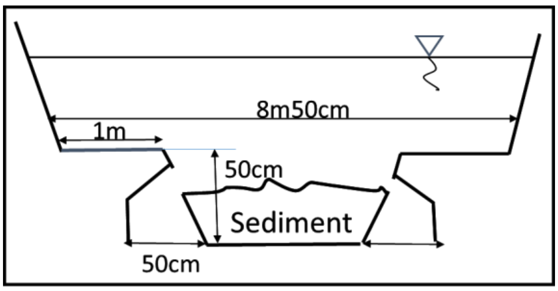

Fig. 1 Cross-section of the Ooe drainage channel at a fish pool reach

In order to evaluate the characteristic of denitrification in the drainage channel, especially for the fish pool, physical factors of the drainage channel (water temperature, water depth, weather) were measured on site and water and sediment core are sampled at two fish pools (points A and G). The water quality indices (nitrate, nitrite and ammonia ions), N_2O flux from the cores kept in an incubator and the amount of organic matter (ignition loss) in the sediment were measured in the laboratory.

The acetylene inhibition method was adopted to measure the released nitric gas from the cores (Tiedje et al., 1989; Iida et al., 2007). The method suppresses nitrous oxide reductases that further reduce N_2O into N_2 gas and also inhibits the production of NO_3^- via nitrification (Iida et al., 2007). The N_2O flux was measured every 2 hours during 8 hours after sampling the undisturbed cores of sediments using a gas chromatography (GC-2014 equipped with an ECD detector; Shimadzu Co., Ltd.).

The sampled water was filtered through membrane filter of 0.45 μm pore size and cast into an ion chromatography (ICA-2000; TOA-DKK Co., Ltd.) to identify the NH_4^+, NO_2^-, and NO_3^- concentrations.

Results and Discussions

Figures 2, 3 and 4 show the concentration of dissolved inorganic nitrogen, the ratio of organic matter (ignition loss) in the sediment and the N_2O fluxes from the cores of the sediments at point A, respectively. (The results at point G will be shown in the presentation.) As seen from the data, the characteristics of gas emission at points A and G seems slightly different, which might be due to the difference in the amount of organic matter. The concentration of dissolved inorganic nitrogen decreases in summer (irrigation period) in which amount of dissolved inorganic nitrogen must be diluted by large discharge of irrigation. Some periodical fluctuation is seen in the ratio of organic matter in the sediments. We could not identify the correlation among the concentration of dissolved inorganic nitrogen, the ratio of organic matter and gas fluxes by denitrification precisely, but it becomes clear that the denitrification ability of the drainage channel become greater or equal to that from tidal flats and lakes. (e.g. the average gas flux in tidal flats in Ariake sea in Japan is about $13 mgN \cdot m^{-2} \cdot d^{-1}$; Koga et al.,2009).

Denitrification is a phenomenon in which nitrate is reduced by a specific group of microbe called denitrification bacteria. In anaerobic condition, these bacteria use nitrogen as an electronic receptor but in aerobic condition, they can use oxygen. To understand the characteristic of denitrification in the agricultural

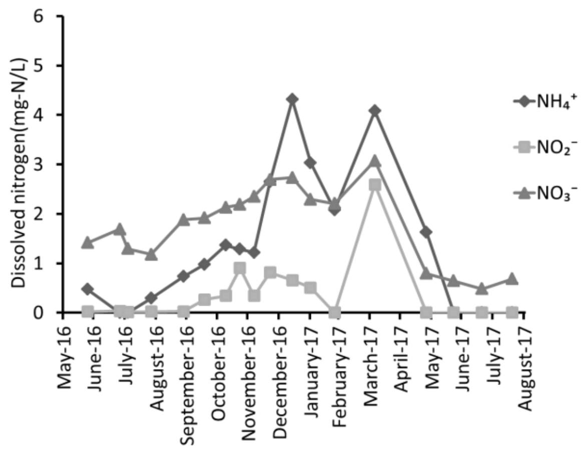

Fig2. Concentration of dissolved inorganic nitrogen in water (point A)

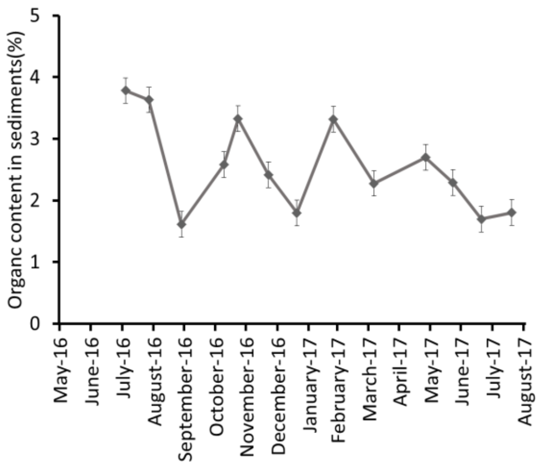

Fig. 3 Organic content in sediments (point A)

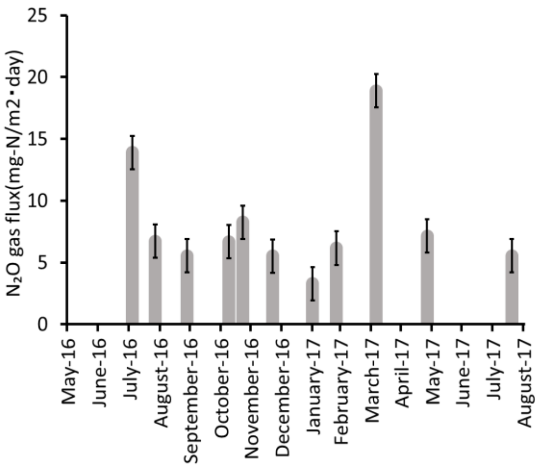

Fig. 4 N_2O gas flux from sediments (point A)

drainage channel, precise concentration of dissolved oxygen and the biota of nitrification bacteria should be examined in addition to the current data (Groffman et al., 2015).

Conclusion

In this study, it becomes apparent that the potential nitrification in the lotic water, i.e., agricultural drainage channel with abundant organic sediments is not less than that lentic waters such as tidal flats or lakes. For several decades, natural purification of lotic water has been mainly discussed on the decomposition of organic matter like the Streeter-Phelps model and not discussed on nitrification. The results obtained in this study indicates the purification process is much more complex than thought previously and denitrification plays an important role also in the lotic waters. Moreover, it suggests that the design of agricultural drainage channel could not be considered by only focusing on the aquatic ecosystem conservation and the biological diversity, but also nitrogen cycle, in other words, natural purification of the water. Finally, it is necessary to examine more environmental factors to clarify the characteristic of denitrification in the drainage channel, because of its inherent complexity of nitrification in physical, chemical and biological aspects.

Acknowledgement

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Alternate Wet and Dry irrigation technique – an adaptable solution to climate change for rice cultivation in the Red River Delta, Vietnam

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SUMMARY

Rice production in Vietnam has consumed a huge water every year. Irrigation water for agriculture is becoming increasingly scarce under climate change impacts. Alternate Wet and Dry Irrigation (AWDI) with a controlled water level of 2÷3 cm from the surface, an irrigation schedule of 10 wet days alternated with 3 dry days and keeping 7÷10 dry days at the last branching stage is a proposed solution. The paper reviews previous research results in the access adaptation of this irrigation solution applied in the Red River Delta, Vietnam. The AWDI has significantly increased water use efficiency in the Red River Delta, uses less water (0.25 billion m^3/year saved) without significant reduction in grain yield (6.68 t/ha) compared with conventional irrigation (6.8 t/ha). Besides, the AWDI may well reduce the green gas emissions (CH_4, NO_2, CO_2…) in the rice fields and increase aerobic microorganisms density in root region, therefore control soil toxic such as Fe (II), Mn (II). Due to drying aerobic time, AWDI has a greater potential to supply necessary nutrient supplements to soil compared with conventional irrigation method. Transformation of nutrients N, S and Zn, etc. from fixation to more mobile behavior in soil is also advantages of this irrigation solution applied in the Red River Delta, Vietnam.

Keywords: Alternate wet and dry irrigation (AWDI), Water saving, Water use efficiency, Nutrient transformation.

1. Introduction

Vietnam has been seriously affected by climate change. Annual average temperature rises about 0.5 ºC leading to reduce significantly cool air frequency during two decades and strengthen hurricane. The results of the climate change contributed to increasing the seawater lever about 20 cm within 50 years (Ministry of Natural Resources and Environment of Vietnam, 2016). Furthermore, the climate change caused to change flow regime, increase water evaporation and reduce groundwater level. As estimated, the groundwater level can be reduced dramatically in the dry season after 2020. If the flow in the dry season in the Mekong Delta reduces by 15÷20 %, the groundwater can be lower 11 m compared with current flow. In the last 5 years, reducing surface water resource in the dry season, irrigation water deficiency, drought and salt intrusion are faced problems in downstream river basins. Some sections of the Red and Thao rivers had inertias periods due to low water level, the water resource for 5 years from 2003÷2007 was lower from 9÷20 % than each year. The water level of Red River in Ha Noi region has a low level at 22 %, sometimes under 30 %; especially the water level was under 50÷60 % in the dry season (Ministry of Natural Resources and Environment of Vietnam, 2016).

To deal with the reduced water amount and quality, the irrigation solution for plants awards to a saving water and reduces greenhouse gas emissions to be one of the useful solutions to adapt climate change. Because rice is a main crop type in The Red River Delta and Mekong Delta of Vietnam, with average irrigation level of 5÷7 cm, consuming water for 7 million hectares of rice area were about 52.5 billion m^3/crop (Tran Viet On, 2016). Thus, the solution of saving water irrigation awards a low carbon economy, protected environment, and sustainable development is very necessary for Vietnam.

Although the AWDI was encouraged by The Government, however, this irrigation technique has been applied in some regions as Phu Xuyen, Thuong Tin, Ba Vi (Ha Noi), Nam Sach (Hai Duong), Quynh Hong (Nghe An). Besides that, research about AWDI in Vietnam indicated that the positive effects of this technique, including, saved water (1,995 m^3/ha), maintained yield, reduced methane emission, restricted some pests to rice (Nguyen Viet Anh, 2009, Tran Viet On, 2016, Nguyen Xuan Đong, 2008). Thus, this paper proposed some saving water irrigation solutions for rice in the Red River Delta climate change adaptation.

2. Materials and methods

This paper reviews the sustainable irrigation solutions for rice cultivation in The Red River Delta based on the researched results.

The article's content focuses on performance evaluation of saving water irrigation techniques in the Red River Delta under aspects of water save, greenhouse gas emission mitigation and rice yield. As results, suitable irrigation solutions are proposed to apply to rice cultivation in the Red River Delta under climate change condition.

3. Results and discussion

3.1 Introduction to rice conventional irrigation methods in the Red River Delta

Conventional irrigation is a popular technique applied to most of the rice cultivation areas in The Red River Delta. The water level was kept above 5 cm from the surface in all growing rice stages. Therefore, the fields were only drying at the harvesting stage. The saving water irrigation has two irrigation technique, including, continuous moistening irrigation and Alternate Wet and Dry irrigation. The continuous moistening irrigation includes the highest irrigation level at 5 cm and a dried field from 5 to 0 cm between irrigation periods. Since surface dried, supply irrigation water to 5 cm immediately. As a result, keeping moistening time was maintained from the seedling stage to the harvesting stage without any drying field times. The AWDI technique with the highest water level 5 cm, however, the drying field time was implemented from 3 to 9 days between irrigation times. Thus, the AWDI creates an aerobic paddy field in a long time to promote humus-forming and mineralizing processes in the soil environment.

Beside of controlling water level, rainwater storage in the fields was applied in some regions in Vietnam. By research were conducted in the Liem Tuyet region (Ha Nam province) in continuous years from 2005 to 2008, rainwater utilization was proposed by Nguyen Xuan Dong with different storage levels, including, 5 cm, 10 cm, and 15 cm. The research indicated that the rainwater storage effects on the total amount of irrigation water during crop season (Nguyen Xuan Dong, 2008).

3.2 Saving water irrigation technique, increased water use efficiency

Research results of Nguyen Xuan Dong showed that the continuous moistening irrigation saved 326.33 m^3/ha while the AWDI saved more than two times (794.5 m^3/ha) (Nguyen Xuan Dong, 2008). Although the AWDI allowed rainwater storage levels of 5 cm, 10 cm, and 15 cm, however, both of 10 cm, 15 cm storage levels had affected yield because of preventing diffuse oxygen in the soil to increase toxic H_2S, S^{2-}, HS^-, Fe^{2+}, Mn^{2+} for rice roots leading to decreased yield (S. Yoshida, 1981). Therefore, the storage level of 5 cm is the best rainwater storage solution to rise effects on water use also yield.

Field experiments with rainwater use indicated that the moistening irrigation with a storage level of 5 cm saved 553.5 m^3/ha/crop, while the AWDI saved 1,598.75 m^3/ha/crop. The water was saved from the

AWDI nearly one-third of total irrigation water per a crop (Nguyen Xuan Dong, 2008) (804.25 m^3/ha). Thus, rainwater storage with the 5 cm level on the surface was not only saved water but also protect the soil environment from water logging and toxins.

On the other side, drying field time had influenced on irrigation level by the irrigation amount. Four irrigation experiments, including, the continuous moistening irrigation, the AWDI at level of 3-5 cm with 3 drying days (AWDI -3), the AWDI at level of 3-5 cm with 6 drying days (AWDI -6) and the AWDI at level of 3-5 cm with 9 drying days (AWDI -9) were conducted by Tran Viet On in Thuong Tin (Ha Noi, Dan Phuong (Ha Noi) and Quynh Luu (Nghe An) regions. A drying field times include between irrigation periods and the last branching stage (Tran Viet On, 2016).

The results showed that there is an irrigation level difference between the methods. The details, the AWDI-3 consumed about 78.46 m^3/ha less 22.81÷39.3 % than flood irrigation. In addition, this irrigation technique reduced about 8-9 times of irrigation water and increased more 0.4÷4.2 % yield than flood irrigation. Both of AWDI – 6 and AWDI - 9 reduced significantly 32.93÷38.56 % than flood irrigation, however, the drying field in a long time led to lack water for the rice to inhibit the metabolic activities as well as leaf growth, and tillering. Furthermore, this phenomenon had become clear in the sunny season to cause reducing 10.55 % yield in the AWDI – 6 and 18.25 % in the AWDI – 9 (Tran Viet On, 2016). So, the results have shown that the AWDI – 3 is a useful solution.

Although a water control of the continuous moistening irrigation (CMI) with a returning irrigation after drying field. However, this irrigation type reduced only 5.82 % than flood irrigation (Tran Viet On, 2016), which was less 4 times the AWDI – 3. Further, CMI's yield was not reduced 0.56 %.

The experiments about different irrigation levels were conducted in Phu Xuyen region (Ha Noi) by Nguyen Viet Anh. An irrigation level of 2-3 cm with drying field 2-3 days between irrigation periods and drying field about 7-10 days at last branching stage to reduce 12.2 % of methane gas emission and increase 4.5 % of yield more than flood irrigation (Nguyen Viet Anh, 2009).

The saving water irrigation (SWI) has researched by many authors in the world since 1980. Research results of Sandhu (1980), F.N. Ponnamperuma (1985), IRRI (1991-1998), Bhuiyan (1992-1993), Tabbal (1992), Kijne (1994), Bhuiyan and Tuong (1995), MaoZi (1996) and Anbumozhi (1998) showed that the SWI saved about 10÷17 % and increased about 20÷27 % yield than flood irrigation.

Because of the irrigation level of conventional rice production of Farmers in The Red River Delta is always higher than 5 cm and over 7-10 cm in the rainy season. The fields were dried before harvesting 10 days. Thus, the conventional rice cultivation contributed to consume significant water. For example, keeping water level from 7-8 cm increased 200÷300 m^3/ha, nearly about 1,400÷2,100 m^3/ha/crop more than the flood irrigation with the water level of 5 cm, while rice yield remained. Consequently, the flood irrigation increases anaerobic soil environment to release the toxins for roots.

By 2016, there are about 1.8 million Vietnam's farmers applying AWDI to the total area of 395,000 hectares in different areas (Tran Viet On, 2016). The total cultivation area in the Red River Delta is about 557,000 hectares with an average yield of 65.7 quintals per ha. However, the AWDI is only applied about 2 % per total areas in some regions, such as Phu Xuyen, Thuong Tin, Ba Vi (Ha Noi), Nam Sach (Hai Duong).

Estimated by the irrigation level is applied over 557.7 thousand hectares, the amount of effective water is over 1 billion m^3 per crop. According to National Environment Report 2016, the total useful capacity of the reservoirs in Vietnam is 37 billion cubic meters of water (accounting for 4-5 % of total annual surface water volume), in which The Red River and Thai Binh River basins account for over 45 %. Wastewater was estimated about 2 billion m^3 per year, accounting for 9 % total reservoir water in The Red River Delta. As a result, the AWDI with the water level of 2-3 cm and drying field 3-5 days between irrigation periods, especially drying field 7-10 days at last branching stage was considered to apply. If this solution applied on total cultivation areas of The Red River Delta, significantly saves irrigation water around 0.25 billion m^3/crop while remains rice yield.

3.3 Irrigation method for reducing greenhouse gas emissions and protecting the paddy soil

Effects of flood irrigation on the paddy soil environment were studied by many authors in the world. S. Yoshida and M.R. Chaudhry (1979) concluded that, wetlands are a favorable environment for the decomposition of organic matter by anaerobic bacteria. This is the main cause of greenhouse gas emissions (CH_4) and toxins (CH_3SH, H_2S, HS^-, S^{2-}) (Shouichi Yoshida & M.R. Chaudhry, 1979, S. Yoshida, 1981).

With a flood level of 5-7 cm is applied popular to paddy soil in some regions of The Red River Delta released an amount of methane gas on the acid alluvium soil about 278.5÷677.1 kg/ha and on the neutral alluvium soil with 348.5÷738.9 kg/ha (Nguyen Huu Thanh, 2011).

Nevertheless, the regular flood irrigation with a water level of 6 cm, as a result, parameters including oxygen gas, Eh, pH, micronutrient content, and minerals were reduced more than the AWDI with a level under 3 cm. More, applying AWDI with the water level is under 3 cm to ensure anaerobic status for the microorganism activity (Xianqing Lin et al., 2011).

The methane emission rate is inversely proportional to mobile manganese and Eh (F.N. Ponnamperuma, 1985, Nguyen Huu Thanh, 2011), but correlated with water level (Xianqing Lin et al., 2011) and organic content in the paddy soil (Bouman et al., 2005). In addition, the AWDI created favourable conditions for oxygen entering the soil to limit the anaerobic decomposition of organic matter into methane (Bouman et al., 2005, Tran Viet On, 2016). If the fields were dried at the last branching stage and after 15 days of seeding stage with the regular water level of 5 cm, amount of CH_4 emissions reduced about 10 % (45.7 kg/ha/crop, respectively). Furthermore, this method increases rice yield about 3 % (515.3 kg/ha/crop) compared with the continuous flood irrigation (5 cm) (Tran Viet On, 2016).

In New Delhi (Indian) (Jain M.C et al., 2000) concluded that the amount of greenhouse gas from applying AWDI field was less than from flood irrigation field. The saving water irrigation with a drying field in the semi-tropical conditions CH_4 emissions varied between 14 ÷ 18 kg/ha/crop, reduced 28 % compared to the flood irrigation. However, different varieties also effected on emissions gas, the research indicated that decreasing methane emissions from the Pusa-169 variety was higher than the IR72 that 28 %. On the other hand, using organic fertilizer also increase greenhouse gas emissions about 12÷20 %.

Research of Thuy Loi university (Vietnam) was conducted in some regions of The Red River Delta, the Centre of Vietnam, and The Me Kong Delta about the saving water irrigation from 2009-2011 with the variety and cultivation regime together. The purpose of the project awards for reducing greenhouse gas emissions in the climate change condition in Vietnam, the results showed that, the AWDI with water level of

3-5 cm contributed reducing methane emissions to be about 20.4÷34.6 % during Spring and 16.31÷37.71 % during Summer compared to flood irrigation with water level of 5-7 cm. Amount of methane emissions were 262.97÷355.76 kg/ha/crop and 357.30÷390.71 kg/ha/crop in the spring and the summer seasons, respectively.

Especially, the water level was 2-3 cm drying time 3-5 days between irrigation periods decrease 10.11 % methane emissions compared to flood irrigation with a level of 5 cm (Nguyen Viet Anh, 2009).

In addition to methane emissions, there are other greenhouse gases such as CO_2, NO_2. These gases also reduce emissions when applied to alternate wet and dry irrigation. The project of greenhouse gas emission reduction in Agriculture was conducted by the Vietnam Academy of Agricultural Sciences in Van Noi region (Ba Vi district, Ha Noi) in 2015, showed that with an irrigation level of 2-5 cm and drying field 2-3 times per crop reduced greenhouse gas emission by 25÷30 %, CH_4 14÷21 %, NO_2 15÷22 %, CO_2 22÷27 %. In addition, fertilizers and plant protection products also reduced dramatically in applying the AWDI such as down 20÷28 % nitrogen fertilizer and 39÷62 % cost of plant protection products.

Besides reducing greenhouse gas emissions, the AWDI also reduces Fe (II) and Mn (II) toxins to the rice root (Tran Minh Nguyet, 2013). In the wetland, the oxidation of Fe^{3+} and Mn^{4+} were reduced to toxic Fe^{2+} and Mn^{2+}. In contrast, drying field in the AWDI method creates to anaerobic soil to increase the redox potential Eh to limit some toxic Fe (II) and Mn (II) (F.N. Ponnamperuma, 1985).

Compared to the conventional flood irrigation, the AWDI has a long time for drying field (3-5-7 days) to create small cracks on the surface of the field, this process helps to diffuse deeply oxygen to the soil to anaerobic microorganism metabolism (N, S) into the nutrients in rice (NO_3^-, SO_4^{2-}) and reduce toxins harmful Fe (II), Mn (II), H_2S (Shouichi Yoshida & M.R. Chaudhry, 1979, Tran Minh Nguyet, 2013, Dinh Thi Lan Phuong, 2015).

Studies about the AWDI in the fluvial neutral soil in Tien Lu region (Hung Yen province) indicated that, after transforming flood field into a dry field, the redox potential increase from -198 to -111 mV and sulfate concentration rise too. Clearly, the Eh and sulfate content have a proportional relationship, when Eh increase 10.73 mV leading to the sulfate concentration rise 0.07 mg/100g (Dinh Thi Lan Phương, Tran Viet On, 2015).

F.N. Ponnamperuma (1985) demonstrated that flood irrigation reduced mobile zinc in the paddy soil. Experiments with waterlogged clay soil in Louisiana (pH = 4.8; organic content 2.8 %) showed that the mobile zinc concentration reduces from 0.3 to 0.09-0.08-0.03 ppm after 2-4-6 weeks.

Rice farming in the Red River Delta using conventional flooded irrigation at the level of 5-7 cm formed a reduction environment to reduce sharply the redox potential from -203 to -256 mV after flooding in a long time. Besides, pH reduced from 6.69 to 6.21 may be harmful for rice growth. Mobile sulfur content reduced from 11.26 to 10.89 mg/100g (Dinh Thi Lan Phuong, 2016), mobile zinc decreased about 0.055±0.001 mg/100g soil when the Eh reduced 10 mV. After 8-week flood soil, mobile zinc reduced about 6.6 times from the original (Dinh Thi Lan Phuong, Nguyen Thi Hang Nga, 2016). Furthermore, regular wetlands at 5 cm also reduce availability nitrogen *(Quyen Thi Dung, 2015)*.

In addition to protecting the soil environment, the AWDI also reduces fertilizer costs by 15÷30 %, creating rice quality with a nitrate content of 4.97÷6.76 mg/kg, which is lower than allowed by the World Health Organization (Can Tho University, 2014).

Thus, applying AWDI not only save water but also reduce greenhouse gas emissions for environmental quality improvement to award low carbon agriculture. The irrigation level under 3 cm ensures an anaerobic condition to the active microorganism to limit toxins (Fe (II), Mn (II)) aiming to protect soil environment. Moreover, a drying field time over 3 days helps to oxygen diffusion deeply to microorganisms metabolize minerals into important nutrients for rice.

4. Conclusion

The AWDI solution with an irrigation level of 2-3 cm and drying field time of 3-5-7 days is the sustainable irrigation solution to suit the global climate change in The Red River Delta, a main cultivated region in Vietnam. This irrigation solution has many advantages, so applying AWDI in total areas of The Red River Delta to save about 0.25 billions m^3 of water annual year and remaining yield. In addition, the AWDI reduces greenhouse gas emissions (CH_4, NO_2, CO_2…) and limits to increase global temperatures. The AWDI with water level under 3 cm and drying field time over 3 days ensure aerobic status for microbial activity to protect the soil environment and to limit toxins to rice. A drying field time is the best method to utilize the available nutrients in the soil and avoid the use of excess fertilizer causing soil pollution.

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Water Management along the Year
A case Study in Pineapple Plantation under humid tropical climate of Indonesia

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SUMMARY

Pineapple is a very unique crop. It is very sensitive to waterlogging, and could survive in dry condition, however, under water stress, the yield could reduce significantly. The humid tropical climate of Lampung, Indonesia, had total rainfall 2600 mm /year, where dry season usually occurred from June to October, sometimes very severe with zero rainfall in August and September. However, in rainy season, more than of 2000 mm rainfall will be poured during November until April, so waterlogging become severe problem, especially in flat area, and soil erosion in sloping area. Due to the facts that pineapple crop need long periods from planting to harvesting (around 18 months), the pineapple will face dry season and rainy season. In consequence, in pineapple culture , irrigation and drainage would be done during its cycle life. Irrigation were generally done in all pineapple stage, with the amount 20-30 mm/ha every 10 days using big gun sprinkler irrigator, and applied at the moisture content in soil readily available water (RAW) or 50% of soil field capacity. The source of irrigation water is deep well and natural pond, so preventing local pond from soil sedimentation due to soil erosion in rainy season become very important. Drainage system was designed based on local problems in each field (5-10 ha) and also in catchment scale (200-500 ha). In severe waterlogging area, natural pond and its tributaries must be deepen to reduce water table in catchment area scale, while local drainage channel with 0.5-1 m deep between pineapple field, will be dug along the field area. The natural pond which was used to improve drainage in rainy season, became source of irrigation water during the dry season.

Key words: pineapple, waterlogging, irrigation, humid tropical climate,

Introduction

The pineapple (*Ananas comosus* L., Merrill) is an herbaceous perennial plant. In Indonesia, pineapple could be harvested 15-18 months after planting, and after that it could be continued as ratoon crop for about 15 months. As reported by Rouffiange (1993), in Guyana, pineapple cycle for first crop could be 19 months, and followed second cycle (1st ratoon crop) around 12 months, and third cycle (2nd ratoon crop) for 12 months. The pineapple cycle depends on several factors, such as size (big, medium, or small size) and type of planting material (crown, sucker), type of clones, as well as growing environment conditions (soil fertility, nutrient, weeds, drainage).

Pineapple is a CAM (*Crassulacean Acid Metabolism*) plant, in which CO_2 is mainly fixed during night in which the stomata opened, and closed during the day. Due to this mechanism, pineapple is well known as drought plant tolerant due to the special characteristic of this plant. Bartholomew and Kadzimin (1977) showed that pineapple crop could grow without irrigation in many areas where rainfall is 1000 mm or less, and in the tropics and subtropics potential evaporation often greatly exceeds this value. Asoegwu (1988) in Nigeria showed that increasing irrigation frequency increased growth parameters of number of leaves, D-leaf length and days to 50% flowering, however, potential and harvested yields were reduced in irrigation when N > 150kg/ha. Alamiada et al.(2001) showed that there was a positive effect of increasing irrigation on the natural differentiation and the timing of the fruit harvest period, resulting in a shortening of the plant cycle, without reduction of fruit weight, in the plots with the highest irrigation. The higher irrigation also resulted in a more even distribution of the fruit harvest over its period.

Pineapple is very sensitive to waterlogging and need good soil drainage for root development. Bad drainage could induce the risk of plant loss from fungal pathogens of the genus *Phytophthora* (Souza and Reinhardt, 2007). Min and Bartholomew (2005) showed that flooding and drought stressed could effects pineapple yield. Plants induced to flower with ethephon after continuous flooding or drought stress had significantly smaller fruits than control plants, hence significantly reduced pineapple fruit mass**.**

Due to the long period life cycle of a pineapple, so growing pineapple in Indonesia, which is have two seasons, dry season and rainy season, will face either dry season and rainy season. As consequence, irrigation will be done during the dry season, and drainage will be done during the rainy season.

This paper discuss the water management of pineapple during dry season and rainy season of pineapple cv. ‘‘Smooth Cayenne’’ grown in humid tropical of Lampung, Indonesia, in plantation scale.

Pineapple Structure related to water

Pineapple has a photosynthetic adaptation (crassulacean acid metabolism (CAM)) that facilitates the uptake of carbon dioxide at night, and improves its water-use efficiency under dry conditions (Carr, 2012). There are relatively few stomata per unit of pineapple leaf area, small and situated mainly on the underside of the leaves in depressed channels, and protected by a heavy coat of waxy trichomes, so the pineapple has a very low rate of transpiration (DPI,2009).

There are two types of root system in pineapple, the main root in the soil and axillary roots in the stem (Fig.1).The axillary roots that can absorb moisture and dissolved nutrients directly in the same way as soil roots do (DPI,2009).

Climate and Water Balance

The climate data consisted of monthly rainfall, maximum and minimum temperature, relative humidity, and day length which collected from PT.GGP climatology station (4°49’07”S, 105°13’13”E) were presented in Fig.2 and Table 1.

The climate data was analyzed using Cropwat v.8. which was designed by FAO, using data from 1972-2009.

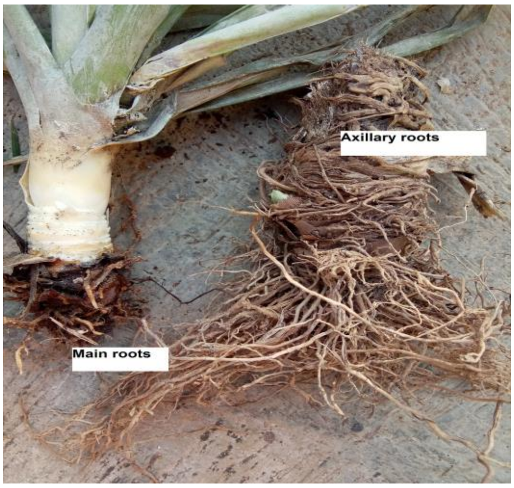

Fig. 1. Main roots and axillary roots of pineapple

Table 1. Climate properties in pineapple plantantion in Lampung, Indonesia

Month	Temp (^{0}C)		RH	Wind	Sun	Rad	ETo
	Min	Max	%	km/d	hours	MJ/m^2/d	mm/d
Jan	22.2	31.8	91	107	4.1	15.8	3.4
Feb	22.2	32	90	106	3.2	14.6	3.2
Mar	22.3	32.4	91	83	4.5	16.5	3.6
Apr	22.8	32.5	91	78	4.4	15.6	3.4
May	23.1	32.8	90	80	5.5	16	3.4
Jun	22.5	32.4	90	82	5.4	15.2	3.2
Jul	22	32.5	88	92	5.4	15.5	3.3
Aug	22.1	32.8	87	109	6.3	17.8	3.8
Sep	22.6	33.4	86	117	6	18.5	4.1
Oct	22.8	33.8	86	107	5	17.3	3.9
Nov	22.6	33	88	93	4.2	15.9	3.6
Dec	22.7	31.9	90	91	3.4	14.6	3.2
Aver	22.5	32.6	89	95	4.8	16.1	3.5

The average maximum evapotranspiration (ETo) is about 3.5 mm/day, and with Kc around 0.89 (Azevedo et al., 2007), the actual evapotranspiration from pineapple is around 3.1 mm/day. As shown in Fig.2., the deficit month occurred from May until October (6 months).

Low value of pineapple evapotranspiration was found by Hanafi et al. (2010), which found requirement water was found 2.43 mm/day in initial stage , and subsequent development stage required smaller amount of irrigation water (approximately 1.55 mm/day).

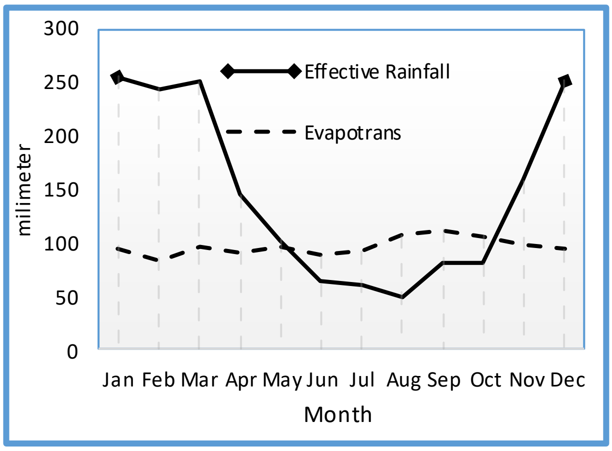

Fig.2. Water balance , with pineapple Kc=0.89 and effective rainfall (70% of rainfall)

Analysis of rainfall data from 1972-2014 showed that the amount of rainfall during dry season was from 2.3-15% of total rainfall in the year, mostly below 5% (Table 2). It means that almost 95% rainfall was pour during rainy season, which make soil erosion due to rainfall factor will be high.

Table 2. Long dry season recorded 1972-2014

Year	Month					Total Dry	Total Rainfall	% rainfall
	6	7	8	9	10			
	mm							
1982	48	15	0	3	26	92	1737	5.3
1991	12	8	3	6	32	61	2350	2.6
1994	4	35	0	15	45	99	2433	4.1
1997	13	21	2	0	0	35	1557	2.3
2002	94	99	12	7	0	210	2169	9.7
2004	19	84	0	97	98	297	1986	15.0
2006	44	9	0	0	18	71	2263	3.1
2011	59	84	0	0	92	234	1695	13.8

Irrigation in Pineapple

For irrigation purposes, pineapple could be devided into five stage based on its age after planting : first vegetative growth (0-3 month after planting), fast vegetative growth (3-9 month), flowering (9-12 month), fruit formation (12-14), and fruit harvest (14-15 month). As long as the irrigation water and equipments are available, all the stage must be irrigated during dry season. If the water is not enough during one stage, it will effects the following stage, and finally effects the final yield.

Irrigation on early vegetative growth, has other objective. The pineapple root in the soil is not developed yet, however, making contact between soil and pineapple should be done in order the pineapple has a good "set plant", hence have good rooting Irrigation will make the soil disperse, so it could fill the space that might be occurred around the base of planting material.

around the base of the planting material

The source of irrigation water in pineapple is from deep well and natural pond. The irrigation water applied using big gun sprinkler, with capacity of the sprinkler around 5 ha/day and rotated 180^{O} when irrigated. If enough rainfall occurred during dry season, the irrigation will stop temporary.

Based on water balance analysis, the irrigation should be started from May until October with the amount around 90-110 mm.. The soil texture dominated in pineapple area are clayey, sandy clay, and sandy loam, with aivalable water 16, 9, and 20% respectively. The iirrigation was given at 50% of field capacity or in readily water available (RAW) or when the water is in managable allowance deficite (MAD) condition. So teroritically, in 20 cm soil depth with 10% of RAW at sandy loam soil, the amount of water given was 20 mm. With evapotranspiration of pineapple around 3.1 mm/day, the pineapple should be irrigated again after around 7 days.

In practice, the amount of water given was already accordance the soil water avaibility, between 20-30 mm per ha, however, there is still doubt about the evaporation rate of pineapple, especially the flowering stage, because the canopy of pineapple already almost 100% covered the soil. The second is pineapple is a CAM plant in which the stomata closed during the day, so the transpiration should be lower. Based on this reasons, the return period of pineapple irrigation was done every 10 days.

To see the effects of irrigation and non irrigation in pineapple, there was a good measurement was done using Licor 6400 XT when the age of plant was around 6 months by R & D PT.GGP (2011). The observation was done at night from 19:00 until 22:00 during the dry season in September 2011. The pattern of photosynthesis and transpiration rate were very different in irrigation and non irrigation treatment (Fig.3 and Fig 4). Under irrigation treatment, photosynthesis and transpiration rate were higher, while in non irrigation treatment the process was almost stagnant. The average of photosynthesis and transpiration rate at irrigation treatment were 3.39 **μmol CO_2 m^{-2} s^{-1}** and 0.32 mmol H_2O m^2 s^{-1} respectively while in non irrigation treatment only 0.03 and 0.01 respectively. The yield from sampling with the amount of 400 pineapple plants showed that the average of pineapple fruit was 1,398 kg in irrigation treatment with different significantly with non irrigation treatment which only 1,164 kg.

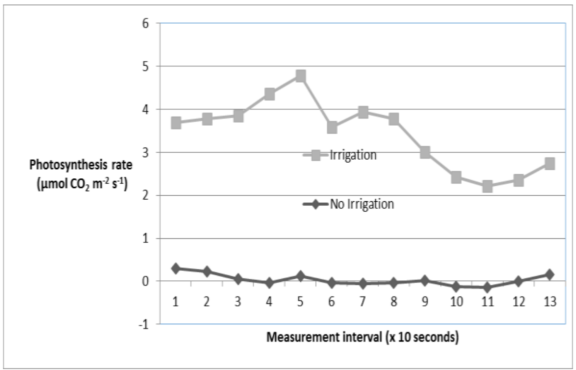

Fig.3. Photosynthesis rate in irrigation and non-irrigation

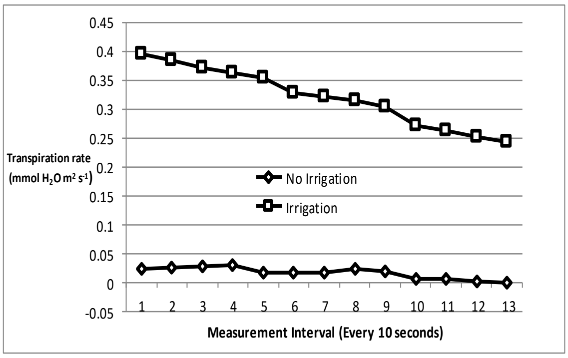

Fig.4. Transpiration rate in irrigation and non irrigation

Drainage Practice in Pineapple

In pineapple area, during rainy season, there are three types of water that occurred due the rainfall: ponding, waterlogging, and surface runoff. Probably, waterlogging is the most important factor that affecting pineapple yield. Water logging will reduce oxygen from the soil, and change the soil situation, from oxidation to reduction, as well as induced phytophthora disease in pineapple.

Ponding is the accumulation of excess water on the soil surface; waterlogging is the accumulation of excess water in the root zone of the soil (Ritzema et al (1996). So, the excess of water due to ponding will be remove by surface drainage, and the excess of water due to waterlogging will removed by subsurface drainage. The other term is sedimentation in the natural pond which is resulted from surface runoff which induced soil erosion

Before 2008, the pineapple crop was planted on raised bed about 1.2 m wide with double row crop (Fig.5). However, there were several limitation using the bed system, such as soil erosion destroy the bed system, sensitive to drought during dry season, and the population is less. The raised bed system was good in avoiding ponding or waterlogging during rainy season. Since 2010, the pineapple was planted in row system or single row (Fig.6), however, fresh pineapple was still planted in raised bed due sensitive to waterlogging.

Fig.5. Raised bed for double system in pineapple

Fig.6. Single row system in pineapple

Because surface and subsurface drainage is very important in pineapple, there are several strategies to apply drainage system in pineapple

(a)sub soiler application for counting waterlogging problems. Sub soiler with mole was used before finishing land preparation until the depth of 90 cm to break out soil hardpan and making sub surface drainage. However, under high rainfall, the sub soil is not effective and the hardpan appear again 4 after planting (Fig.7).

(b)surface drainage; surface drainage as well as surface runoff, were control by making (i) tertiary channel between plot which collected water between crops as well as road (ii) secondary channel, collected water from tertiary channel and passed to primary channel and (iii) primary channel. A silt trap was usually built at the secondary and primary channel to entrap sediment from soil erosion.

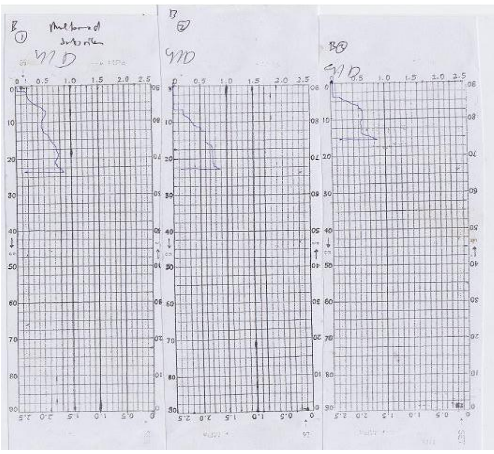

Fig.7. Penetrograph measurement 4 months after subsoiling

The last strategy to reduce water table in catchment scale is deepening natural pond. During rainy season, natural pond could collect rainfall which will be used as irrigation water during dry season.

In addition to requirement of pineapple for good soil drainage, the purpose of the drainage system in plantation scale was to control soil erosion in the road and sedimentation in natural pond, and the ease of farming equipment's transportation of equipment, such as tractor, harvesting's car etc.

Conclusion

In Indonesia, pineapple culture would be faced dry and rainy season, and irrigation and drainage must be designed correctly. Although pineapple could be said as xerophyte plant, irrigation was proved to be able increase its crop performance, such as photosynthesis. The pineapple was irrigated with the amount of 20-30 mm with 10 days interval irrigation. During rainy season, ponding, waterlogging and surface runoff must be control to improve pineapple crop, control soil erosion and sedimentation as well as the accessibility of farm equipment.

Acknowledgement

The writer wish to thank to PT.Great Giant Pineapple (GGP), Central Lampung.

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Sediment Trap using Small Farm Reservoir in Rainfed

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SUMMARY

Small-Farm Reservoir (SFR) is a method to harvest rain water while rainfall and be used while short drought occurred. The experiment aims to measure sedimentation which flowed into SFRs from catchment area. Three SFRs were observed from November 2013 to September 2014. Catchment of SFR-A and SFR-C are farm field which was cultivated paddy and non-rice food. Catchment of SFR-B consists of farm field, teak plantation, asphalt road and residence. SFR-B has higher SDR than SFR-A and SFR-C. Silt particle is highest particle which can be trapped in SFRs. Bedload sediment has higher C organic than origin catchment soil. SFR can prevent soil loss and fertility by trap the sediment and can be returned into farm field.

Introduction

Erosion or soil loss is a common degradation which become problem in intensive land use, like in agriculture field. Soil loss often occurred in rainfed cultivation and it becomes serious problem because field surface is opened and the soil explored by human which affected the soil easy to be transported. Although the erosion is natural process (Daniel et al. 2015) which can be occurred in everywhere as impact of run off increasing, but heavy erosion must be prevented so that land degradation will not be occurred (Winarno et al. 2008; Fuady, Satriawan, and Mayani 2014). The other solution constructs sediment trap in the field, but it is need space which can be decrease agriculture area.

The experiment aims to measure sedimentation which was trapped in the SFR from catchment area.

Material and Method

The observation was conducted from October 2013 to September 2014 where located in Central Java, Indonesia (Figure 1). The location is rainfed area which is consisting of three crop season. Those are 1st crop season started October to January, 2nd crop season started February to May and 3rd crop season started June to September. First crop season commonly cultivate rice, majority in 2nd crop season cultivate non-rice foods crop (*palawija*), and last crop season few field cultivated because irrigation rarely.

Climate data along observation were collected from Portable Automatic Weather Station which installed in the observation area. Water level data were collected loggers which were installed in each SFR.

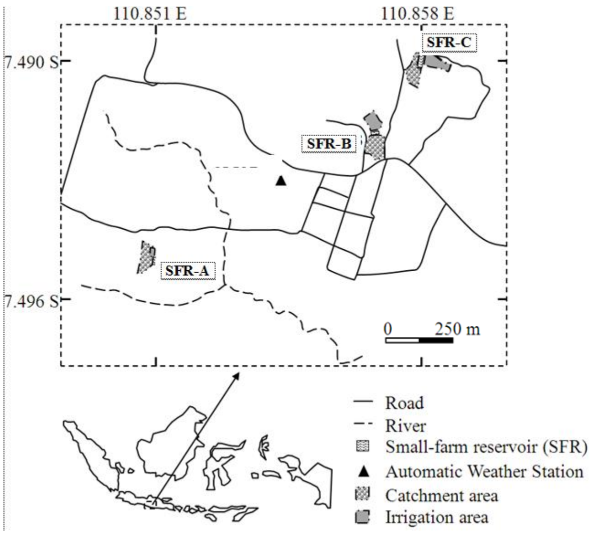

Figure 1: Map of observation site (Ariyanto et al. 2016)

Sediment bedload sample from each SFRs were taken in September 2014 or in dry season after SFRs empty or dried by pump. Bedload solutions were taken for sample during SFRs were dried and evaporated in laboratory.

The observation was done by three SPRs in a village. The characteristic each SFR is shown Table 1. SFR-A and SFR-C have different in size and catchment area as farm field and SFR-B consist of farm field, teak plantation and residence.

Table 1: Catchment area characteristic, SFR and irrigation area size (Ariyanto et al. 2016)

	SFR No.	SFR-A	SFR-B	SFR-C
Catchment area (m^2)		2,877	4,184	4,068
SFR (m^3)		66	132.5	182.6
W (m)*D(m)*H(m)		10*5*1.32	25*5*1.06	22*5*1.66
Irrigation area (m^2)		232	1,733	2,968
	Characteristics of catchment area			
Land use (%)	Farm land	100.0	65.4	100.0
	Teak plantation	0.0	33.2	0.0
	Asphalt road	0.0	0.0	0.0
	Residence	0.0	1.4	0.0

Result and Discussions

Soil characteristic in catchment area is dominated by silt particle for SFR-A and SFR-C and sand particle in SFR-B. It caused total catchment area of SFR-A and SFR-C used once each year for paddy culture so that many sand particles became smaller particles. SFR-B is not all used for farm field, although it is dominated of catchment area. The others were used for teak plantation and smaller for residence.

Result of sediment analysis shows SFR-B has higher sediment delivery ratio (SDR) than SFR-A and SFR-C (Table 2). It means much sediment from catchment area flow and can be trapped by SFR. Farm field which has terrace system can prevent soil loss from catchment area. Residence and asphalt road are indicated to increase sediment delivery because those land use increase run off discharge.

Table 2. Soil loss balance in each SFR from December 2013 to September 2014

	SFR-A	SFR-B	SFR-C
(1) Total rainfall (m^3)	4,157	6,046	5,586
(2) Suspended inflow (m^3)	536	589	1334
(3) Sediment inflow (kg)	568.94	1,568.74	3,617.79
(4) Sediment bedload (kg)	188.02	1,449.16	2,118.43
SDR [(4)/(3)]	0.33	0.92	0.59
(5) Sediment overflow (kg)	319.20	27.82	250.06
[(5)/(3):%]	56.10	1.77	6.91
(6) Sediment irrigation (kg)	61.72	91.76	1,249.31
[(6)/(3):%]	10.85	5.85	34.53

Sand particle is higher than other particle from sediment texture. It means sand particle is particles which easy to transport by run off and settle down in SFR. Diameter particle influence particles movement and settle down in SFR.

Table 3. Soil catchment and sediment bedload characteristics in each SFR

	SFR-A	SFR-B	SFR-C
Catchment soil			
C organic (%)	1.31	1.19	1.98
Sand (%)	25.79	52.29	18.77
Silt (%)	62.88	38.89	66.62
Clay (%)	11.33	8.82	14.61
Bedload sediment			
C organic (%)	2.44	1.24	2.98
Sand (%)	1.38	6.27	2.40
Silt (%)	83.51	73.58	80.04
Clay (%)	15.11	20.15	17.56

Sedimentation content higher C organic than soil origin. Sediment was trapped in SFR which increase C organic. Other reason, much of organic matter, such as leaf, also trapped and decomposed in SFR which increase C organic content.

Conclusion

SFR can prevent soil loss from catchment area which located upper. SFR also collect C organic which can be returned to the field.

Acknowledgement

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Recent water management technology of rice cultivation in Japan and our future research needs

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SUMMARY

Due to a constant population movement from the rural area to the urban area, the rice production in Japan currently confronts serious problems such as a shortage of successors and high labor costs. To cope with these problems, entrustment of farm land to the selected pillar farmers is encouraged to increase the management scale of them. Under this policy, labor productivity should be enhanced especially by streamlining of water management. Owing to recent rapid development of ICT, the water management in rice cultivation can be drastically eased by making use of such modern technology. In Japan, various ICT systems have been developed and deployed at canal systems and also field plots. However, it has still been unclear how much water management work can be reduced by how much investment to the ICT system. Actual concrete needs of farmers with regard to water management have not been investigated closely so far. As both Vietnam and Japan live on rice, exchange of experiences and knowledge with each other and collaborative research activity on these issues must be fruitful.

Introduction

1) Rice cultivation in Japan

Japan is located at the northeast edge of monsoon Asia, where the staple diet is rice. As rice has been the principle agricultural product in Japan, rice paddy fields occupy 54.4 % of the total agricultural land in Japan. Because rice is grown under the flood condition, plenty of water is required during the crop season to compensate the evapotranspiration and the percolation in paddy fields. The well-developed irrigation and drainage system have been constructed in every region to carry the water resources for rice cultivation. It is important for farmers to maintain and control the appropriate water condition in paddy fields in order to get higher yield and better quality of rice.

2) Problems in rice production in Japan

The rice production in Japan currently confronts serious problems such as a shortage of successors and high labor costs. There is a constant population movement from the rural area to the urban area and most of the young people in the agricultural area are reluctant to succeed farmhouse management. Because of the shortage of successors, considerable areas of farmland have been abandoned as the farmers get old and eventually retired. The land abandonment would induce adverse effects such as soil erosion, increase in flood frequency, or spreading of insect pests.

To cope with the above problems, the Japanese central government is taking measures to promote the increase of the management scale of the selected pillar farmers. Especially, entrustment of farm land to the pillar farmers is strongly encouraged (Japanese Ministry of Agriculture, Forestry and Fisheries, 2016). This policy must realize management of the larger area of paddy fields by less workers, causing considerable increase in labor per a farmer. Under the future provision of further expansion of cultivation areas per a farmer, labor productivity should be enhanced especially by streamlining of water management activities in rice cultivation.

Recent water management technology

1) ICT in irrigation and drainage

Owing to recent rapid development of ICT, it has become possible to instantly transmit information on the amount of available water and on the demand of farmers interactively, making use of Internet and various field sensors (Olalla *et al.*, 2003). It is considered that the water management in paddy fields can be drastically eased by making use of such modern technology. In future, irrigation systems should be a service providing systems for farmers and the service quality should be further improved from a demand-oriented point of view (Renault & Montginoul, 2003).

2) Canal system

In Japan, the canal system for irrigation and drainage is managed by Land Improvement District (LID), which is a community of farmers who uses the canal water for their agricultural production. There are nearly 4,000 LIDs in Japan operating headworks, diversion works, pump stations, gates and so on. It has already realized in the major LIDs that the water flow at important points along main canals can be continuously monitored and major gates or pumps can be remotely manipulated from the LID office or by various mobile terminals. The system is called Tele-Meter Tele-Control System (TM/TC) (Fig.1). Many field sensors and networks have been deployed in the canal network. Such system releases the operators of the canal system from frequent patrol works throughout the canal network.

Fig.1 TM/TC system for canal management.

Fig.2 Remote controlled valve at a water inlet of a paddy field plot.

3) Plot system

For each paddy field plot, "irrigation information service system (IISS)" has already been manufactured in Japan. IISS gives the information on the variation of the floodwater depth, the picture of the field plots and the basic meteorological data directly to the farmers through various information terminals. The floodwater depth of each paddy plot is monitored in much more shorter interval than the conventional patrol. The spread of IISS is beneficial for LIDs as well because a good deal of information concerning irrigation water use can be obtained. Recently, even the water inlet valve and the drainage valve at each paddy field plot can be remotely operated by usage of ICT (Fig.2). These ICT gadgets must reduce the patrol frequency, bringing about surplus time for the farmers. Consequently, the farmer can be entrusted more plots from an elder farmer without a successor. The surplus time also enables the farmers to launch cultivation of other cash crops or sales promotion, resulting in economic improvement of their farmhouse management.

Our future research needs

In both Vietnam and Japan, the staple diet is rice and more than half of the agricultural land is occupied by rice paddy fields, which require a lot of irrigation water and water management labor. On the other hand, the constant population movement from the rural area to the urban area is observed in both country. Especially, the reluctance of young people to succeed farmhouse management may be a common serious problem.

Introduction of ICT to agriculture can be one of the solutions of this problem. Can ICT be really an effective remedy? It has still been unclear how much water management work can be reduced by how much investment to the ICT system. Actual concrete needs of farmers with regard to water management have not been investigated closely so far. It is necessary to clarify the critical point for reduction of water management labor and to propose effective service for farmers to ease their water management. In these points, there may be common problems and the differences according to the real situation in Vietnam and Japan. As both country live on rice, the exchange of experiences and knowledge with each other and collaborative research activity on these issues must be fruitful.

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Co-design of adaptation to Climate Change with the current strategy in the water management sector in Thailand -A concept for multi-criteria analysis-

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SUMMARY

Climate Change is a challenge in managing risk. The objective of our study is to develop a framework to co-design an adaptation strategy. It is essential to assess the effects of policies quantitatively from various aspects, to share the result of assessment among stakeholders, and to identify the priorities. We collected various socio-economic and natural environment data. We are planning to develop a damage function which will be applied to impact assessments of CC on human health, poverty, and economic loss. The effect of adaptations alleviating the damage in various criteria will be assessed. The expected outcome of this analysis is to identify the priority of local strategies considering regional characteristics of natural and social conditions.

Introduction

The Working Group II (WGII) of the Intergovernmental Panel on Climate Change (IPCC) to the Fifth Annual Report (AR5) considers the vulnerability and exposure of human and natural systems, the observed impacts and future risks of climate change, and the potential for and limits to adaptation (IPCC, 2014). One of the key messages is that Climate Change (CC) is a challenge in managing risk. Three points that are important are (1)global annual economic losses are estimated between 0.2 and 2.0% of income for additional temperature increases of up to 2℃, (2)co-benefits, synergies, and trade-offs exist between mitigation and adaptation and among different adaptation responses, and (3)available strategies and actions can increase resilience across a range of possible future climate while helping to improve human health, livelihoods, social and economic well-being and environmental quality.

Toward incorporation of adaptation to CC into national master plans, there are three challenges. First, adaptation is still in the research and development process. Even in Japan, the national master plan including adaptation to CC has formulated in 2016. This is because the quantitative estimation of adaptation is limited. The second is that adaptation should have diversities considering local characteristics. Especially, case studies of adaptation to CC considering local characteristics in the middle income countries and the developing countries are invaluable. Third is that adaptation to CC should be integrated with governmental strategies of existing sectors such as disaster risk management, integrated water resources management and rural development. Furthermore, instead of the individual adaptation to CC, the well-balanced good portfolio of the various adaptations to CC should be composed.

The objective of our study is to develop a framework to co-design an adaptation strategy. Political or economic barriers to the adaptations to CC have been raised as 1) trading cost, 2) market failure, 3) culture and customs, 4) fairness, 5) government failure and 6) prediction uncertainty. To overcome these barriers, it is essential to assess the effects of policies quantitatively from various aspects, to share the result of assessment among stakeholders, and to identify the priorities. In this study, we are developing an assessment in terms of human health, poverty reduction and economic growth.

Material and Method

Various data were collected for the purpose of developing the assessment scheme: socio-economic data such as population, gross regional production, poverty ratio, disaster damage and natural environment data such as topography, precipitation, flood frequency etc.

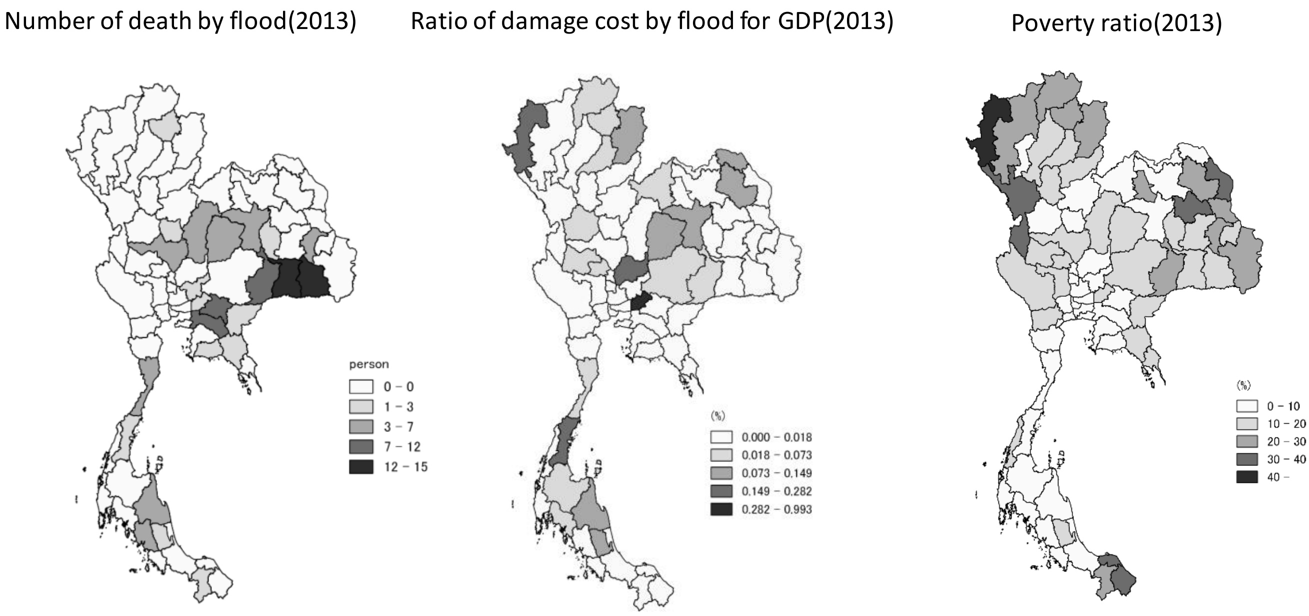

Fig.1 Spatial distribution of the number of death by flood, ratio of damage cost by flood to GDP and poverty ratio in 2013

Result and Discussions

As an example of collected data, spatial distributions of the number of death by flood and ratio of damage cost by flood to GDP are shown in the left and middle of Fig.1. In Thailand, frequent flood occurs in the middle and northeast region; the topography is very flat and the flood can be recognized as 'inundation.' For this reason, the main reasons for death by flood are accidental fall in a hidden hole and electrification. Economic damage concentrates on the Bangkok capital and industrial zone such as Ayuttaya and Nakhon Ratchasima.

In contrast, flash flood occurs in the northern region; the topography is steep by mountains and the value of poverty ratio is seriously high. The number of death is not significant due to low population density and the local knowledge to protect from flood damage. Economic damage by flood is relatively high in the northern region such as Mae Hong Son; agriculture is the main industry in this region and vulnerable to flood damage.

Conceptual result for the multi-criteria analysis is shown in **Fig.2**. BAU showed a future projection based on the business as usual. Policy 1 and 2 indicates the result of scenario analysis in multi-criteria of the number of death, GDP and poverty ration when the same amount of investment is embarked. This information will contribute to decision making by stakeholders.

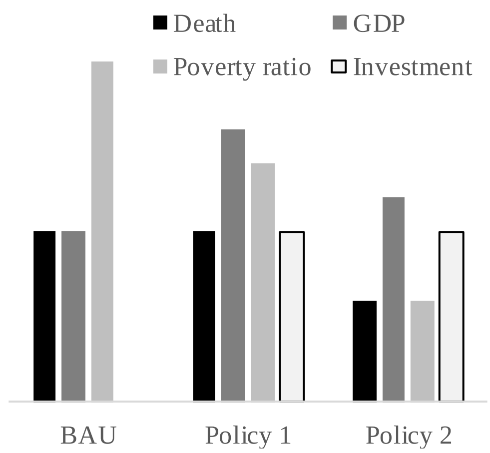

Fig.2 Conceptual result for the multi-criteria analysis

Conclusion

We are planning to develop a damage function which will be applied to impact assessments of CC on human health, poverty, and economic loss. The effect of adaptations alleviating the damage in various criteria will be assessed. The expected outcome of this analysis is to identify the priority of local strategies considering regional characteristics of natural and social conditions.

Acknowledgement

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Energy use efficiency of integrated rice-duck farming in a selective area of Ha Nam province, Northern Viet Nam

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SUMMARY

Integrated rice–duck farming, a form of organic agriculture, has been widely applied in Viet Nam with many economic, environmental, and ecological benefits. This is an alternative system that aims to reduce the consumption of fossil fuels, pesticides, and mineral fertilizers as compared to conventional paddy rice cultivation. The current study was conducted in Ha Nam province of northern Viet Nam. In this study, we collected data in recent times and make comparison of energy inputs and outputs of organic rice– duck farming system to conventional rice production system in Ha Nam province. Our results show that energy input of organic rice–duck is lower than that of conventional rice. On the contrary, the energy output of organic rice–duck is higher than that of conventional rice. Besides that, integrated rice–duck farming has more energy efficiency than conventional rice farming. The fuel was amounted approximately to 33,2 % of total energy for integrated rice–duck farming and 32 % for conventional paddy rice. The machinery consumed 14,6% of total energy for integrated rice–duck farming and 11,2 % for conventional rice. Then, fertilizers consumed 0 % of total energy for integrated rice–duck farming versus 21,6 % for conventional paddy rice.

Keywords: Renewable energy**,** Paddy rice, Rice–duck farming, Sustainable agriculture

Introduction

Population growth is believed to be one of the main challenges for the future of human civilization (Kibirige 1997; Swaminathan 2010) because of food shortage caused by limited resources and the limitations of traditional agriculture. Fortunately, modern agriculture has successfully solved the problems by developing more efficient techniques, such as using more efficient plant and animal varieties, increasing the use of fertilizers, extending irrigation, effectively controled insects and diseases, etc. (Guangyong et al. 2011; Mosher and Corscadden 2012), however modern agriculture requires higher amounts of nonrenewable energy sources such as fossil fuels for operating farm and irrigation machinery, producing chemical fertilizers, pesticides, and herbicides and using electrical inputs which may be produced by fuel consumption in power plants. Besides, modern agriculture has also to face the problems of the emission of trace greenhouse gases and soil characteristics decline (Anh, N.V, 2010; Phuong, D.T.L 2014). Therefore, methods of decreasing the energy needs of modern agriculture are very necessary for agriculture production.

Some researchers show that the use of renewable energy may reduce the consumption of fossil fuels, saving natural resources and leading to sustainable agriculture (Kizilaslan 2009). Organic agriculture, which has been widely studied in recent years, is seemed to lower energy consumption and balance long-term productivity with ecological sustainability (Mingl and Sauerborn 2006). Rice–duck farming, a form of organic agriculture, has many economic, environmental, and ecological benefits. They have been recommended to apply in many Asian countries, particularly Japan, China, Indonesia and Philippine. This system creates an yield increasing because of integrated cultivation of rice planting and duck breeding. It also saves farmer's inputs of herbicides, insecticides, fungicides, and chemical fertilizers which are replaced with duck manure and frequent movements of ducks to control weeds and insects. Recent studies have investigated high advantages of this system with respect to environmental and ecological issues compared to conventional cultivation methods.

Rice (*Oryza sativa* L.) is one of main agricultural products in Viet Nam contributed significantly to the GDP. However, the paddy crops requires plenty of water and labor, it is believed to consume much energy. The rice conventional cultivation method in Vietnam used chemical fertilizer and organic matters increase the cost for rice product and effects long term on environment. Thus, efforts are immediately required not only to improve rice production but also to decrease the costs by solving environmental problems such as nitrate leaching and eutrophication. Rice-duck multualism organic farming has been widely applied in Vietnam, especially in flood areas. This study aims to make comparison of the energy use efficiency between organic (rice –duck cultivation) and conventional rice production methods.

Material and Method

2.1 Site description

The current study was conducted in Duy Tien District of Northern Ha Nam Province, the gateway to the South of Hanoi. Red River is along the northeast of the district (Fig.1). This area is located between 105053'26" and 106002'43" lat. N and 20032'37" and 20032'37" long. E. The climate of the area is tropical monsoon, and characterized by the annual average rainfall from 1,800-2,000mm, distributed mostly in autumn (took account for nearly 80% of total rainfall). During the study period, anual precipitation measured 1,660.6 mm in 2014 and 1,520 mm in 2015. The annual average temperature is 23.2°C to 24.6°C, with a monthly maximum ranging from 32-35°C in June and July and a minimum of 6-8°C in November and December. The main type of soil here is alluvium soil.

2.2 Data collection

The study was collected data for a two year period from 2014 to 2015 by gathering data from different five rice planting farms regarding to variety and cultivation method in two communes, Duy Tien District. The study took both conventional rice cultivation as well as rice-duck mutualism organic farming into consideration with the average area of 1ha.

The survey volume was determined by the simple random sampling method (Yates et al 2008; Ghasemi Mobtaker et al 2010):

$$n = \frac{N \times s^2 \times t^2}{(N-1)t^2 + s^2 \times t^2} \qquad (1)$$

Where: n is the required sample size

s is the standard deviation

t is the t value at a 95% confidence level

N is the number of holding in target population

d is the acceptable error (permissible error 5%)

Fig 1. Location of Duy Tien District, Ha Nam Province

2.3 Data mining

The inputs considered for these two modes were machinery, human labor, diesel fuel, chemical fertilizers, organic fertilizers, pesticides, fungicides, and herbicides as biocides, water for irrigation, seed, rice bran, and duckling. The outputs considered were grain, straw, and duck as a product. The input and output amounts of 1 ha utilized in two rice production systems are referenced in Table 1.

Human energy as an energy input was calculated by multiplying the number of man-hours (hha^{-1}) based on the estimated power rating of human labor (MJh^{-1}) from Table 1. The energy used by machinery was estimated as follows (Kitani et al. 1999):

$$ME = E \times G \times T \quad (2)$$

where ME is the machinery energy (MJ), E is the production energy of the machine (Table 1), G is the mass of the machine (kg), and T is the economic life of the machine (years). Chemical fertilizer energy, diesel fuel, seed, biocides, organic fertilizers, water, rice bran and duckling in rice production can be calculated by multiplying the quantity of the material used on the farms by the energy equivalent of each material.

The energy output which included paddy rice, straw and duck can be separately estimated by multiplying yield of each output (kg ha^{-1}) by the energy equivalent (MJ kg^{-1})

The total input energy equivalent was the sum of the energy equivalence of each input (MJ). Similarly, the total output energy equivalent can be calculated by adding up the energy equivalences of all outputs (MJ). From the two measurements, the energy use efficiency, energy productivity, specific energy and net energy were also calculated. (Hulsbergen et al. 2001; Yilmaz et al. 2005; Dermircar et al. 2006; Shahan et al. 2008).

$$Energy\ use\ efficiency = \frac{Energy\ Output\ (MJ\ ha^{-1})}{Energy\ Input\ (MJ\ ha^{-1})} \quad (3)$$

$$Energy\ Productivity = \frac{Production\ (kg\ ha^{-1})}{Energy\ Input\ (MJ\ ha^{-1})} \quad (4)$$

$$Specific\ Energy = \frac{Energy\ Input\ (MJ\ ha^{-1})}{Production\ (kg\ ha^{-1})} \quad (5)$$

The total energy input was also classified into either direct and indirect or renewable and nonrenewable forms. Direct energy (DE) included human labor and diesel fuel energy used in the production process, while indirect energy (IDE) consisted of machinery, seed, chemical fertilizer, biocide, organic fertilizer, rice bran, water, and duckling and duck energy. In this study, Renewable energy (RE) consisted of seed and human labor, organic fertilizer, rice bran, water, duckling and duck; nonrenewable energy (NRE) included machinery, diesel fuel, biocides, and chemical fertilizers.

Results and Discussions

The inputs and outputs for the rice–duck and the conventional rice cultivation are shown in Table 2.

Table 1. Energy equivalent of inputs and output in two different rice production systems

Input	Unit	Energy equivalent (MJunit-1)	References
A. Inputs			
1. Machinery	h	62.70	Royan et al.(2012),
2. Labor			
Male	h	1.96	Singet al.(1994,
Female	h	1.54	Singet al.(1994
3. Diesel	L	56.31	Alikhani (2013)
4. Chemical fertilizer	–		
Nitrogen (N)	kg	66.14	Kitani (1999)
Phosphorus (P2O5)	kg	12.44	Kitani (1999
Potassium (K2O)	kg	11.50	Kitani (1999
Zinc (Zn)	kg	8.40	Alikhani (2013)
5. Organic fertilizer	ton	303.10	RaiJadidi (2010)
6. Biocide	–		
Insecticide	kg	229.00	Kitani (1999)
Fungicide	kg	115.00	Kitani (1999)
7. Seed	kg	14.70	Kitani(1999)
8. Rice bran	kg	12.55	Sayin et al.(2005)
9. Water	m3	1.02	Alikhani (2013)
10. Duckling	kg	14.10	William (2008)
B. Outputs			
1. Paddy rice	kg	14.70	Alikhani (2013)
2. Straw	kg	12.50	Alikhani (2013)
3. Duck	kg	14.10	William (2008)

Duck farming is labor-intensive, thus the human labor for the rice-duck mutualism organic farming was higher than conventional rice cultivation system (320 h and 290 h., respectively). Rice-duck organic farming requires less energy input in machinery than the conventional rice cultivation, around 150 h ha^{-1} of rice-duck organic farming compared with 202.1 h ha^{-1} of conventional rice cultivation. Besides, only 2.4 tons of organic fertilizer was used in the rice-duck mutualism organic farming system compared with about 8 tons required to apply in the traditional rice cultivation.

The long-term adverse health and environmental effects of biocides such as insecticide, herbicide, and fungicide as well as chemical fertilizers like Nitrogen (N), Phosphorus (P_2O_5) was be minimized. Because there is no chemical fertilizers or biocides needed to utilize in the rice-duck mutualism organic farming areas (table 2). Therefore, the system seems to be more beneficial to the environment. The amount of diesel fuel utilized for conventional rice cultivation was greater than the rice-duck mutualism organic farming, at approximately 654.5 and 600L, respectively. Fuel consumption energy input in both systems was 52.67% for the rice-duck mutualism organic farming and 32.65% for the conventional rice cultivation.

The rice-duck organic farming used less energy inputs than the conventional rice cultivation, but the energy outputs of the rice-duck organic farming was obtained more. The energy input required in the rice-duck organic farming was significantly lower than the conventional rice cultivation, at 64,146.5 MJ ha^{-1} and 112,893.5 MJ ha^{-1}, respectively, but the total energy output in the rice-duck organic farming was slightly greater than that of the conventional rice cultivation, at about 134,801.2 MJ ha^{-1} and 124,488.3 MJ ha^{-1}, respectively.

Table 3 shows the energy consumption, productivity, and energy gain of various processes in rice production. The energy efficiency of the rice-duck organic farming was doubled compared with the conventional rice cultivation, at 2.1% and 1.1%, respectively. The energy productivity values of the rice-duck mutualism organic farming was estimated to be 0.15 kg MJ^{-1}, while the figure for the conventional rice cultivation was only 0.08 kg MJ^{-1}. The net energy values in the rice-duck mutualism organic farming 70,655 MJ ha^{-1}, in contrast to the figure for the convention rice cultivation, which only 11,595 MJ ha^{-1} was produced. The indirect energy was nearly equally used, at 45.6% for the rice-duck mutualism organic farming and 42.87% for the conventional rice cultivation. Meanwhile, the figure for direct energy in both systems was sharply different, 53.54% for the rice-duck mutualism organic farming and 33.09% for the conventional rice cultivation system. The percentages of renewable and nonrenewable energies for the rice-duck mutualism organic farming were 31.80% and 67.33%, respectively. These figures for the conventional rice cultivation were 8.49% and 67.47%, respectively. This facts show that a much higher percentage of nonrenewable energy was utilized for the conventional rice cultivation, but the difference gap was closer for the rice-duck mutualism organic farming.

Conclusion

The rice–duck organic farming, a form of organic agriculture, has many economic, environmental, and ecological benefits in Vietnam. According to the results of the current study, the ratio of renewable energy to nonrenewable energy utilized in this system was greater than that in the conventional rice cultivation where the main nonrenewable inputs were chemical fertilizers and biocides. The rice–duck mutualism organic can improve the structure of paddy soils and suppress weeds using renewable energy resources. The results of this research can provide theoretical and practical bases for further optimizing the cultivation method and increase the economic benefits for farmers through the effective use of energy and ecosystem conservation.

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Table 2. Amounts of used inputs and outputs and their energy equivalences in two rice production systems

Item	Rice–duck mutualism organic farming			Conventional rice cultivation		
	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Percentage (%)	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Percentage (%)
A. Inputs						
1. Machinery (h)	150±7.40	9405±464	14.66	202.1±7.64	12,671.7±479	11.22
2. Human Labor (h)	320±28.7	555.8± 63.4	0.87	290.1±6.17	501.2±15.6	0.44
Male (h)	150±8.09	294±15.9	0.46	130.0±5.07	254.8±10	0.23
Female (h)	170±30.9	261.8±47.6	0.41	160±3.70	246.4±5.7	0.22
3. Diesel (L)	600±6.2	33,786±349	52.67	654.5±1.9	36,854.9±107	32.65
4. Chemical fertilizer (kg)	0.00	0	0	900.00	24,480±1,380.2	21.68
Nitrogen (N)	0.00	0	0	250±20.2	16,535±1,336	14.65
Phosphorus (P_2O_5)	0.00	0	0	500±2.1	6,220±26.1	5.51
Potassium (K_2O)	0.00	0	0	150±1.83	1,725±21	1.53
Zinc (Zn)	0.00	0	0	0	0	0
5. Organic fertilizer (ton)	2.40±0.92	727.4±278.9	1.13	8.00	2,424.8	2.15
6. Biocide (kg)	0.00	0	0	15.02±0.93	2162.9±244	1.92
Insecticide	0.00	0	0	6.22±0.83	1,424.4±190	1.26
Herbicide	0.00	0	0	4.90±0.27	416.5±23	0.37
Fungicide	0.00	0	0	2.80±0.27	322±31	0.29
7. Seed (kg)	50.20±2.3	738±33.8	1.15	50.20±2.07	738±30.4	0.65
8. Rice bran (kg)	950.00±28.6	11,923±359	18.59	0	0	0
9. Water (m^3)	5500.00±8.4	5610±8.6	8.75	5800.00±18.4	5,916±18.8	5.24
10. Duckling (kg)	60.00±4.40	846±62	1.32	0.00	0	0
Total energy input	–	*64,146.5*	*100.0*	–	*112,893.5*	*100*
B. Outputs						
1. Grain (kg)	6500.65±156.17	95,559.6±2,296	70.89	6300.2±146.2	92,612.9±2,149	74.39
2. Straw (kg)	2575.12±124.5	2,189±1,556.3	23.88	2550.03±122.8	31,875.4±1,535	25.61
3. Duck (kg)	500.19±14.9	5,702.7±210	5.23	0.00	0	0
Total energy output	*9,575.96*	*134,801.2*	*100*	*8,850.23*	*124,488.3*	*100*

Table 3. Energy forms and indices in two rice production systems

Item	Unit	Rice-duck organic farming	Percentage (%)	Conventional rice cultivation	Percentage (%)	
Energy use efficiency	–	2.1±0.11	–	1.1±0.1		
Energy productivity	(kgMJ-1)	0.15	–	0.08	–	–
Specific energy	(MJkg-1)	6.70	–	12.76	–	–
Net energy	(MJha-1)	70,655±2,379.9	–	11,595±237	–	
Direct energy	(MJha)	34,342±412.6	53.54	37,356.1±122.6	33.09	
Indirect energy	(MJha-1)	39,249±1,206	45.60	48,393.3±2,155.5	42.87	
Renewable energy	(MJha)	20,400±806	31.80	9,580±64.8	8.49	
Nonrenewable energy	(MJha)	43,191±813	67.33	76,169.4±2,213	67.47	
Total energy input	*(MJha)*	*64,146.5*	*100.00*	*112,893.5*	*100.00*	–

Deficit Irrigation of Soybean

The Effect of Deficit Irrigation on Root/Shoot ratio, Water Use Efficiency and Yield Efficiency of Soybean

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SUMMARY

An experiment was conducted in a vinyl house at Gifu University, Japan, to investigate the effects of water stress on root:shoot ratio and water use efficiency (*WUE*) at different growth stages, and its influence on yield efficiency (*YE*) of soybean. The treatment imposed was deficit irrigation with five levels including D_1 (0-20%), D_2 (20-40%), D_3 (40-60%), D_4 (60-80%), and D_5 (80-100%) water deficits of total available water (*TAW*). The treatments were arranged in a randomized complete block design with nine replications. Samplings were done at 49 DAS (flowering stage), 77 DAS (seed growth stage), and 140 DAS (maturity stage) during the experiment. Soybean grain yield (*Y*, g/plant) significantly correlated to the crop water requirement (*CWR*, g/plant) as well as to the leaf area index (*LAI*, m^2/m^2) and total dry biomass (*TDB*, g/plant) at different growth stages in response to water deficit levels. These relationships indicated the water stress decreased *CWR* which in turn caused the decrease in *LAI* and *TDB* and a subsequent decrease in grain yield. However, *WUE* and *YE* values increased with increasing root:shoot ratio up to the D_4 treatment and thereafter, decreased up to the D_5 treatment in response to increasing water deficit levels. The study showed that, the most effective economic water usage with the highest *YE* was at D_4 (60-80 % of *TAW*) water deficit. It could produce 21% lower yield per unit area, but could conserve 18% irrigated water to produce the same yield compared to the potential yield produced under full irrigation (D_1).

Introduction

Soybean is economically important crop with widespread consumption, utilization in vegetable oil and veterinary industries. Soybeans can be processed into Tempe, Tofu, and Soya, which are included in cuisines. Soybean is a traditionally nonirrigated (rain fed) crop that occupies quite extensive areas in agro ecosystems. Drought is a worldwide problem, constraining global production and quality of crop seriously, and recent global climate change has made this situation more serious. The great challenge for the future will be the task of increasing food production with less water, particularly in countries with limited water and land resources. In the context of improving water use efficiency, there is a growing interest in "deficit irrigation". At present and more so in the future, irrigated agriculture will take place under water scarcity. To cope with scarce supplies, deficit irrigation, defined as the application of water below full crop-water requirements (evapotranspiration), is an important tool to achieve the goal of reducing irrigation water use. According to James (1998), full irrigation is economically justified when water is readily available and irrigation cost is low. Shortage of available water is one of the most significant environmental stresses that cause yield reductions (Boyer, 1982).

Demand for evapotranspiration can be reduced either through agronomic measures or through the use of deficit-irrigation programs (Kirda et al. 1999). The main approach in deficit irrigation practice is to increase crop water use efficiency by partially supplying the irrigation requirement and allowing water stress to planned plant during one or more periods of the growing season with the least impact on crop yield. Deficit irrigation management requires optimizing the timing and degree of plant stress, within the restriction of available water.

Improvements in yield efficiency of crops through water use efficiency are essential under the scenarios of water scarcity predicted by global climatic changes. Direct impacts of drought stress to the physiological development of soybean depend on its water use efficiency (*WU*E) (Earl, 2002). In agriculture management involving soybean as a crop, *WUE* is an important physiological characteristic related to the ability of plants to cope with water stress. According to Passioura (1997), grain yield (*Y*) is a function of the amount of water transpired, *WUE*, and harvest index. Soybean, as a C3 plant, is less efficient in water-use due to high evapotranspiration and low photosynthetic rates.

Water stress disrupts the balance between roots and shoot ratio (Shangguan et al. 2004). Water use efficiency also reduced by increasing root per shoot ratio. Benjamin and Nielsen (2006) reported that shoot dry weight of water stressed chickenpea reduced relative to root dry weight. Numerous studies have shown that soil water stress has significant effects on plant growth. Far fewer studies have focused on the root:shoot ratio response of plants, especially soybean crops, to water stress. Water stress in soybean has been shown to reduce growth of above-ground organs, leaf photosynthesis and leaf transpiration. However, studies are not available on the adaptation of soybean crop to water stress and its effects on root:shoot ratio for water uptake and its relationship to water use efficiency (*WUE*) and yield efficiency (*YE*).

Therefore, the research was conducted with the objective to investigate the effects of water stress on root:shoot ratio and water use efficiency at different growth stages and its relationship to yield efficiency of soybean. This research can be used to determine water saving irrigation schedules to ensure optimum production of soybean.

Material and Method

Area description

This research was conducted in a vinyl house (surrounding sides were open) located in the experimental farm of Gifu University (35°27' N. & 136°44' E.), Japan. The average temperature was 22.4℃ and the relative humidity was 67.5% during experiment duration. The soil was clay loam in texture (0.40g/g sand, 0.27g/g silt and 0.33g/g clay) and classified as Inceptosl. The bulk density was 1.07 (g/cm^3). Soil water content at field capacity (34.7kPa) was 0.516 m^3 /m^3 and wilting point (185kPa) was 0.296 m^3 /m^3. Therefore, the total available water (*TAW*) was 0.220 m^3 /m^3.

Treatments and experimental design

Five water deficit treatments namely; *D1* (0-20%), D_2 (20-40%), D_3 (40-60%), D_4 (60-80%) and D_5 (80-100%) of total available water deficit (*TAW*) were arranged in a completely randomized block design with nine replications. The water deficit level of D_2 (20-40%), for example, meant that the available water was maintained between 20% and 40% of *TAW* throughout the growing season. When the maximum allowable depletion of available water came closer to 40% of *TAW*, water was applied to restore the available water to the deficit level of 20% of *TAW*. The *TAW* is defined as the water content between field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}).

Plastic pots (10 liters volume and 23.8cm diameter) with no drainage holes were filled with 7 kg air-dried Inceptisol (clay loam in texture). Then five soybean seeds [*Glycine max* (L.) Merrill] were sown in each pot. Prior to planting, uniform water was applied to all the pots to bring them to field capacity (θ_{FC}) for uniform germination. The soil moisture for all pots was maintained at field capacity (θ_{FC}) until 14 days after sowing (DAS). After 14 DAS, the deficit irrigation treatments were initiated. The irrigated period of soybean was 20 weeks from June 16 to November 3. The plants were thinned to one per pot at the 2- to 3- leaf stage. Three replicate pots of each water deficit level were sampled at 49 DAS (flowering stage), 77 DAS (seed growth stage), and 140 DAS (maturity stage) during the experiment. Three plants per treatment were used for final yield analyses.

Measurements

Agronomic variables evaluated in this research were crop water requirement (*CWR*, g/plant), oven dry (at 65°C for 96 h) weight of total biomass including roots (*TDB*, g/plant), root dry weight (g/plant), shoot (leaves and stem) dry weight (g/plant) and air-dried grain yield of soybean (*Y*, g/plant). Leaf area index (*LAI*, m^2/m^2) were measured according to Fehr and Cavines (1977) using a portable leaf area meter (Model LI 3000A; LI-COR Inc. Lincoln, NE, USA) from each pot. Crop water requirement (*CWR*, g/pot) was calculated from the evapotranspiration during the irrigated period of soybean according to Allen *et al.* (1998). Daily evapotranspiration (*ET*, mm/d) was measured by weighing the pot every day.

<u>Result and Discussions</u>

Crop water requirement (*CWR*) and water stress coefficients (K_s)

The crop water requirement (*CWR*, g/plant) of soybean at the different growth stages significantly decreased with increasing water deficit level **(Table 1).** Similarly, leaf area index (*LAI*, m^2/m^2) also significantly decreased at the different growth stages with increasing water deficit level. **Figure 1** shows that *CWR* significantly correlated with *LAI* at different growth stage in response to the water deficit level. This result agrees with Van Wijk et al. (2005) who demonstrated that *LAI* is a key variable, functionally related to canopy microclimate, water interception, radiation extinction, and water and carbon exchange. Setiyono et al. (2008) also demonstrated that transpiration is directly controlled by *LAI*. In the present study, the highest correlation was observed at seed growth stage (77 DAS) compared to the flowering and maturity stages, because *LAI* reaches maximum at this time.

According to Allen et al. (1998), evapotranspiration under water stress condition is referred to as the adjustment evapotranspiration (ET_{cadj}, mm/d) which can be calculated by the following equation.

$$ET_{cadj}=K_s\,ET_c \qquad (1)$$

where ET_c (mm/d) is the crop evapotranspiration under standard condition, K_s is water stress coefficient (no dimension).

The value of K_s is important for estimating ET_{cadj}, and can be used for deficit irrigation scheduling. K_s describe the effect of water stress on crop transpiration (Allen et al. 1998). Assuming that the evapotranspiration at D_1(0-20%) occurred under the ideal condition for plant growth in which the soil water content is near the field capacity, the actual evapotranspiration (ET_a) at D_1 is crop evapotranspiration (ET_c), which means the evapotranspiration of plant under standard conditions (Allen et al., 1998). Water stress coefficient (K_s) is calculated as the ratio between the actual evapotranspiration (ET_a) at each water deficit level and the crop evapotrarspiration (ET_c). The ratio of water depletion to the total available water in the root zone, referred to as "*p*", is an indicator of the water deficit level. For example, the average value of "*p*" under the water management of D_2 (25-50%) treatment is calculated as "*p*" = (0.20+0.40)/2=0.30.

The variation of K_s values of soybean is displayed in **Table 1**. Water deficit level had significant effects on water stress coefficient (K_s). The variation of K_s values of soybean depends on the growth stages and the water deficit level. **Figure 2** shows that the K_s values decreased linearly with the increase of water deficit level "*p*". The fastest decline of K_s value was at the seed growth stage (77 DAS) which indicates the most sensitive period to water deficit. Our result agrees with Doorenboss and Kassam (1979) who stated that, water requirement is higher during emergence, flowering and early yield formation than early (vegetative, after establishment) and late growth periods (ripening).

Table 1 The effect of water deficit level on crop water requirement (*CWR*), leaf area index (*LAI*), root:shoot ratio, total dry biomass (*TDB*), water stress coefficient *(K_s)* and water use efficiency (*WUE*) of soybean under different growth stage

Growth stage (DAS)	Water deficit level (%)	*CWR* (g/plant)	*LAI* (m^2/m^2)	Shoot dry weight (g/plant)	Root dry weight (g/plant)	Root: shoot ratio (g/g)	*TDB* (g/plant)	K_s	*WUE* (g/g)
		①	②	③	④	⑤=④/③	⑥=③+④	⑦	⑧=⑥/①
Flowering (49)	D_1	24183 a	5.8 a	48.93 a	12.70 a	0.2595 a	61.63 a	1 a	0.00255 a
	D_2	20220 b	5.6 b	40.70 b	12.07 b	0.2965 a	52.77 b	0.84 b	0.00261 a
	D_3	17754 c	4.8 c	36.50 c	11.37 c	0.3114 a	47.87 c	0.73 c	0.00270 a
	D_4	14080 d	4.5 d	29.47 d	9.60 d	0.3258 a	39.07 d	0.58 d	0.00277 a
	D_5	12867 e	3.7 e	25.30 e	5.97 e	0.2360 b	31.27 e	0.53 e	0.00243 b
Seed growth (77)	D_1	50475 a	6.7 a	87.87 a	16.87 a	0.19196 a	104.73 a	1 a	0.00207 a
	D_2	46270 b	6.5 b	81.60 b	16.57 a	0.20302 a	98.17 a	0.92 b	0.00212 a
	D_3	39039 c	5.9 c	71.00 c	14.97 b	0.21080 a	85.97 b	0.77 c	0.00220 a
	D_4	31759 d	5.5 d	59.33 d	13.60 c	0.22921 a	72.93 c	0.63 d	0.00230 a
	D_5	25608 e	4.5 e	41.37 e	7.10 d	0.17164 a	48.47 d	0.51 e	0.00189 a
Maturity (140)	D_1	82130 a	6.2 a	117.10 a	19.80 a	0.1691 b	136.90 a	1 a	0.00167 a
	D_2	74719 b	6.0 b	113.83 b	19.53 a	0.1716 b	133.37 a	0.91 b	0.00178 a
	D_3	64460 c	5.7 c	109.83 c	19.50 a	0.1775 a	129.33 b	0.78 c	0.00201 a
	D_4	53155 d	5.3 d	95.50 d	17.53 b	0.1836 a	113.03 c	0.65 d	0.00213 a
	D_5	40205 e	3.9 e	67.50 e	11.80 c	0.1748 b	79.30 d	0.49 e	0.00197 a

Means followed by different small letters (a-e) in the same column in each growth stage under different water deficit levels are significantly different according to Tukey's multiple comparison test ($p<0.05$).

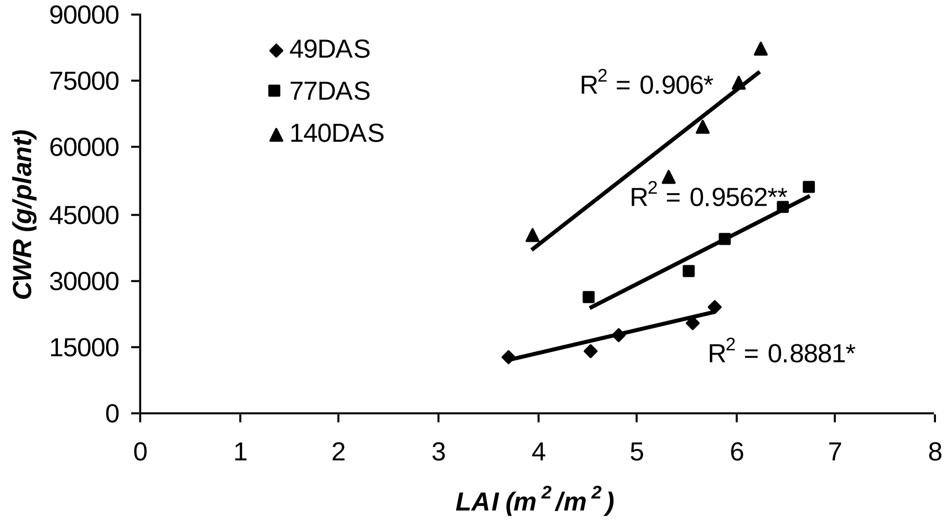

Figure 1 Effects of water stress on the relationship between leaf area index *(LAI*) and crop water requirement *(CWR)*

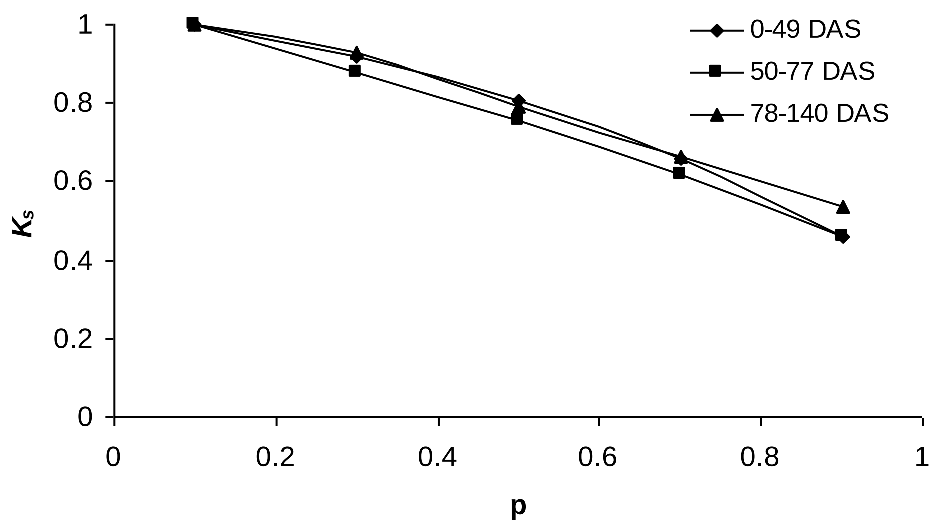

Figure 2 Effects of available water deficit (p) on water stress coefficient (K_s)

Total dry biomass (*TDB*) and water use efficiency (*WUE*)

The shoot dry weight and root dry weight as well as total dry biomass (*TDB*, g/plant) at each growth stage significantly decreased with increasing water deficit level **(Table 1).** However, the root:shoot ratio increased up to the D_4 and thereafter, decreased to the D_5 treatment with increasing water deficit level **(Table 1).** Under water stress conditions, water can be easily lost by evaporation from the surface layer of soil. Therefore, soybean root profile is characterized by a low amount of roots in the dry surface layer and a maximum root proliferation in the deeper and wetter soil layer. On the other hand, shoot growth might be restricted due to the restriction of cell division and enlargement under water stress conditions. Our results agree with Nicholas (1998) who stated that the root:shoot ratio increases under water-stress conditions to facilitate water absorption. The root growth decline was greater in the top soil than deeper soil, because water uptake per unit root length generally increased with depth in the soil.

Water deficit had significant effects on total dry matter accumulation (*TDB*) (**Table 1**). Water deficit reduced final dry matter by an average of 42% ($P<0.05$) at D_5 treatment compared to the full irrigation (D_1). The *TDB* at different growth stage significantly correlated with *CWR* under the water deficit level **(Figure 3)**. Our study indicates that the decrease in total dry biomass was due to the considerable reduction in plant growth and canopy structure caused by the water stress conditions. This phenomenon agrees with Hong-Bo Shao et al. (2008) who found that the biomass of soybean plant was reduced by the water stress imposed.

Water use efficiency (*WUE*, g/g) is defined as the ratio of total dry biomass (*TDB*, g/plant) to the crop water requirement (*CWR*, g/plant). The *WUE* value increased with the increase of water deficit level, except water deficit level in D_5 (**Table 1**). In addition, *WUE* showed significant positive correlation at different growth stage with root:shoot ratio in response to increasing water deficit level **(Figure 4)**. In fact, when evaluated over the entire growing season, the stressed plants have higher water use efficiencies than the well-watered plants. Our findings are in agreement with those of Burriro et al. (2002) who reported that *WUE* increased with the increase of soil moisture stress.

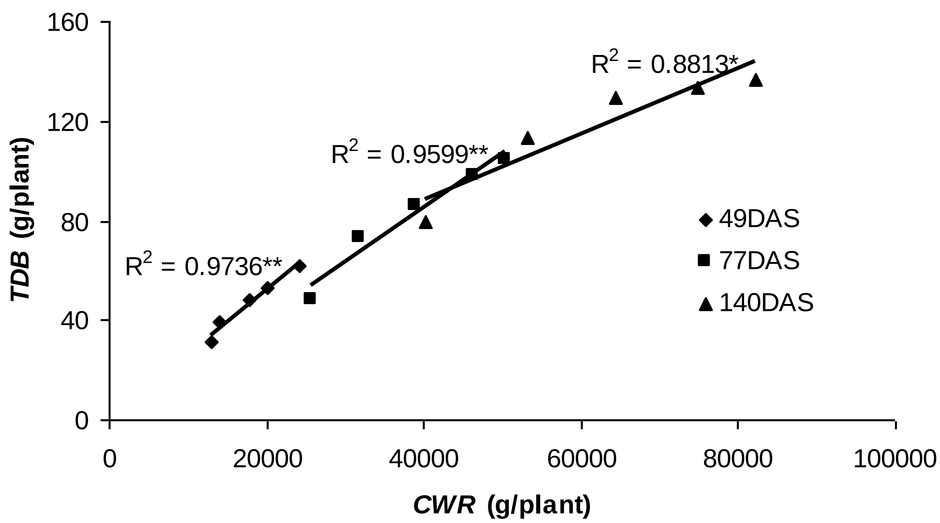

Figure 3 Effects of water stress on the relationship between total dry biomass *(TDB)* and crop water requirement *(CWR)*.

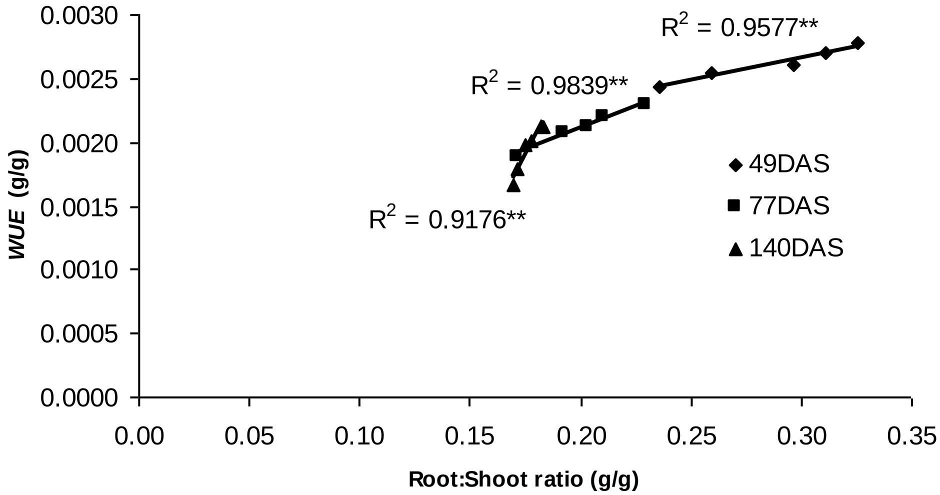

Figure 4 Effects of water stress on the relationship between root:shoot ratio and water use efficiency *(WUE)*.

Grain yield and yield efficiency (*YE*)

The grain yield declined with the increase of water deficit levels (**Table 2**). There was no significant difference between the decreasing trend of D_1 and D_2 treatments but significantly decreased from D_2 to D5 treatment. It was found from the study that, the grain yield numerically lowered by 1, 11, 21 and 47 % in D_2, D_3 , D_4 and D_5 water deficit levels, respectively, as compared to the D_1 (full irrigation).

Table 2 Effects of water deficit level on grain yield (Y), crop water requirement (*CWR*), yield efficiency (*YE*), and yield response factor (K_y)

Water deficit (%)	*Y* (g/plant)	*CWR* (g/plant)	*YE* (g/g)	$1\text{-}Y_a/Y_m$	$1\text{-}ET_a/ET_m$	K_y
	①	②	③=①/②	④	⑤	⑥=④/⑤
D_1(0-20)	17.7 a	82130 a	0.000216 b	0	0	-
D_2(20-40)	17.5 a	74719 b	0.000234 b	0.01 a	0.09 a	0.13 a
D_3(40-60)	15.8 b	64460 c	0.000245 ab	0.11 b	0.22 b	0.50 b
D_4(60-80)	14.0 c	53155 d	0.000263 a	0.21 c	0.35 c	0.59 c
D_5(80-100)	9.4 d	40205 e	0.000234 b	0.47 d	0.51 d	0.92 d

Y_a: actual yield, Y_m: maximum yield, ET_a: actual evapotranspiration, and ET_m; maximum evapotranspiration
Means followed by different small letters (a-e) in the same column under different water deficit levels are significantly different according to Tukey's multiple comparison test ($p<0.05$).

The grain yield of soybean was strongly influenced by *CWR* **(Figure 5)**, *LAI* **(Figure 6),** and *TDB* **(Figure 7)** at maturity stage (140 DAS). These results indicated that the reduction in *CWR* as well as *LAI* and *TDB* by water stress caused the decrease of soil water uptake and consequently the decrease of soybean grain yield through reduction in photosynthesis. Passioura (1997) found the same phenomenon that grain yield is a function of the amount of evapotranspiration.

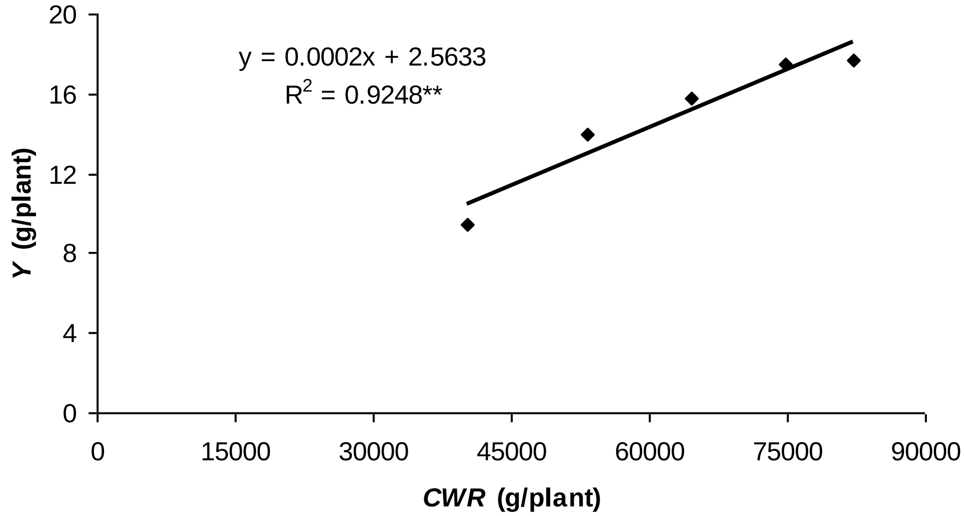

Figure 5 Effects of water stress on the relationship between crop water requirement *(CWR)* and grain yield *(Y)*.

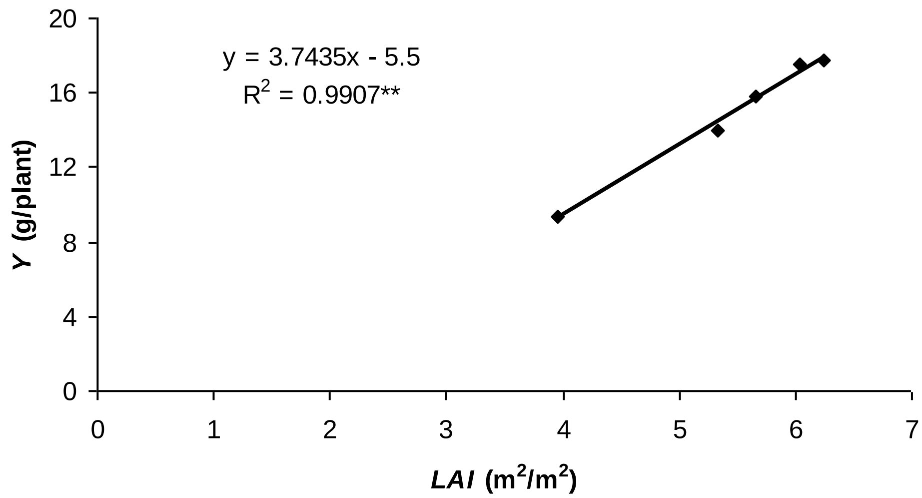

Figure 6 Effects of water stress on the relationship between leaf area index *(LAI)* and grain yield *(Y)*.

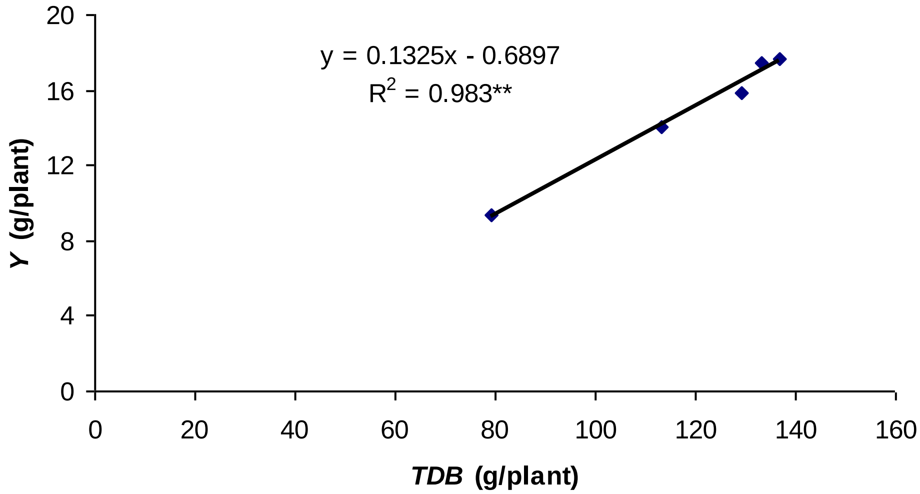

Figure 7 Effects of water stress on the relationship between biomass *(TDB)* and grain yield *(Y)*.

Yield efficiency (*YE*, g/g), the ratio of grain yield (*Y*, g/plant) to crop water requirement (*CWR*, g/plant) is a term used to assess how efficiently a crop uses water. Using less water to produce more grain yield is important in saving water. The *YE* value increased with the increase of water deficit level from D_1 to D_4 and thereafter decreased up to the D_5 treatment **(Table 2)**. The significant positive relationship between *YE* and root: shoot ratio at maturity stage (140 DAS) showed that the *YE* increased with the increase of root:shoot ratio in response to increasing water deficit levels up to the D_4 treatment and thereafter decreased to the D_5 treatment in response to increasing water deficit levels **(Figure 8)**. Our study indicates that, the soybean crop utilize the least irrigation water to produce more grain yield at D_4 water deficit level. Therefore, the highest *YE* were recorded at D_4 water deficit level compared to the full irrigation (D_1).

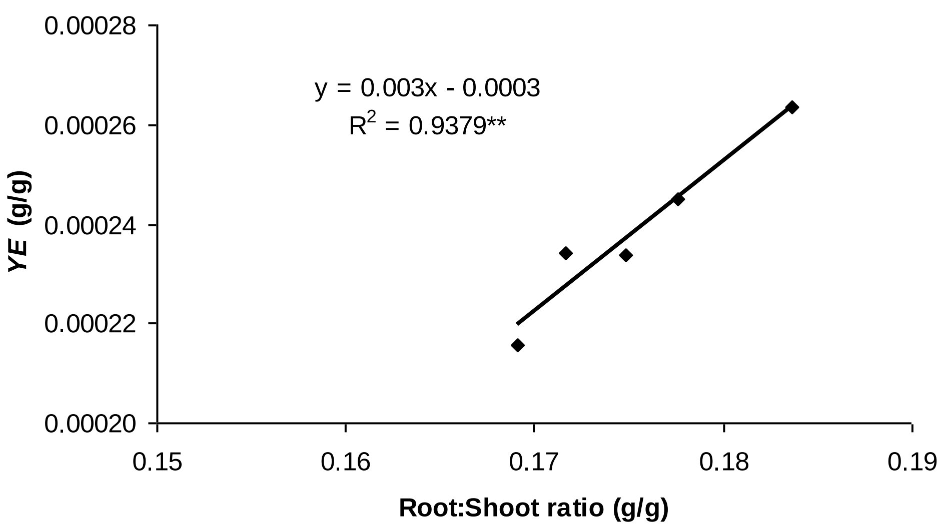

Figure 8 Effects of water stress on the relationship between root:shoot ratio and yield efficiency *(YE)*.

Yield response factor (K_y)

The effect of water stress on yield is quantified by relating the relative yield decrease to the relative evapotranspiration deficit through an empirically derived yield response factor (K_y) (Doorenboss and Kassam, 1979).

$$1-\frac{Y_a}{Y_m}=K_y\times(1-\frac{ET_a}{ET_m}) \qquad (2)$$

where 1-Y_a/Y_m: relative yield decrease, Y_a: actual yield, Y_m: maximum yield (under no stress condition), 1-ET_a/ET_m: relative evapotranspiration decrease, K_y: yield response factor, ET_a: actual evapotranspiration, and ET_m: maximum evapotranspiration

Under conditions of limited water distributed equally over the total growing season, involving crops with different K_y values, the crop with higher K_y value will suffer a greater yield loss than the crop with a lower K_y value (Moutonnet, 2000). According to a report by Doorenboss and Kassam (1979), the K_y of soybean under water deficit for the whole growing period was found to be 0.85.

Table 2 shows **t**he values of the yield response factor (K_y) calculated using equation (2). The K_y values obtained for the D_2, D_3, D_4 and D_5 treatments were determined throughout the growing period were 0.13, 0.50, 0.59 and 0.92, respectively; with an average value of 0.53.

The relationship between relative yield decrease (1-Y_a/Y_m) and relative evapotranspiration deficit (1-ET_a/ET_m) is shown in Figure 9. It shows that, the relation between the relative yield loss (1-Y_a /Y_m) and relative water deficit (1-ET_a/ET_m) for water deficits lower than 60-80% of *TAW* is almost linear with a mean K_y value of 0.41. These results agree with the experiment by Doorenboss and Kassam (1979) who showed that the relationship between relative yield (Y_a/Y_m) and relative evapotranspiration (ET_a/ET_m) was linear and valid for water deficit of up to about 50 % or 1- ET_a/ET_m=0.5.

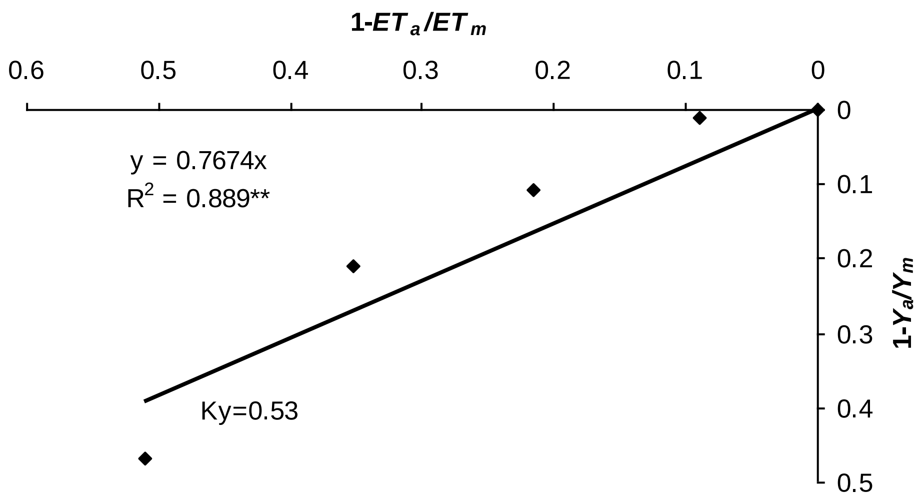

Figure 9 Relationship between relative yield decreased (1-Y_a/Y_m) and relative evapotranspiration deficit (1- ET_a/ET_m) in Inceptisol.

Optimum deficit irrigation

The optimum yield of soybean with the highest values of *YE* was attained by the deficit irrigation which maintained the available water deficit at 60-80% of *TAW* (D_4) with water stress coefficient (K_s) of 0.65 and yield response factor (K_y) of 0.59. The value of *YE* at water deficit level D_4 was 1.5 times as much as under the full irrigation (D_1). It was also seen that the 60-80% (D_4) deficit irrigation reduced 21% of the grain yield per unit area, and could conserve 18% of irrigation water to produce the same grain yield compared to full irrigation (D_1).

Conclusion

The most unique result of our study is that we established a strong positive correlation among the root:shoot ratio, water use efficiency (*WUE*) and yield efficiency (*YE*) of soybean under deficit irrigation management. Our present study suggests that the yield efficiency increased with the increase of water use efficiency as well as the increase of root:shoot ratio in response to increasing water deficit levels. The study showed that, the most effective economic water usage with the highest *YE* was at D_4 (60-80 % of *TAW*) water deficit. It could produce 21% lower yield per unit area, but could conserve 18% irrigated water to produce the same yield compared to the potential yield produced under full irrigation (D_1).

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