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Developing Seasonal Operation for Water Table Management in Tidal Lowland Reclamations Areas at South Sumatera, Indonesia

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ABSTRACT

The objective of the study was to develop the water management operational plan at tertiary blocks for the growth of rice and corn. Study was conducted at reclaimed tidal lowland area which was located at Primer 10, Delta Saleh. This area was classified as a C-typhology land (dry). The methods of the study were survey, field measurements, computer simulation, and field action research. Study stages were consisted of survey and monitoring, water status evaluation, water management scenarios design, model simulation, and model adaptation. Computer model of DRAINMOD had been used to estimate the water table status and to design water table control operation at tertiary blocks. Simulation results showed that the model worked properly which was indicated by root mean square error of 1.45 cm, model efficiency of 0.97, and correlation coefficient of 0.84. Model adaptation for dry land condition (C-typhology) showed that the best scenario was land utilization pattern of rice-corn. This paper presented monthly water management operational plan for rice crop in first cropping season (CS1) during November-February period and for corn crop in second cropping season (CS2) during May-August period. Results of computer simulation and field study showed that the main objective of water management in this area was water retention in combination with land leaching.

Keywords: DRAINMOD, tidal lowland area, water table control

INTRODUCTION

Most of reclaimed tidal lowland area in South Sumatra is located at the east coast. The land in this area is characterized by sulphate acid layers either in the potential or actual form. Field identification results showed that sulphate acid layers are affected by sea water fluctuation (tidal) and land hydrotophography classes. Reclaimed tidal lowland area of Delta Saleh is classified as potential sulphate acid land. Rice production level in this area was in average of 2.5-3.0 Mg ha^{-1} and cropping index was once per year (Imanudin *et al.* 2004). This low production was related to water status heterogenity in the farm at tertiary blocks. Water availability in swamp area is directly related not only to crop evapotranspiration requiremenet, but also to dynamic of soil fertility status (Imanudin and Susanto 2007).

According to Imanudin and Susanto (2004), water table dynamic condition in relation to phyrite layer depth is a critical factor in developing water management strategy and cropping pattern determination at each unit of swamp development areas. This is especially applied on tidal lowland having C-flooding type. This area is frequently experienced fresh water supply deficit due to high tidal water that could not reach the land. Moreover, porous soil condition creates high hydraulic conductivity of soil which produces very high water loss due to percolation and rain water is difficult to retain (Suryadi, 1996). This condition causes a fast water table drawdown especially during dry condition in which water table is dropped below phyrite layer that creates oxidation process. Oxidation process produces sulphate acid which is followed by iron and aluminum precipitations that are harmful for plants. The land that experienced phyrite layer oxidation had low quality and it takes a long time to restore (Minh *et al.* 1998; Hussona *et al.* 2000a). In addition, land leaching process is poor due to limited water availability and improper channel system (Bronswijk *et al.* 1995; Imanudin *et al.* 2009). The tidal lowland area remediation need a long time due to the above conditions (Suryadi *et al.* 2010).

A computer model had been develepod to test the effectiveness of drainage system on micro levels.

This model is called DRAINMOD (Skaggs 1982; Skaggs 1991). It was developed to evaluate water balance on shallow water table condition which made it very suitable to be used for tidal lowland areas (Susanto 2002). This model was also well adapted to many land conditions according to characteristics of area agroclimate. It was tested successfully at several countries such as America (Ale *et al.* 2008); Australia (Yang 2006); Europe (Borin *et al.* 2000), China (Zhonghua and Wan 2006); and Indonesia (Susanto 2001; Imanudin *et al*. 2009).

In term of time and cost considerations, development concept of water management operational system in this study was not done by total reclamation strategy (*maximum disturbance)* but by using swamp reclamation with minimum possibility of land degradation (*minimum disturbance)* in combination with total reclamation through land leaching and water table control (Surjadi 1996; Imanudin *et al.* 2009). The main objective of this system is for water management at tertiary level in order to prevent excessive drainage, toxic elements disposal and water control according to plants requirement as well as to prevent phyrite layer oxidation. This concept is expected capable to decrease the effect of acid sulphate oxidation (Hussona *et al.* 2000a).

Based on the above potentials and constraints, this study is focused toward efforts in improving water management at micro level (tertiary block level). It was done because the currently main system is relatively good in which most channels has been improved. Development of several water management scenarios at tertiary level is expected to guarantee water requirement for crops and increasing agricultural production at tidal lowlandareas.

The research objective in general was to develop seasonal operational plan of water table control at tertiary block for the gowth of rice and corn. In order to achive the above objective, there were several specific objectives that should be achieved as follows: (1) to evaluate the water status condition at tertiary block to design the land utilization pattern, (2) to evaluate the performance potential of water management system as supply and drainage channels, and (3) to develop the operational plan of water level control at channels and teriary blocks by using the computer model of DRAINMOD.

MATERIALS AND METHODS

Place and time

Research and field study had been conducted at reclaimed tidal lowland areas. Location of demonstration plot was at Primer 10, Delta Saleh, Banyuasin Disrict (Figure 1). Research and field monitoring was done at two cropping seasons consisting of wet and dry seasons. Observation period (water table monitoring) was done from November 2008 to November 2009. Field data since 2005 was used for model simulation.

Equipments

The equipments used in this study were piezometer, wells (perforated plastic pipes), measuring boards, water pass, measuring tape, soil

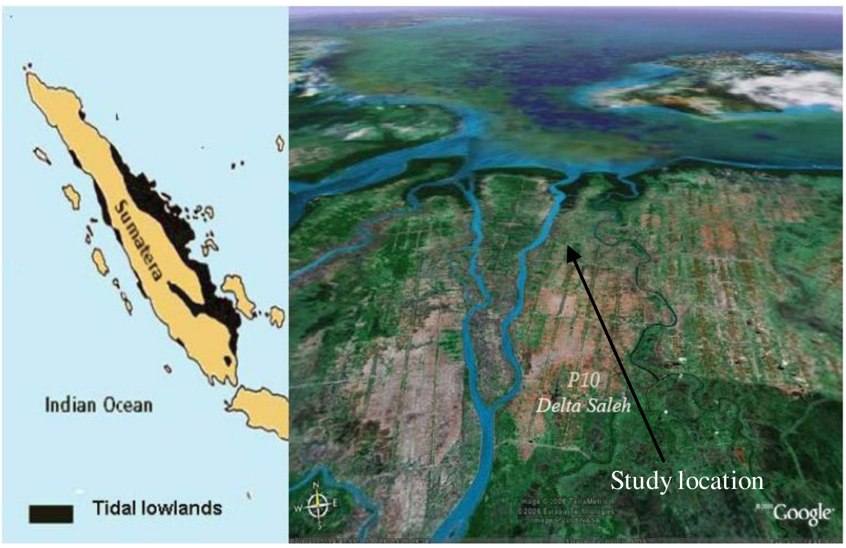

Figure 1. Situation map of research area

auger, discharge tube (*bailer*), stopwatch, digital camera, and agricultural equipments. Water status evaluation at tertiary blocks was done by computer simulation using software of DRAINMOD 5.1 (Skags 1991).

Water table fluctuation measurements at land plots were done by using observation wells made from perforated plastic pipes having 3 m in length and 2.5 inches in diameter. These pipes were perforated at their sides and sink at depth of 2-2.5 m from soil surface. Upper part of pipes was closed and was only opened during the measurement period. In addition daily rainfall was recorded directly from rain gauges every 07.00 *a.m.*

Research Methodology

Research Phase. The research phases consisted of: 1) Survey and monitoring, 2) Evaluation of water status at tertiary blocks, 3) Scenario design and computer simulation, and 4) Adaptation of DRAINMOD model. Soil survey was conducted to determine soil physical characteristics: texture, volume weight, total pore spaces, soil hydraulic conductivity, and depth of acid sulphate layers. Observation of soil physical characteristics was done at depth of 0-30 cm and 30-60 cm. Potential of high tide water at channels and water table fluctuation at tertiary blocks was observed daily within two cropping season period (wet and dry seasons).

Results of field data observation were analyzed by comparing observation results with critical value of water table depth needed for rice and corn. The critical value used for rice was -20 cm and -60 cm for corn below soil surface.

Conceptual Model for Field Water Balance Analysis in DRAINMOD Model. DRAINMOD had been used as a tool for optimization and evaluation of water management system either in surface drainage or subsurface drainage. DRAINMOD model (Skaggs 1982) is hydrological model to simulate water table fluctuation. The calculation base for this model is water balance analysis within a unit of vertical soil column per unit surface area starting from impermeable layer toward soil surface which is available between drainage channels. Calculation of water balance within soil profile at time DT is mathematically can be written as:

$$\Delta Va = F - D - Ds \quad [1]$$

$$P = F + RO + \Delta S \quad [2]$$

where ΔVa is the change of soil air volume (or storage change, cm), F is infiltration (cm), ET is evapotranspiration (cm), D is lateral flow (negative sign indicates drainage flow and positive sign indicates subsurface irrigation condition, cm), *Ds* is side seepage flow (positive sign indicates upward capilary flow, cm), P is precipitation (cm), RO is surface flow (cm), and ΔS is the change of soil water surface storage. The water balance components in DRAINMOD are shown in Figure 2.

Rainfall input in DRAINMOD model is hourly rainfall whereas maximum and minimum temperatures are recorded from climatic data and water balance that are measured hourly. Summary of model prediction for hydrology components such as rainfall, infiltration, drainage, ET, and others are produced daily, monthly, or yearly. Perfomance of system design or management alternatives can be

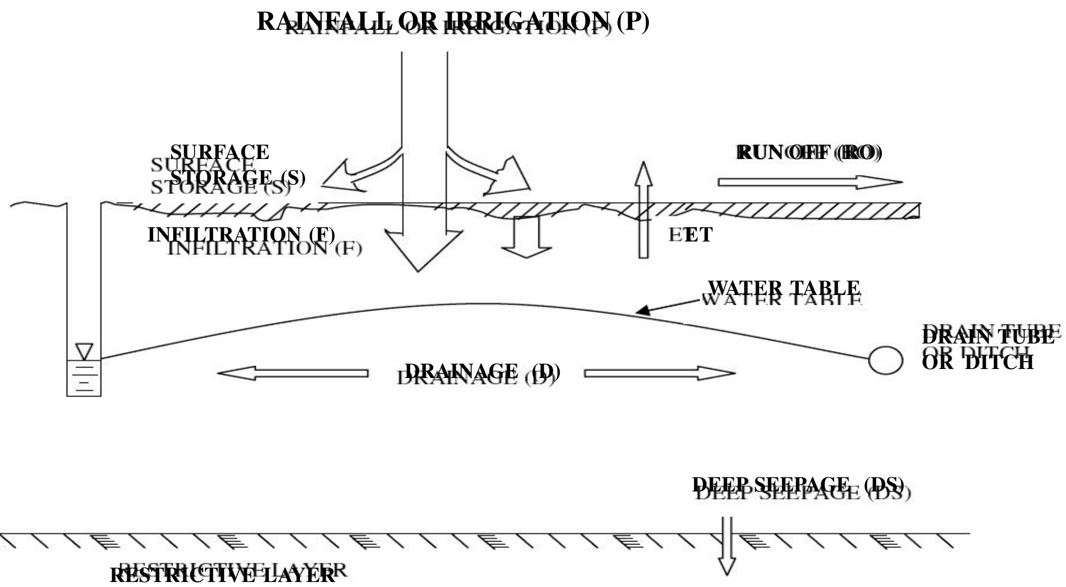

Figure 2. Components of water balance in DRAINMOD model (Skaggs 1991).

simulated from climatology data at long period, for instance 20 up to 40 years by considering yearly effect and seasonal variability (He *et al.* 2002).

Reliability Analysis of DRAINMOD Model. Before conducting the evaluation of selected water management scenarios, the first step is calibration in using DRAINMOD model computer. Some data input, especially soil data and drainage system parameters should be simulated in order to produce simulated data that closely resemble field measurement data. If this occurred, then DRAINMOD model can be used as a tool to evaluate the performance of each selected scenarios.

Determination of DRAINMOD model reliability is done by using statistical analysis with the main objective to compare between simulated computer model data and field measurement data. The model is reliable if simulation results are similar to field measurement data. The tools testing is represented through calculation of *absolute error,* RMSE (*root mean squre error*), model efficiency, and correlation test (r^2).

Simulation Computer of DRAINMOD. The planned scenarios that might be developed are as follows (Table 1). Hydraulic structures would function to keep high tidal water so that the main water input was from rainfall. On land having C-type (dry condition), there were three options of water management consisting of controlled drainage that keep water in combination with land leaching, maximum water outflow during non-planting period in order to drain all harmfull elements, and possibility of pumped-irrigation for short-period growing plants.

Model Adaptation and Field Study

In order to investigate water management scenarios at each sample areas that had been constructed (wet and dry areas), the field study was conducted together with farmers. The observation indicators were daily water table fluctuation monitoring and plant growth. Water management operational model consisted of water gate operational aspect and micro water management scheme improvement.

The flow diagram for testing processes of several water management scenarios in computer simulation of DRAINMOD is shown in Figure 3.

RESULTS AND DISCUSSION

Evaluation of DRAINMOD Computer Model in Estimating Shallow Water Table Fluctuation

DRAINMOD has been used as a tool in optimization and evaluation for water management system either at surface drainage condition or subsurface drainage condition. Input for DRAINMOD model consists of soil characteristics, climatic data, harvest yield variable, and location parameter. Soil characteristics input consist of saturated hydraulic conductivity (due to layers), relation between drainage volume and water table depth, and information of upward movement change of water table. Effective root zone as a function of time is also used as input for DRAINMOD model. Moreover, soil water retention characteristic is also the main input in DRAINMOD (Salazar *et al.,* 2008). Data of soil characteristics input is shown in Table 3. Preliminary test of model adaptation was conducted at Delta Saleh. Simulation was done

Table 1. Planning of water management operational strategy at tertiary blocks for wet land and dry land at reclaimed tidal lowland area.

Scenario plans	Simulation computer of DRAINMOD	
	Water Management Objective	Simulation Process of Computer Model
A-Scenario	Controlled Drainage • Water Retention • Leaching and Channels Flushing	• Soil characteristics function (soil retention) • Soil hydraulic conductivity function • Function of rainfall • Function of time and cropping pattern • Rice and corn crops
B-Scenario	Water outflow (maximum drainage) during no plant period up to land tillage	• Soil characteristics function (soil retention) • Soil hydraulic conductivity function • Function of rainfall • Function of time and cropping pattern • Rice and corn crops

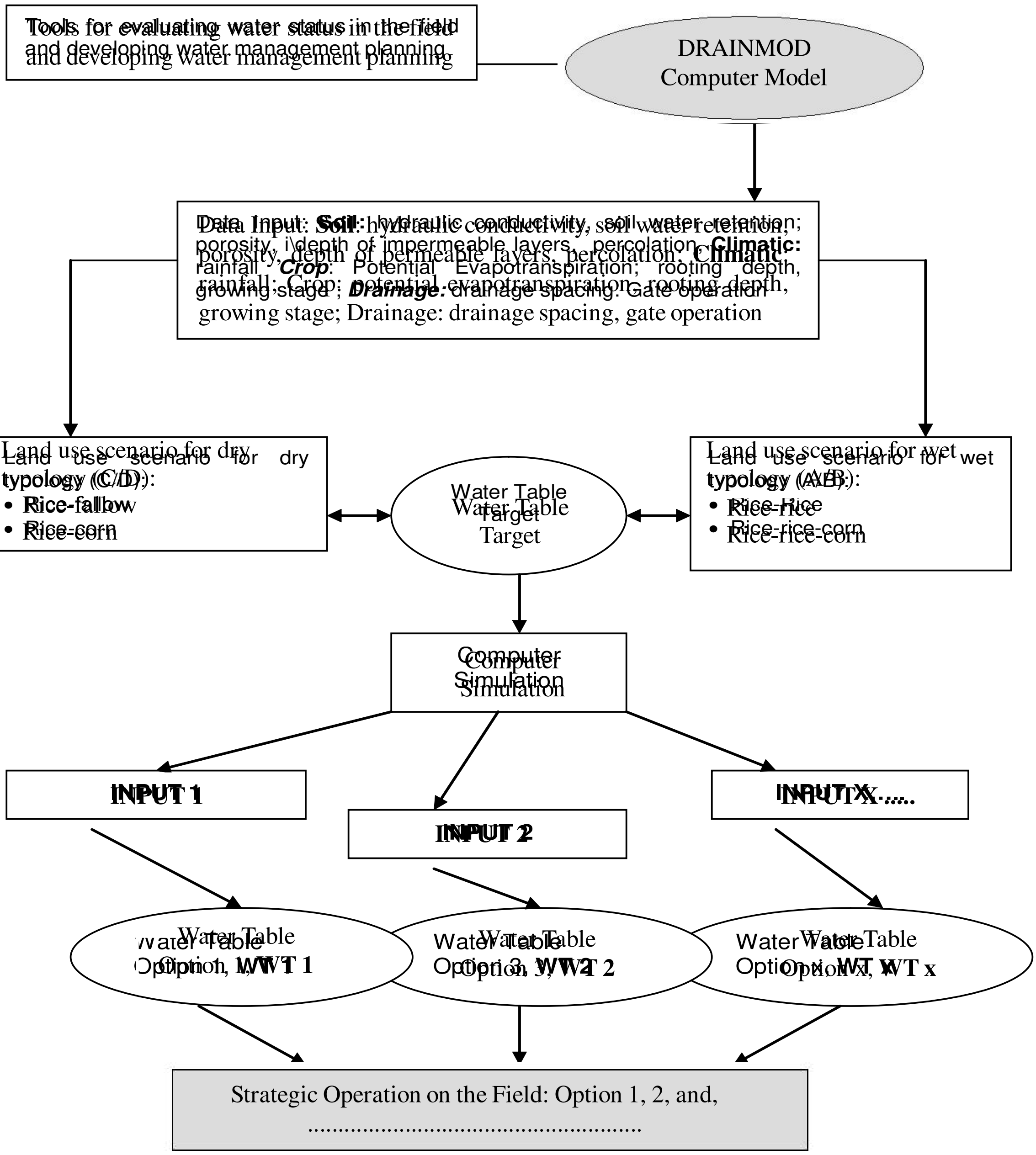

Figure 3. The diagram flow for development of water table control in DRAINMOD.

in one tertiary block (*boundary condition)* with inter-channels distance of 200 m. Soil hydraulic conductivity was 8-9 cm day^{-1}.

The statistical analysis for DRANMOD simulation results using one-year data (wet and dry seasons) showed a good performance in which the model results and observation results had similar water table fluctuation patterns (Figure 4).

The statistical analysis results showed that model can be accepted with high reliability. This was shown by correlation coefficient with magnitude of 0.84 (Figure 5); Model efficiency has positive value with magnitude of 0.97 and *Root Mean Square Error* value of 1.45 cm. It can be concluded that model perfomace was very good and DRAINMOD model can be used to evaluate the shallow water table status. According to Singh *et al. (*2006), DRAINMOD simulation results showed cumulative value of flow at subsurface drainage system was 2% higher than that of field measurement value. Results of model adaptation test in America showed the correlation coefficient values between 0.80-0.90 (He *et al.* 2002).

Testing results in Australia at sugarcane land showed that simulation results had *Root Mean Square Error* standard of 0.007 m compared to field measurement results. Model could not be used to develop daily water management operation. However, this model was very good in evaluating the performance of network system and to develop

Table 3. Input of several parameters in simulation of DRAINMOD.

No	Input of Data	Unit (dimension)
1	Soil Characteristics	
	• Soil saturation water content	58 cm^3 cm^{-3}
	• Water content of wilting point	32 cm^3 cm^{-3}
	• Soil volume weight	0.89g cm^{-3}
	• Organic matter content	4.5%
	• Soil hydraulic conductivity (lateral)	
	Depth of (30-100) cm	0.09 m day^{-1}
	Depth of (100-200) cm	0.05 m day^{-1}
2	Drainage system parameters	
	• Drainage depth	1.50 m
	• Inter-channels distance	200 m
	• Depth of impermeable layer	3 m
	• Effective radius of drainase	0.5 m
	• Surface storage	100 mm
3	Control drainage parameters	
	• Wet season : water gate is set at 40 cm	0 Cm
	• Dry season: water gate is set at 50 cm	50 Cm

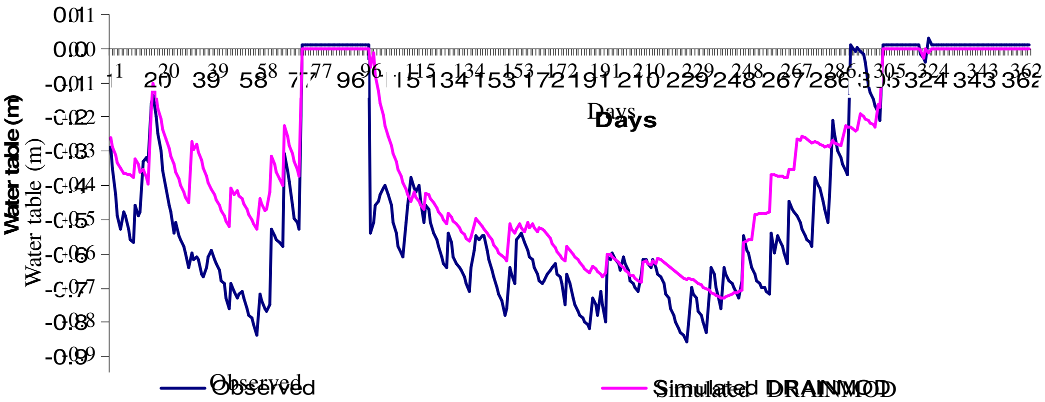

Figure 4. Daily water table dynamics during one year for field observation results and DRAINMOD computer simulation results.

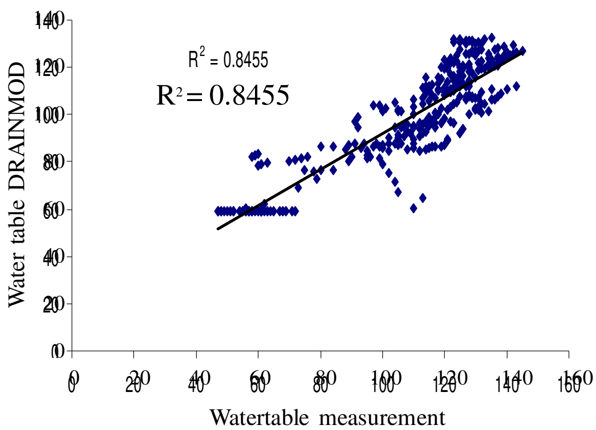

Figure 5. Results of correlation test for DRAINMOD simulation results and field measurement results.

water management plan at several land conditions (Yang 2006). Imanudin *et al.* (2009) added that this model was relatively good to construct monthly water management operation plan based on land use. DRAINMOD model was also very helpful if daily water table data was not available because this model was capable to estimate water table dynamic at crop root zone provided that daily rainfall and soil physical characteristics data were available.

Adaptation of DRAINMOD Model in Constructing Water Management Operation

DRAINMOD simulation had been conducted at dry land.This simulation used assumptions that flow condition was *steady state* and crop water requirement was determined by using empirical approach in which potential evapotranspiration was calculated by using Thronwhite equation (Skaggs 1982; He *et al.* 2002). It used drainage system with inter-channels distance of 200 m and assumed impermeable layer depth was 1.5 m below soil surface.

Water management scenario was based on potential of land utilization pattern and socioeconomic aspect of farmers in which the proposed cropping pattern was rice-corn. Based on water status at land, the main objective of water management at Saleh area was water retention and water leaching.

Model Adaptation in Developing Water Control Operation for Rice and Corn at C-Typhology Land (Dry Condition). Water management concept at C-typhology land was maximum utilization of rainfall water as irrigation water source. Rainfall water was utilized as irrigation water as well as for leaching and flushing operations. Management at this land was by using controlled drainage concept without over drain such as be worried by farmers (Imanudin *et al.* 2009). This is due to the fact that the study area had average acid sulphate layer of 60 cm below soil surface, whereas water table dropped up to 70-80 cm depth below soil surface (Figure 7). If the water table was droped below this acid sulphate layer, then oxidation would take place which made low soil pH and increased iron and aluminium precipitations. This condition was harmful for crops and crop production could decrease more than 50% (Minh 1998).

Analysis of water table depth variation either from computer simulation of DRAINMOD results or field measurement results can be refered to Figure 7. Water table fluctuations in general showed the similar pattern. Water table during rainfall period was located above phyrite layer, whereas it was located below phyrite layer during dry season. Land utilization scenario of A-type could be designed such as shown in Table 4. The recommended land utilization pattern was rice-corn. The main target if farmers could carry out this scenario was that the frequency of crop planting could be double (IP 200).

Results of soil water status evaluation such as presented in Table 4 show that in minimum water table control condition (conventional), the land was still experienced significant water table drawdown although during condition of wet period. This was shown during rice crop reproductive phase (February) in which land experienced water table drawdown below zone of 30 cm so that plants faced water stress and decreased in production. Experience in TIDAL LOWLAND areas management of Vietnam showed that water table control was very important, *i.e.* the negative effect would be produced if water table dropped in zone of 60-90 cm below soil surface that represented by increase of aluminium accumulation and soil pH compared to water table control in zone of 30 cm below soil surface (Minh *et al.* 1998).

Meanwhile, water management objectives that could be conducted was water retention (permanent water gate closing) and controlled drainage in which gates were partly opened and water in channel was not totally drained and there was possibility of high tidal water to enter the channel. Farmers are frequently kept the water by using plastic sack in height of 40-50 cm. This height provides high tide water to enter plastic sack weirs and some water are retained at tertiary channels during low tide water period.

The recommended water management scenario was land cultivation using cropping pattern of rice-corn in which rice was planted on first cropping

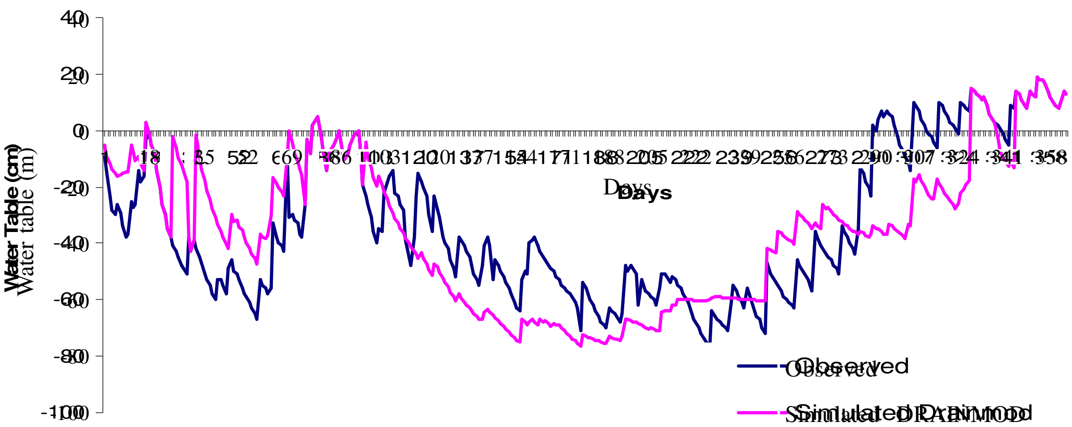

Figure 6. Water table dynamics pattern from computer simulation of DRAINMOD and field measurements.

Table 4. Adaptation of DRAINMOD model in developing land utilization pattern guidance at C-typhology land (dry).

Months	Water status condition in land		Recommendation of land utilization
	Observation	DRAINMOD simulation	
January	Saturation	Saturation	Rice
February	Saturation	Saturation	Rice
March	Drop below soil surface, below zone of 30 cm	Drop below soil surface, below zone of 30 cm	Rice
April	Saturation	Saturation	Bare soil
May	Drop below soil surface, above zone of 30 cm	Drop below soil surface, above zone of 30 cm	Land preparation for corn
June	Drop below soil surface, below zone of 30 cm	Drop below soil surface, below zone of 30 cm	Corn cultivation
July	Drop below soil surface, below zone of 30 cm	Drop below soil surface, below zone of 30 cm	Corn cultivation
August	Drop below soil surface, below zone of 30 cm	Drop below soil surface, below zone of 30 cm	Bare soil
September	Drop below soil surface, above zone of 30 cm	Drop below soil surface, above zone of 30 cm	Land preparation for rice
October	Saturation	Saturation	Land preparation for rice in first cropping system
November	Flooding	Saturation	Rice cultivation in first cropping
December	Flooding	Saturation	Rice cultivation in first cropping

Note: Model Drainmod model is sensitive to water table above 10 cm, flooding land is considered as water saturated soil (excess water status).

season in November-January/February and corn was planted in April to June/July. Problem for corn crop cultivation was that soil still in water saturated condition on February, March and April which required drainage outflow. On the other hand, the water table dropped below 30 cm in early May that created water stress for corn. This condition required water retention in channels and irrigation if possible. Water table dynamics from DRAINMOD simulation result is shown in Figure 8.

DRAINMOD was capable to estimate water table fluctuations in order to develop water management plan for application in year of 2009 (Figure 8) only by using rainfall and soil physical characteristics data. Results of yearly water table observation showed deficit condition in which water table in land was frequently existed below zone of 30 cm even in wet season. This condition created water stress for rice crops. Computer simulation using DRAINMOD model recommended water gate operation at tertiary channel through water retention mode. The results indicated upward movement of water table located in zone of 30 cm and land was water saturated. This provides a good environment for better growth of rice.

The model adaptation in field that was conducted in 2009 cropping season showed good results in which the effect of water gate retention and holding gate in secondary channels produced significant upward movement of water table (Figure 8). The availability of water in tertiary channel created condition of controlled water table and water could be retained in the field during rainfall period, which in turn made flooding land condition and had impact toward increasing of crops production. Production for year of 2005 in average was 2.5 Mg ha^{-1}, whereas production for 2009 increased with average of 4 Mg ha^{-1}.

Figure 8 clearly showes that there was water deficit in Delta Saleh area without water table control operation (data of 2005). The water table dropped far below acid sulphate layer and the land practically could not be cultivated for almost a year. Computer simulation results showed that water table dropped below root zone of 0 cm even in wet season without water retention measure in tertiary channel. Therefore, most farmers agree to hold water during wet season, especially during rice crop cultivation.

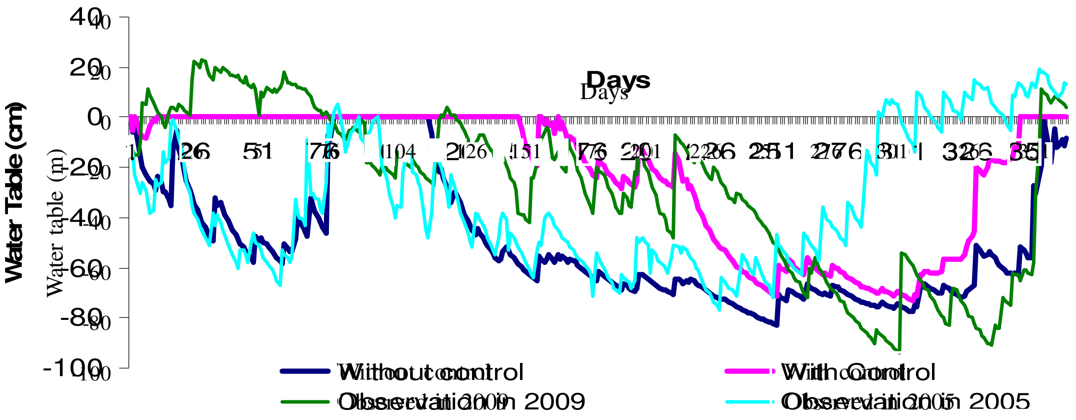

Figure 7. Daily water dynamics from water table control using computer simulation of DRAINMOD model.

Monthly water gates operation in tertiary level according to crop growth was shown in Table 5. Soil tillage operation was started since November for rice crop. The main objective of water management was water disposal at early period of soil tillage. This drainage process had been started since September or October. Its objective was to leach toxic elements and soil pH out of crop root zone. Water retention process was started since soil puddling up to seed sowing operation. The water disposal was conducted in seed sowing phase in which quarterly gates were opened so that water in land could be disposed through quarterly channels into tertiary channels.

Water gates were closed in tertiary channels during rice growth period from December to February. The closing operation was not fully closed but only about 40-50 cm. It is hoped that water could enter during high tide and water in tertiary block was not all disposed due to the retention action of gates at height of 40-50 cm during the low tide.

The recommended cropping pattern based on field study and suggestion from farmers was rice-corn. The gates operation was mostly hold during rice crop cultivation that was started from October-December and January-February. The holding was done at 50 cm height. The water gate operation system was by holding water at 50 cm depth. This depth might provide water in tertiary channel be kept at 50 cm height, whereas water surface in tertiary channel upstream would be raised into 60 cm that made the entering of high tidal water to fill tertiary channel. The entering of high tidal water could also improved water quality and raised water surface in tertiary channel. This concept is known as combination of water retention and water supply.

Model Adaptation in Developing of Water Control Operation for Corn at C-typhology Land (Dry Condition). Corn cultivation can be started if water table was dropped 30 cm below root zone. This could not be done directly after rice harvesting period because water table was still high that made soil layer within root zone was in saturated water condition. Therefore, the water gate

Table 5. Tertiary gate operation in the field for first cropping season of rice in December-February 2009 period.

Crop growth phases	Activity time	Gates operation	
		DRAINMOD simulation	Field adaptation
Land preparation	September-October	Open	Open
Soil tillage	October-November	Close/water retention	Close/water retention of 50 cm
Planting, direct seeds sowing (Tabela)	November	Close/water retention	Close/water retention of 50 cm
Vegetative growth	December-January	Close/water retention of 50 cm	Close/water retention of 50 cm
Reproductive growth	January-February	Close/water retention of 50 cm	Close/water retention of 50 cm
Maturity stage	February	Close/water retention of 50 cm	Close/water retention of 50 cm

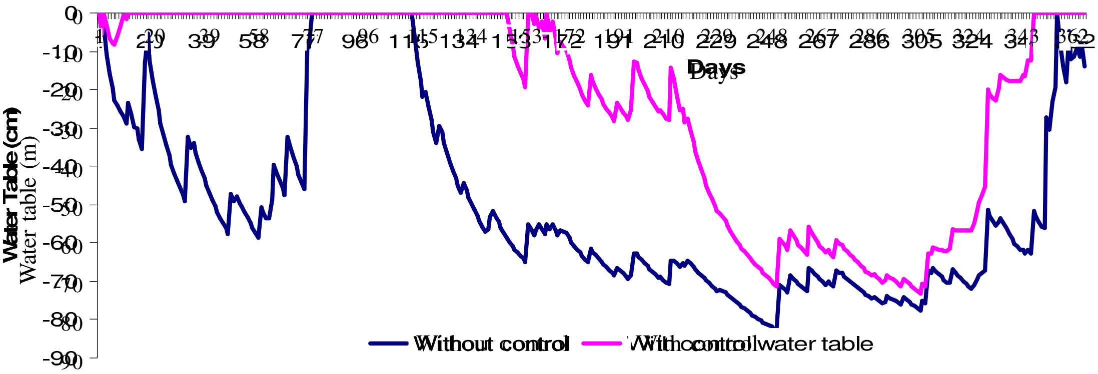

Figure 8. Results of DRAINMOD simulation in term of water gate effect on water table control for corn crop.

was totally opened in March in order to flush accumulated acid elements during water retention at rice growth period. Computer simulation of DRAINMOD model had succed to develop monthly operational plan for water table control. The result of required water table for corn crops as an impact of water table control was shown in Figure 8.

Figure 8 clearly showed that eventhough the water retention had occurred when crop was in generative phase (August), but water table was dropped near 60-70 cm below soil surface. This was due to no rainfall water and high tidal water could not be entered into tertiary channel. It was dangerous condition because crops would experience water stress (Kent and Hanson, 1990). Crops need water supply from outside source in this period.

Water table control operation for corn is shown in Table 6. Water gates were opened and tertiary channel should be equipped with smaller channels to lower water table during early corn planting. The water retention facilities and the entering of high tidal water were needed during generative phase of corn that was occurred in May-June. The efforts to control water table for corn had many constraints. Shallow condition of tertiary channel due to sedimentation made the water from quarterly channel and paddy field could not be discharged so that land was in water saturated condition on April. Farmers can do planting in the end of May. This made crop experienced water stress during generative phase because water table dropped below 60 cm in June-July. According to Zwart and Bastiaansen (2004), capillary water movement was not sufficient to fulfill crop evapotranspiration requirement if water table depth was dopped below 60 cm.

The effort to maintain field condition where water table depth was 40-50 cm below soil surface in dry season was very difficult. Recommended results of DRAINMOD simulation showed that to maintain field condition with water table close to 30 cm zone dictated water surface in tertiary channel should be in height of 40-50 cm. However, field fact showed that water in tertiary channel was always empty because high tidal water during dry

Table 6. Water management operational strategy for corn crop at C-typhology land (dry condition) at Delta Saleh

Crop growth	Months	Required water status condition	Water management objective	Water gate operation
Soil tillage	May	Field capacity, water table depth was -30-50 cm	Maximum drainage – land leaching	Maximum opening
Planting	May	Field capacity	Maximum drainage – land leaching	Maximum opening
Vegetative growth	June	Field capacity	Water retention	Closing/retention of 50 cm
Reproductive growth	June-July	Field capacity	Water retention	Closing/retention of 50 cm
Maturity-harvest phase	July	Field capacity	Water retention	Closing/retention of 50 cm

season was not totally entering tertiary channel. The only way to maintain water table condition was that by closing the secondary drainage channel (DAM).

The strategy for corn crop cultivation was to accelerated cropping season so that corn was not experience water stress in reproductive phase. Soil tillage should be started in April and crops can be planted in May. However, rainfall intensity in April was still available and soil was in water-saturated condition that required channel discharge at tertiary blocks. The above conditions dictated that network improvement for corn cultivation was by acceleration of corn cultivation in April and by maintaining water table control so that water table was not quickly dropped at dry season.

CONCLUSIONS

The potential cropping pattern at C-typhology land was rice-corn based on water availability in land. Soil physical properties such as high porosity produced high hydraulic conductivity that created main problem of water losses. Therefore, water retention in tertiary channel was the main option in water table control in this area.

Determination of water table dynamics at tertiary block could be conducted by using DRAINMOD program. Evaluation results showed that this model could be used as a tool for estimating water status at tertiary blocks. Results of water table dynamics pattern from simulation was tend to be similar to the results of field measurements. Statistical analysis showed that the root mean square error was 1.45 cm, model efficiency was 0.97, and correlation value was 0.84. These data showed that DRAINMOD model was acceptable.

Model adaptation in dry land condition (C-typhology) showed that the best scenario was land utilization pattern by using rice-bare soil. Monthly operational plan of water management for rice crop (first cropping season) was as follows: water gates was opened (maximum drainage) at early phase of soil tillage (plowing); water control was needed by operating water gates as combination of supply and water retention in tertiary channel (kept at 50 cm) near the end of soil tillage. Water gates were opened (maximum drainage) in seeds sowing phase which was followed by operation of water gates as combination of supply and water retention until ripening stage. Field test showed that this operational system was capable to maintain water table condition in zone of 20 cm above soil surface.

Recommended operation for corn crop was dominated by water table control system in tertiary channel (water retention) where all water gates operation at all corn crop growth phases was as water retention and as water supply before the entering of salt water (June-July). The maximum drainage was only be carried out after rice planting had finished and during land tillage for planting preparation.

Application of water management in field should be supported by complete water management infrastructures, especially the availability of water gates in tertiary channel. Water gates in tertiary channel were absolutely needed to hold water during crop growth period. Water management concept with water retention system on dry land condition (C-typhology) could create water quality problem in the long run. Therefore, water flushing in channel should be conducted. Water gates opening operation should be carried out in quick and proper manners to prevent over drain from land. Some aspects that should be considered in developing water management operational plan were that the model should be simple and socially accepted by farmers. In order to minimize environment degradation and to accelerate land remediation process, water management operation should always be conducted eventhough land was not be cultivated.

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