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Water Table Control Model for Maize Cultivation of C Typology Land on Tidal Lowland Reclaimed Area of South Sumatra, Indonesia

Momon Sodik Imanudin[1]*, Abdul Madjid[1], Bakri[1], Mustika Edi Armanto[2], Satria Jaya Priatna[1], Warsito[1] and Edwin Mardiansa[2]

[1]*Soil Science Study Program, Faculty of Agriculture, Sriwijaya University, Jl. Raya Palembang-Prabumulih KM 32. Kampus Unsri Indralaya Kabupaten Ogan Ilir Sumatera Selatan, Indonesia*
[2]*Data and Information Center for lowland and coastal areas of South Sumatra, Indonesia, Komplek Perumahan Poligon Palembang, Indonesia*
e-mail:momonsodikimanudin@fp.unsri.ac.id

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ABSTRACT

Tidal lowland productivity in type C is still low. Most of them have only been able to cultivate rice twice a year. The third cultivation of corn often fails due to a lack of water. The research objective is to determine an operational model for water management in the field for maize cultivation at several planting times. Model area is conducted at a tertiary block of reclaimed tidal lowland, Telang Jaya Village Primer 8 Delta Telang I, of Banyuasin District. There are three planting times treatments: the fourth week of April, the second week of June, and the first week of July, 2021. A water management model was applied to control the drainage system, in which the water level in the tertiary channel is maintained at a depth of 50 cm. When groundwater drops below 70 cm, and there is no rain, pump irrigation is provided. Results of the field experiment showed that the maize crop showed similar growth quality at each phase. Land with a planting period of June and July still requires water addition using pump irrigation. It was applied on 14th and 18th August. Moreover, the maize cultivated at the end of April did not require pump irrigation. All treatments have generally similar production with an average magnitude of 8.0 Mg ha^{-1}. The highest production is 8.73 Mg ha^{-1}, which is planted in the first week of July.

Keywords: Water table, drainage control, maize, tidal lowland

INTRODUCTION

In order to face the global recession, the government has no choice but to strengthen the food ecosystem and national food security. Therefore, some efforts had to be made to develop food sustainably. Superior food other than rice is corn. The global recession has also impacted corn-exporting countries, which have applied export restrictions to give priority to fulfill their domestic requirement. This policy results in a price increase of corn in the world due to the impact of global geopolitical conditions, caused by the current conflict between Russia and Ukraine. The average price of maize is increasing to USD 335.71 per ton in June 2022. The international price of corn achieved the highest price of USD 348.17 per ton in April 2022 and tended to decrease slightly up to June 2022. The world maize price, which tends to improve in January-June 2022 with an increase of 21.53% compared to the same period in 2021, becomes an opportunity for Indonesia to conduct corn exports. Area extension efforts are conducted to increase production to fulfill domestic corn requirements and export demand.

Area extension should be executed in the wetland because irrigated land in Java Island is limited due to land function shift, and dry land is being competed with plantation land. Tidal lowland reclamation in South Sumatra, with an area of about 400,000 ha, has potential for maize crop development. However, land drainage is the primary constraint for corn crop development in tidal lowland (Imanudin et al., 2020). The problem with cultivating maize crop in tidal lowland is that rice often has excess water, while if it is planted in the dry season, it often experiences crop failure due to drought in the generative phase (Imanudin et al., 2021a; Dojamo et al., 2022). Apart from that, on typology C land, water loss from the land is very high, so efforts are required to retain water in tertiary channels to reduce percolation. For this reason, the best water management objective is a controlled drainage system (CD). According to Bakri et al. (2020), CD model is an efort to maintain the water level in the tertiary canal at level of 50-60 cm, will be able to maintain the water table at a depth of 60-70 cm below soil surface, and be able to meet the crop evapotranspiration for maize withaut irrigation.

The water table is frequently too shallow for the first planting season after rice, whereas planting during the approaching dry season is frequently constrained by dryness in the generative phase. Controlled drainage effort by maintaining water table depth approaching the dry season is the best alternative for crop cultivation other than rice (Imanudin et al., 2021). The study of controlled drainage (CD) in America was successfully implemented in the wetland area and could produce corn with a magnitude of 10.62 Mg ha^{-1}. This CD model can increase production up to 14 % and decrease the dryness risk (Youssef et al., 2022). The critical value of water table depth for the corn crop is 70cm (SEW-70 cm), at which crop growth significantly changes if the water table depth is less than 70 cm (Fransen, 2019).

On the other hand, corn production will decrease if the water table depth is always found at a depth of 90 cm (Kalita and Kanwar, 1992), so that the optimal depth is in the range of 60-80 cm. Crop should be given a water supply if the water table depth is more than 80 cm (Bakri et al., 2015). In addition, nutrient uptake is better and increases fertilizing efficiency using a controlled drainage system (Paiao et al., 2021). Moreover, controlled drainage systems can also decrease the effect of greenhouse gas (Crézé et al., 2019). Therefore, the controlled drainage model, which maintains water in the tertiary channel at a depth of 50-60 cm, is very proper for testing the water requirement fulfillment of corn in the second season.

This paper will describe the water structure model in the tertiary channel that can store rainfall water and maintain a minimum water depth in the tertiary channel. Variations in planting time will be tested in the field, where the farmer will plant in relatively wet conditions (end of April) and in the second season after rice in June-July. At the initial planting condition of the second period (end of April), the farmer could only conduct two plantings within a year (IP200). In contrast, farmers who plant in June have a probability of rice-rice-maize planting pattern (IP300), and farmers who plant in July have only a probability of rice-maize planting pattern (IP200). The IP300 pattern can technically be applied in this area. However, social and environmental issues are agricultural considerations that should be considered in tidal lowlands and will be discussed in this paper. Imanudin et al (2024) reported that the control drainage system was successfully applied for rice water management in tidal lowland type C and to make a cropping pattern rice-rice-corn.

MATERIALS AND METHODS

The research was conducted in an overflowing type of C of tidal rice fields at the Tidal lowland reclamation area, Telang I. The agricultural land is never flooded by water, meaning that water can only enter tertiary channels and not overflow the land. A field experiment was conducted in the tertiary block of Blok Tertiary 2, 8, and 9 of Telang Jaya Village P8-2S, Muara Telang Sub-district, Banyuasin District, South Sumatra, Indonesia (Figure 1).

Soil physical and chemical properties were measured in the Soil Physical and Conservation Laboratory and the Soil Chemical and Fertility Laboratory, Faculty of Agriculture, Sriwijaya University. The research used a completely randomized design method with three planting time treatments. The first cultivation (P1) was planted on June 14, 2021; the second planting (P2) was on July 2, and the third planting (P3) was on April 25. The physical parameters of the soil analyzed include soil texture (hydrometer), bulk density (gravimetric), total pore space (gravimetric), and permeability (constant head). The chemical properties of soil include organic matter content, pH, nitrogen, phosphorus, potassium, and exchangeable Aluminum. Chemical properties of the analyzed soil in the laboratory, such as pH, C-organic (Walkley and Black method), N-Total (Kjeldahl method), P-available (P-Bray II method), and K-EDTA (Flamephotometry method).

The data analysis carried out was an analysis of variance (ANOVA) on confidence intervals of 95%, and the treatment that had an effect was further tested using Duncan's multiple interval test.

The Telang Jaya area has a C flooding type of land in which irrigation from high tidal water cannot flood the land, but can flood it during rainfall. Water at high and low tidal conditions only affects the water surface in the channel. The water

Figure 1. The field study is at C-typology land, a tidal lowland in Telang I Banyuasin, South Sumatra, Indonesia.

management system in the tidal lowland at this study location is divided into two parts: macro water management, covering primary and secondary channels, and micro water management, consisting of tertiary, quarterly, and micro channels. The Water management network applied at the research location is based on water conservation, in which farmers made water structures to retain water.

Control Drainage (CD) was used as the best option in field water management for C-type land typology. Water drainage design in the tertiary channel is controlled at a 50 cm depth limit (Figure 2).

The equipment used in this research is as follows: 1) Writing Utensil; 2) Belgian Drill; 3) Buku MSCC Book; 4) Camera; 5) Measuring Tape; 6) Physics Board; 7) Wells Pipe; 8) Ring Sample; 9) Scrub. The materials used in this research are: 1) Aquadest; 2) Rubber Bracelet; 3) Label Paper; and 4) chemical substance for soil fertility analysis.

The hydraulic structure was developed in the outlet of the tertiary canal, and a PVC pipe was used with a diameter of 12 inches. It was connected to an elbow as a control, and the pipe could be opened and closed. If the pipe is to retain water, it is

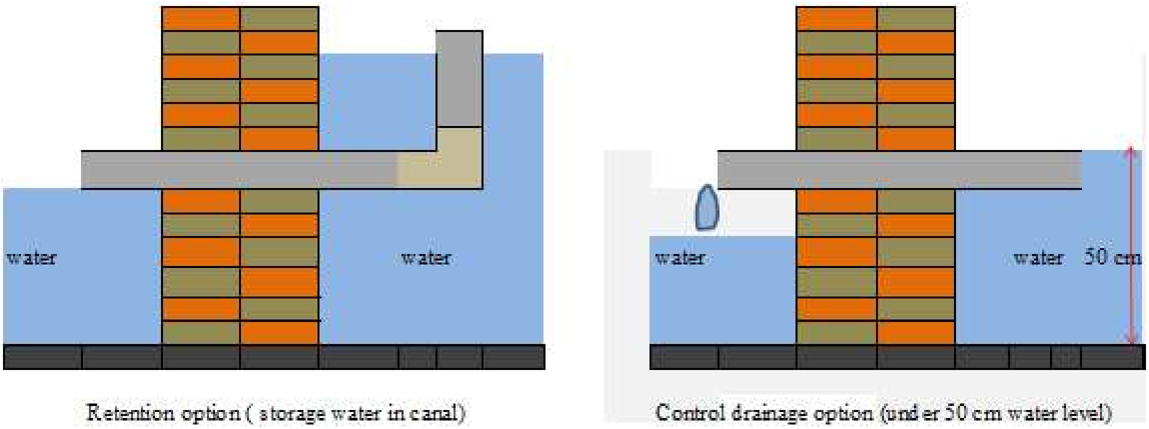

Figure 2. Water level control design in the tertiary canal for the CD option under a 50 cm water level in the tertiary canal of the tidal lowland reclamation area.

Figure 3. Structure hydraulic Operation model of 50 cm Control Drainage (CD) in tertiary channel (study area) at tidal lowland, Telang Jaya Village, South Sumatera.

installed like the letter L, and if the water is to be discharged, the connection pipe is removed, as in Figure 3.

The method used in this field study is a survey method through direct observation in the field. Land arrangement is conducted using an intensive shallow drainage model in which the collector channel development is connected to the quarterly channel. Micro channel is developed with a drain spacing of every 6 m and a depth of 30 cm perpendicular to the collector channel. Water surface observation in the channel is conducted using a physical board installed in the tertiary channel. Observation wells (pipe wells) are installed at the experimental land to monitor the water table condition during crop growth. The area of the experimental land located at P8-2S is 16 ha within one tertiary plot. There are three planting times, in which the first corn planting is at the third week of April (the second planting period); the second treatment is planting at the second week of June (the third planting period), and the third treatment is planting at the first week of July (dry season period). Table 1 shows the treatments of corn planting time and the landowners.

Fertilizers are given three times to every land area within one planting period. The fertilizers used in this experiment are Phonska and Urea, with different doses for each land. A has 150 kg phonska and 150 kg Urea, B has higher fertilizer doses than other areas, consisting of 300 kg Phonska and 200 kg Urea for each application, whereas C has 300 kg phonska and 150 kg Urea.

Soil chemical analysis is conducted to determine the effect of soil fertility on crop growth and production. It is conducted at the laboratory of the Soil Department, Faculty of Agriculture, Sriwijaya University. The analyzed parameters are pH, Total-N, Available-P, Available-K, Organic-C, and Exchangeable Al-d. Three samples were taken for each parameter as replications.

Water excess and shortage in the root zone are determined using the 40 cm critical value approach to the water table. This means that a crop will experience excess water if the water table is located above 40 cm.

$$SEW-40=\sum_{i=1}^{n}(40-x_i)$$

Table 1. Treatment of corn planting time and farmer sample.

Land Plot	Owners and Planting Time Treatment
Land Plot 1(P1)	- Farmer name: Parno
	- Planting time: June 14, 2021
	- Land location: Tertiary 9, Plot 3
Land Plot 2 (P2)	- Farmer name: Ali
	- Planting time: July 2, 2021
	- Land location: Tertiary 8, plot 4
Land Plot 3 (P3)	- Farmer name: Toro
	- Planting time: April 25, 2021
	- Land location: Tertiary 2, plot 1

$_{Xi}$ is the water table depth on day i, i is the first day, and n is the number of days during the growth period. SEW-40 terminology is a certain depth defined as an initial water shortage. The water table, 40 cm below the soil surface, was taken in this case. If the water requirement of the land is in an excessive condition, then it is said that this land has a surplus of water. On the other hand, it is said that land is in a state of water deficit if the water requirement is in a deficit condition. Imanudin et al. (2020) showed that if the water table drops more than 100 cm, corn's water requirement should be supplied with irrigation water. However, crop water requirement is still sufficient due to capillary water movement if the water table depth is 50-60 cm. In addition, Kadioglu et al. (2019) study for Canola (*Brassica napus* L) crop showed that the optimum water table depth is 90 cm. Optimum water table depth is also affected by soil texture. For loam soil, the optimum water table depth for corn growth is at 80 cm depth, and it can be up to 90 cm depth for clayey loam texture soil (Kanwar et al., 1998). The result of a study by Odili (2021) on Spring Wheat (*Triticum aestivum* L.) crop showed that the optimum water table depth is 80 cm below the soil surface.

RESULTS AND DISCUSSION

Soil Characteristics

Analysis of several soil physical properties (Table 2) is done for bulk density, total pore space, permeability, and soil texture. Soil in the study area is mineral soil characterized by bulk density more than 1.0 g cm^{-3}, slow and relatively slow permeability, and the upper layer of the soil is classified as loam class. Table 2 shows the results of laboratory analysis and statistical tests, which show no significant differences in soil physical properties in each experimental plot.

Loam soil texture was evaluated for maize growth and production. It is indicated that the soil is classified as a highly suitable class (Tashayo et al., 2020). Fang et al. (2019) added that soil is important for crop growth. Soil with a loamy texture is very suitable for cultivating maize and common crops because it can provide more available water and nutrients. Soil nitrogen levels in the study area are moderate. The conditions follow the following research (Darma et al., 2022; Budianta et al., 2021), where the tidal lowland area near the overflowing

Table 2. Soil physical characteristics in three experimental plots.

Land Plot	BD (g cm^{-3})	TPS (%)	Permeability		Texture			
			Value (cm min^{-1})	Grade rating	Sand (%)	Loam (%)	Clay (%)	Grade rating
Land P1	1.24a	39a	0.47a	Relatively slow	36	34	30	Loam
Land P2	1.18a	48a	0.22a	Slow	46	32	22	Loam
Land P3	1.12a	51b	0.42a	Relatively slow	54	24	22	Loam

Significant differences among land plots (á = 0.05). BD (bulk density); TPS (total pore space).
Source: Analysis from Physical, Soil and Water Conservation Laboratory, Soil Department, Faculty of Agriculture, Sriwijaya University (2022)

Table 3. Characteristics of several soil chemical properties at the study area of delta taleng I/P8 in three experimental plots.

Land Plot	Total-N (%)	Available P (ppm)	Available K (me 100 g^{-1})	Exchangeable-Al (me 100 g^{-1})	Organic-C (%)	pH
Land P1	0.28a	111.51a	0.51a	1.02a	3.90a	4.18a
Land P2	0.33a	112.24a	0.51a	1.80a	3.51a	4.31a
Land P3	0.26a	115.57a	0.44a	151a	3.51a	4.20a

Significant differences among land plots (á = 0.05). Source: Analysis from Chemical, Biological and Soil Fertility Laboratory, Soil Department, Faculty of Agriculture, Sriwijaya University (2021) river has moderate nitrogen levels. To increase the soil's nitrogen nutrient content, fertilizer was applied at 200 kg N ha^{-1} and combined with manure.

Table 3 shows the results of the analysis of several soil chemical properties. Laboratory analysis results showed that the soil in the study area under dry conditions is very acidic (pH <4.5), and the field pH (moist condition) is acidic (pH 5.0). Exchangeable Aluminum content ranges from 1.0 to 1.80 me $100g^{-1}$. Soil organic matter content is classified as medium, and the Nitrogen nutrient is also medium. On the other hand, available P and K content are classified as high and might result from residual effects of rice crop cultivation and fertilizing application. Statistical analysis showed that the nutrient status had low variability. Each experimental plot was identified as medium fertility soil.

The main problem (key problem) on acid sulphate land is the presence of sulfidic materials, namely materials that contain pyrite (FeS2) > 2%, which is a characteristic of sulfate soil. In the pilot area, the pyrite depth is relatively deep,>100 cm. The pyrite in the saturated zone and soil has not undergone oxidation, which could be because the aluminum content is relatively low. Since the soil is acidic, the applied soil ameliorant was still required. It is in line with the results of research by Imanudin et al (2023) in the Saleh delta area, where tidal soil type C has an acid pH (3.5-4.5), so regular land leaching and canal flushing are still required, in addition to providing the soil ameliorant. Apart from that, compost of various kinds of material can improve the chemical properties of acid sulfate mineral soil from tidal fields, reduce Fe- and Al-dissolution concentrations, and increase P and K availability (Abdillah and Widiyastuti, 2022).

Figure 4 shows a water balance analysis, with dry months from June to August. The rainfall during this period is less than the water requirement for crop evapotranspiration.

Therefore, water addition effort is still required on land at the third planting season. Water is added through a pump irrigation system once in August (peak dry season). Table 4 shows the pump operation schedule. Land planted in the early period or at the end of April does not require a water addition supply (Land P3). The water management option of using a controlled drainage system is sufficient for crop cultivation on this land without water addition from the surface irrigation system.

Water availability can be seen from water table dynamics during the planting period (July-September). Water surface control in a channel at a depth of 50 cm can create a water table condition suitable for crop growth (Figure 5). The water table surface can be dropped to a depth of 50 cm before harvesting the first corn plant. Subsequently, the water surface is available at a depth of 30-40 cm, and it is dropped again to a depth of 60-70 cm before the second harvest at the end of September.

The water charging potential in the channel was observed every hour for 24 hours from 6-7 July 2021 (Figure 6). The peak of water charging occurred during high tide (01-02 West Indonesia Time), during which the water in the channel was 55 cm deep.

Water surface dynamics in the tertiary channel, resulting from daily observation (Figure 7), showed that water increases during high tide and maximum

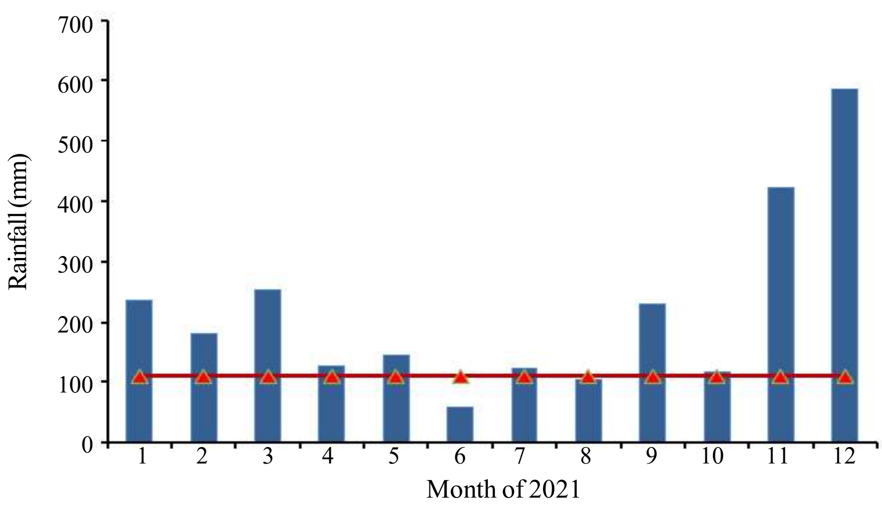

Figure 4. Water balance in the land using monthly rainfall data for 2021. ▬ : Rainfall, ▲ : Evapotranspiration.

Table 4. Water supply using an irrigation system by water pump operation.

Land Plot	Water Pumping Usage	Operation Time
Land P1	Yes	August 14, 2021
Land P2	Yes	August 18, 2021
Land P3	No	-

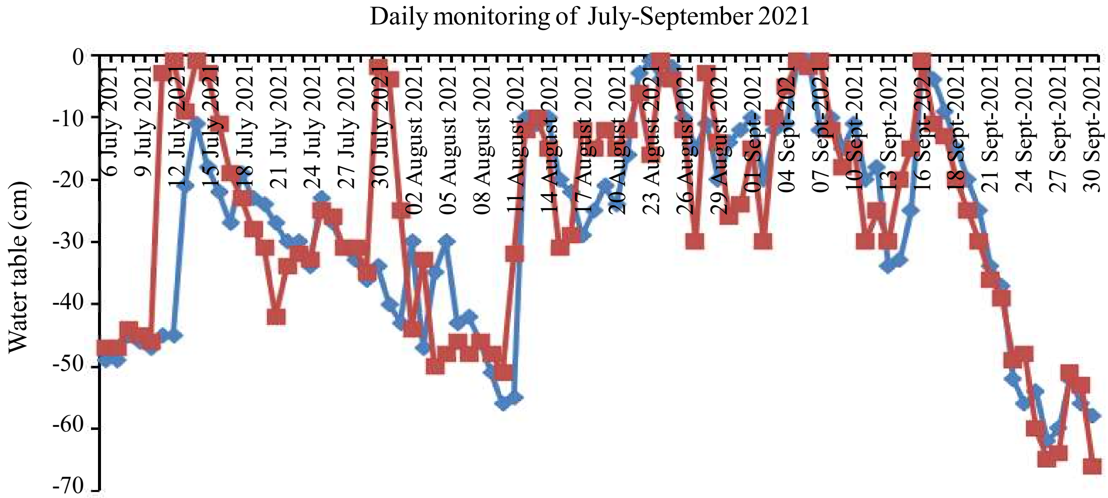

Figure 5. Water table dynamics at the tertiary plot in the tidal lowland of C typology, Telang 1. : Sampling point 1, : sampling point 2.

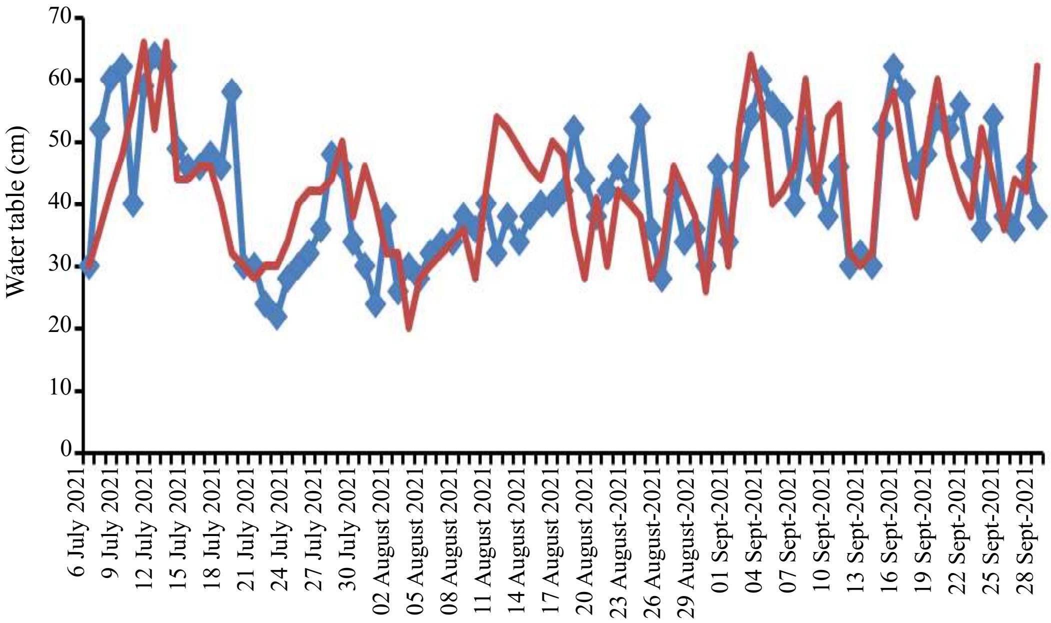

Figure 6. Water table dynamics in the tertiary channel. : land plot A, : land plot B.

rainfall, achieving a 40-65 cm depth. The minimum water depth is 20-30 cm, reflecting the minimum water available in the channel. The water surface in the tertiary channel is, on average, at 40-45cm.

The production results from the testing of different planting times can be seen in Table 5. Crop production generally showed a good yield with an average magnitude of 8.5 Mg ha^{-1}. It showed that

Table 5. Maize production at several planting times in the tidal lowland type C.

Land Plot	Planting time	Harvest yield ($Mg\ ha^{-1}$)	Selling price of dry milling corn ($Rp\ kg^{-1}$)	Harvest time
Land P1	April 25, 2021	4500	4500	August 16, 2021
Land P2	June 14, 2021	7.91 a	3400	October 2, 2021
Land P3	July 2, 2021	8.73 a	3200	October 12, 2021

significant differences among land plots (á = 0.05).

the difference in planting time is not a problem if farmers can provide sufficient water to fulfill the crop evapotranspiration requirement. Odon et al (2022) reported the advantage of earlier planting in swamp land in Ethiopia, where new production reached an average of 3.8 Mg ha^{-1}. However, the maize production potential for lowland with a rain-fed system ranges from 11 to 12 Mg ha^{-1}, so efforts to improve soil fertility must be increased (Aristya & Samijan, 2022). Maize production results show that differences in planting time do not significantly affect yields as long as the plant's nutrient and crop water requirements are sufficient. Crop planting will improve at the beginning of the dry season so that farmers can plant rice twice.

Soil Fertility Status Evaluation

Regarding soil physical appropriateness, land in this area is very appropriate for the corn crop, i.e., the soil has a loam texture. Soil texture in reclaimed tidal lowland areas, in general, is not a limiting factor for corn crop development (Imanudin et al., 2020). Some soil textures, such as loam, clayey loam, sandy loam, and clay, are appropriate for corn crop growth (Abagyeh et al., 2016; Tashayo et al., 2020). According to Yustisia et al. (2021), land appropriateness analysis in West Java showed that 70% of the land is appropriate for the corn crop. Maize cultivation can be conducted at each land typology in the tidal lowland area, and the planting time setting highly determines its appropriateness. Maize cultivation after rice crop through land and water management can make crop appropriateness appropriate (Herawati et al., 2021).

The soil fertility level at three experiment sites is qualitatively the same, characterized by medium nitrogen, potassium, and relatively high phosphorus content. It is because three experiment sites receive fertilizing treatment that is relatively the same and balanced. This fertilizing treatment creates uniform soil fertility in this area, so the crops respond similarly to crop growth. Fertilizing treatment using doses of 150kg ha^{-1} Urea and 300 kg ha^{-1}. Ponska is similar to study results by Yustisia et al. (2021), which applied 200 kg ha^{-1}. Urea and 400 kg/ha NPK. Reporten by Taisa et al., 2019; Prasetyo et al., 2021). Increasing soil fertility can be done by adding biochar. Adding biochar can reduce the need for potassium fertilizer by 30% and improve the physical properties of the soil. Then, the maize growth performed better in the lowland area.

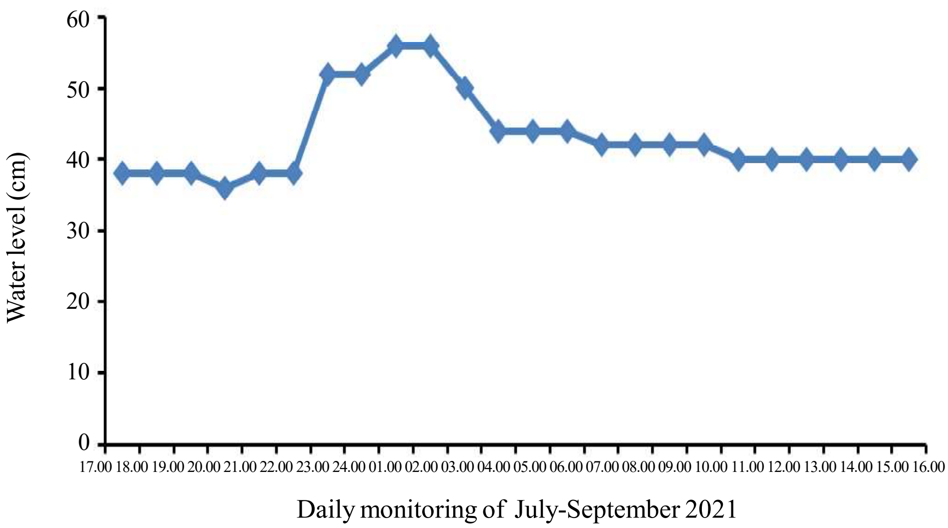

Figure 7. Water level observation in the tertiary channel for 24 hours (6-7 July 2021).

Analysis of Water Table Status and Crop Water Requirement

Analysis results of SEW-40 showed that water table dynamics during crop growth are located at a depth of less than 40 cm for most of the day. This level showed an indicator of relatively wet soil and water excess. This condition is due to relatively more frequent rainfall. The cop water requirement can be fulfilled from capillary water movement under these conditions. Crops experience excess water if the water table depth is above 40 cm. Figure 8 shows that only about 21 days of water table condition is located above 40 cm, with a 40-60 cm range. This condition is relatively good, and the water table is at an optimum depth. The study by Zhou et al. (2000) for corn cultivation in a wetland with sandy loam (upper layer) and clayey loam (lower layer) textures showed that the optimum water table depth is 70 cm.

The availability of the water table is highly dependent on rainfall and surface water dynamics in the channel. If the water surface in the channel is at 50-70 cm, then the water table is also close to the root zone at a depth of 20-30 cm (Figure 9). In order to maintain the water surface in the channel at a level that is not too high, the water structure should be in the open position so that water can be drained into the secondary channel during rainfall. As shown in Figure 3, the water gate position is open. This concept is known as a controlled drainage

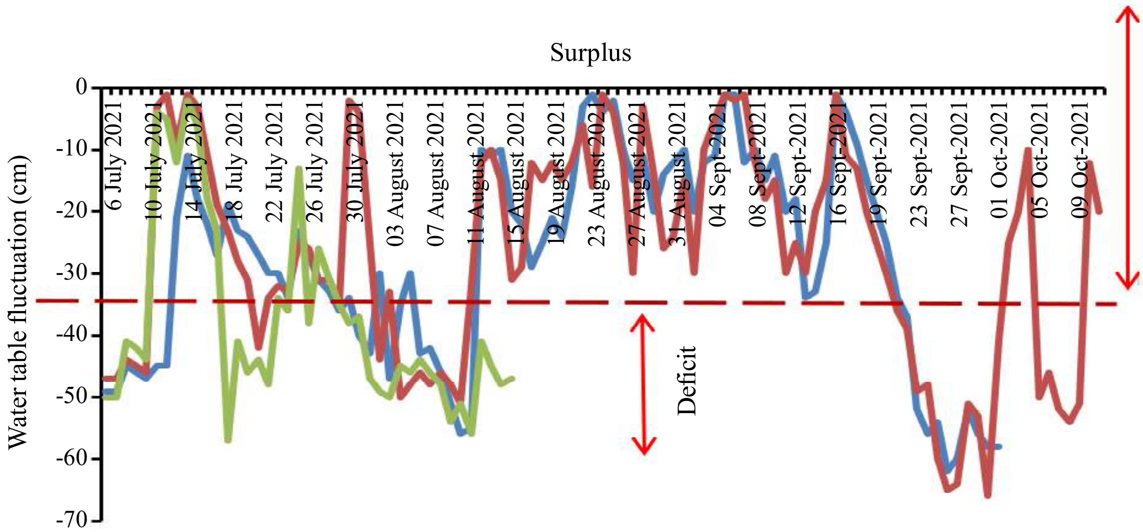

Figure 8. Water table dynamics relative to the SWE-40 cm value in land type C by the CD model. : Pak Parno, : Pak Ali, : Pak Toro.

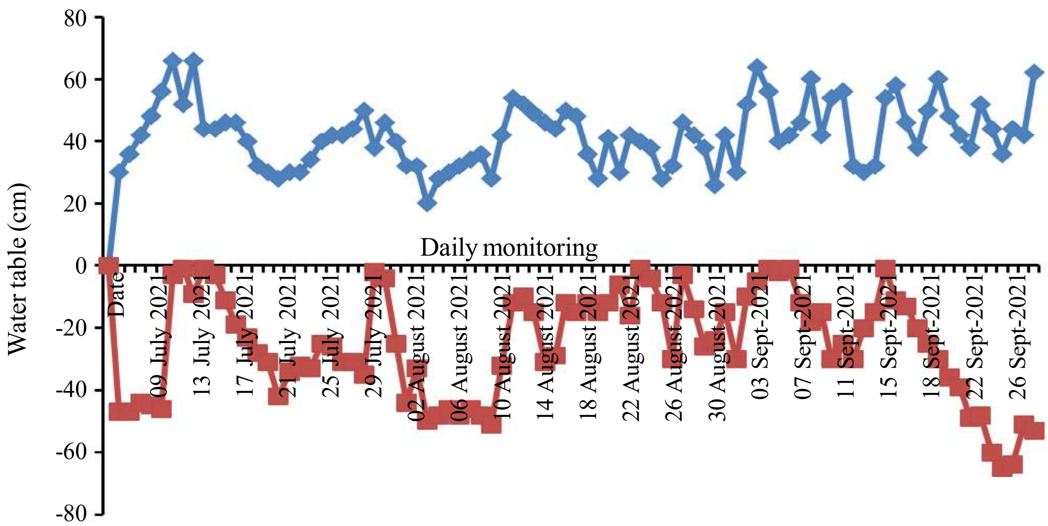

Figure 9. Water table dynamics in the tertiary canal and the groundwater table in type C of tidal. : Water table in tertiary canal, : Ground water table.

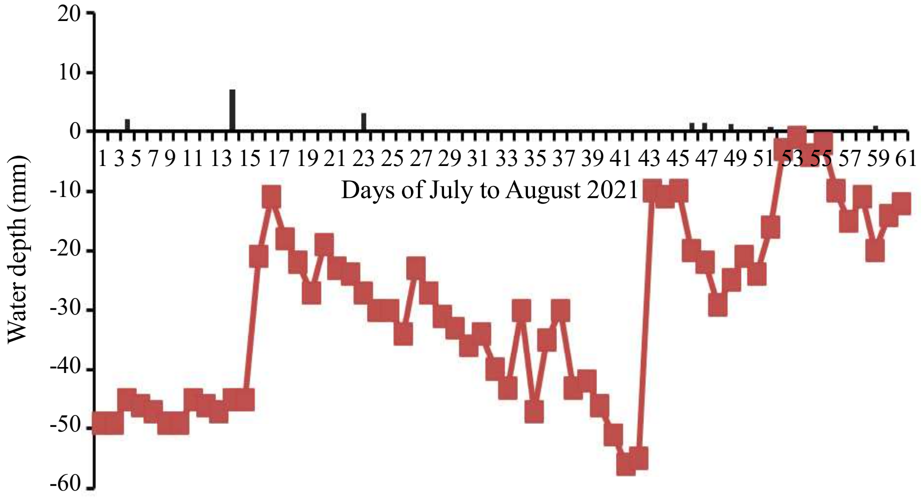

Figure 10. Relationship between rainfall and water table dynamics. ▬ : Daily rainfall.

system, in which water should be available in the channel (minimum elevation that should be maintained) in order to maintain the water table depth, so that it does not drop excessively in the dry season (Craft et al., 2018; Imanaudin et al., 2021; Youssef et al., 2023).

Observation of crop growth from three different planting times showed relatively similar growth. The highest maize production is 8.73 Mg ha^{-1}, planted on July 2 and harvested on October 12. The average national corn production is about 6.4 Mg ha^{-1} (Kementan, 2020). It shows that research results have produced higher-than-average national corn production. The research using a controlled drainage management system in America for corn produced 10-10.5 Mg ha^{-1} (Youssef et al., 2023).

Drainage in tidal lowland aims to control the water table. Crézé et al. (2019) proved that controlled drainage in wetland also creates a water table condition suitable for crop growth, improving soil nutrient uptake and decreasing the greenhouse gas effect. Paiao et al. (2019) showed that nutrient uptake in land with controlled drainage can be 1.2 times that of land without drainage.

Figure 10 describes the water table condition and rainfall during the dry season (July-August). Rainfall has dropped less from the end of July to the middle of August (more than 20 days), forcing farmers to water crops using pump irrigation. This application is only conducted once for B land and C land.

The use of a water pump in a tidal lowland is conducted when the land is in a water shortage condition. Water pumping is conducted when the tertiary channel receives high tidal water, so the water quantity that can be pumped is sufficient. Applying pump irrigation for 1 ha of land using a discharge pipe 8 inches in diameter takes about 4 hours, and it needs solar fuel of about 4 liters, equivalent to Rp. 50000,-.

On the other hand, land C, which is planted from April to July, has a uniform rainfall distribution. Hence, the soil moisture condition is sufficient to fulfill the crop evapotranspiration requirement. Therefore, water application using pump irrigation is not required for the C land.

CONCLUSION

Reclaimed tidal lowland had a C typology in which high tidal water could not irrigate the land. The areas have great potential for maize cultivation after rice cultivation. Planting time can be done from the end of April to the middle of July, through proper water management in the tertiary canal. Field water management by the Control Drainage (CD) model was successfully applied, and maize production was increased. The water table in the tertiary canal was maintained at 50 cm. The pump irrigation system provides a water supply only once in August, where no rainfall occurs for over 20 days.

The production can achieve more than 8.5 Mg ha^{-1}. However, other agricultural inputs could increase the production to achieve maximum production. Sirappa et al. (2021) reported that improving soil quality in the Central Mamuju experimental plot achieved the highest maize production in the 8-12 Mg ha^{-1} range.

The advantage of earlier planting (planting at the end of April and harvesting in August) is receiving a higher price, resulting in higher profit. However, this model can only be applied twice for planting using the rice-corn pattern. This pattern benefits soil management because it produces a longer soil fallow period to flush toxic elements through land flushing and evaporation.

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