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Research Paper

Enhancing Rice Cultivation Efficiency in Tidal Lowland of Delta Saleh, Indonesia: Precision Farming Practices for Water Management and Soil Health Improvement

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Abstract
Tidal lowland is a marginal land characterized by low pH, deficient nutrients, and salinity. Despite these challenges, El Niño phenomenon often occurs during the second planting season, resulting in long droughts. However, tidal lowland must be used for cultivation due to the need for rice and the land should be treated accurately. Therefore, this research aimed to address the issues by improving the efficiency of rice cultivation on tidal lowland through precision farming practices. A survey and land analysis were conducted in tidal lowland of B typology in Delta Saleh, Indonesia, from March 2023 to June 2023. In this precision farming practice, water management was highly prioritized, starting from tertiary channels such as optimizing sluice gate operations and monitoring water levels in channels and groundwater. Additionally, pH, CEC, and C-Organic analysis were also carried out in rice cultivation, as showed by the equation Y = 0.15 - 0.001 pH + 0.000 CEC + 0.000 C-Organic. The highest production yield was 2.05 tons/ha in P5, with the SEW-10 value during cultivation activities being 778 cm and the number of days above -10 reaching 84. Moreover, the efficiency of rice cultivation was improved through precision agricultural practices by using valve sluices and levees

Keywords
Efficiency, Rice cultivation, Tidal lowland, Precision agriculture, Water management

1. INTRODUCTION

The conversion of fertile soil is increasing with following the population growth, necessitating the use of tidal lowland to fulfill food requirements (Ningsih et al., 2020). This land requires accurate treatment considering the enormous potential for agricultural development, including good water management, appropriate technology, and adequate nutrient supply (Arista et al., 2023). Additionally, a significant problem is soil acidity, which greatly affects the productivity of rice (Saputra and Sari, 2021). This phenomenon can be more detrimental since tidal lowland contains pyrite, affecting rice growth when oxidized (Wignyosukarto and Santoso., 2019). In addition, rat infestation causes damage equivalent to five times the feed requirements and the problem becomes a serious threat to productivity (Xuan et al., 2021). The second planting season often coincides with the El Niño phenomenon, causing global warming and prolonged droughts (Domeisen et al., 2019).

Water table control is a major factor in precision farming associated with rice cultivation. The management starts with tertiary channels, including the operation of water gates, the use of monitoring wells, and the piezometer boards for measuring water levels. These tools help farmers determine water requirements in rice paddy plots (Imanudin et al., 2020a). Nutrient fulfilment is also crucial, specifically the provision of N, P, and K to increase crop production (Budianta et al., 2021). To support rice production on tidal lowland, water management, soil amelioration, fertilization, and high-yielding varieties tolerant to tidal conditions are essential (Khairullah et al., 2021). Among the various measures, water management is important for the success of the practice (Pramono et al., 2021). Effective management at the tertiary level is key to ensuring an adequate supply for rice plants through the operation of water gates (Imanudin et al., 2023b).

This research examines precision agriculture systems, particularly in water management for rice cultivation during the second cropping season (March - June) in tidal lowland B typology, Delta Saleh. Water management is analyzed by monitoring the table in paddy fields and tertiary channels using wells, pipes, and piezometer boards. Additionally, this research is centred on rice cultivation during the second planting season, as well as chemical properties and SEW-10 analysis. By conducting these analyses, the efficiency of rice cultivation on tidal lowland is improved through the application of precision agricultural practices, ensuring sustainability.

2. EXPERIMENTAL SECTION

2.1 Research Location

This research was conducted from March 2023 to June 2023 on tidal land of B typology in Sri Mulyo Village, Air Saleh Subdistrict, Banyuasin Regency, South Sumatra, with coordinates 2°42'13.73 "S, 104°59'01.43 "E. In addition, a tertiary plot of B typology was used with a main sample of 5 hectares. The plot consisted of 16 hectares of land and 5 hectares were taken as the main sample.

2.2 Material and Methods

In this research, well pipes and piescall boards were used for groundwater level and channel observation. Subsequently, Belgie drills and various materials were adopted in soil sampling, and cameras were used as documentation tools to record activities. In cultivation activity, 1 hectare of land was used to represent 1 sample with the same variety of Inpari 32. The planting method included the direct sowing of seeds, followed by the creation of a worm water channel every three meters. The type of fertilizer varied according to the individual capacities of the farmers on the respective lands. The method used was survey and direct observation in the field. The survey adopted a level of detail, where one sample represented approximately three hectares of rice fields. The software used was Ms Word, Excel and SPSS in the analysis and surplus water overflow -10 (SEW-10) analysis was also conducted during the second growing season. Subsequently, observations were made using a well pipe as water level measuring device. This water level observation was carried out daily within the same time frame during rice cultivation activities.

2.3 Data Collection

Primary and secondary data were collected through direct observation and interviews in the field. The data collected included rice cultivation activities, water levels, and several soil chemical properties such as pH, CEC, and C-Organic. Meanwhile, cultivation activities were conducted through interviews with farmers and direct observations in the field. In this context, water level observations were made every morning at 1-hour intervals from 7 to 8 am, and soil sampling was carried out before planting.

2.4 Data Analysis

Data analysis used tabulation, simple and multiple linear regression and correlation. Water table analysis used SEW-10, where the -10 point threshold height category was said to be surplus or deficit. Rice cultivation data was tabulated from land preparation to harvesting. Meanwhile, SEW-10 data was taken during cultivation and presented in the form of tabulations and line graphs to determine the value of surplus and deficit. Correlation and regression were also used to obtain the level of relationship between groundwater table and channel water as well as multiple regression for chemical properties and production yield.

3. RESULT AND DISCUSSION

3.1 Rice Cultivation activities

Cultivation activities started with land preparation and application of herbicides to clean up weeds on previously used land in the first planting season. The herbicide application was conducted by spraying with a spray tank, requiring 3 litres of herbicide in 1 hectare of land. After a week of herbicide application, tillage was performed using a hand tractor for 2 times. Meanwhile, the second plowing was carried out a week after the first and the use of hand tractors was very beneficial since the process reduced labor, time and farming costs (Dewi and Supriyanto., 2021). Subsequently, farmers applied dolomite at the rate of 250 kg per hectare to increase soil pH, as shown in Table 1.

The variety used for cultivation on this tidal lowland was Inpari 32 and the planting method was by direct seed sowing with 70 kg/hectare. The application of fertilizers was conducted twice on the 20th and 40th days after planting. In addition, the fertilizers used were Nitrogen and NPK with the respective doses according to the farmer's ability. The pest control process was also performed in the form of insects, rats, fungi and weeds. The application was carried out 5 days before fertilization using various types of pesticides such as insecticides, fungicides, rodenticides and herbicides. The complete absorption of the fertilizer was achieved by passing through worm drains as a passageway. The fertilizer application and pest control processes were carried out by spreading and spraying, respectively, as shown in Table 2.

Rice cultivation during the second planting season based on the growth phase can be seen in Table 1. From Figure 1, the phases of cultivation are divided into vegetative (A), reproductive (B) and maturation (C).

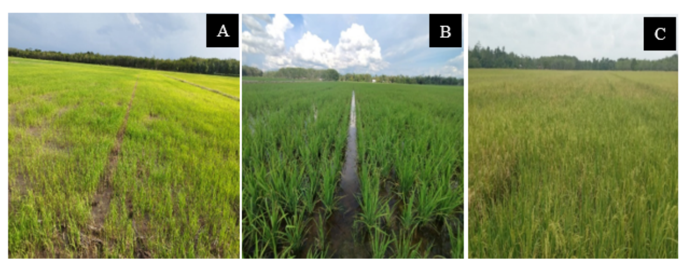

Figure 1. Plant condition during vegetative phase (A), Plant condition during reproductive phase (B), Plant condition during maturation phase (C)

The harvesting preparations are made when rice is nearing maturity. For this activity, farmers used agricultural

Table 1. Land Preparation Activities in The Second Planting Season

Variables	Observation Plots				
	P1	**P2**	**P3**	**P4**	**P5**
			Application of Herbicides		
Time	7 Feb 2023	9 Feb 2023	9 Feb 2023	7 Feb 2023	8 Feb 2023
Dosage	3 Liters	3 Liters	3 Liters	3 Liters	3 Liters
			1st Piracy		
Time	14 Feb 2023	15 Feb 2023	15 Feb 2023	14 Feb 2023	15 Feb 2023
Tool	Hand tractor	Hand tractor	Hand tractor	Hand tractor	Hand tractor
			2nd Piracy		
Time	23 Feb 2023	25 Feb 2023	25 Feb 2023	23 Feb 2023	24 Feb 2023
Tools	Hand tractor	Hand tractor	Hand tractor	Hand tractor	Hand tractor
			Liming		
Lime Used	Dolomite	Dolomite	Dolomite	Dolomite	Dolomite
Time	28 Feb 2023	1 Mar 2023	1 Mar 2023	28 Feb 2023	1 Mar 2023
Dosage	250 kg/Ha	250 kg/Ha	250 kg/Ha	250 kg/Ha	250 kg/Ha

Description: P 1 − 5 = Plots 1 − 5.

Table 2. Planting Preparation Activities, Fertilizer Application and Pest Control in The Second Planting Season

Variables	Observation Plots				
	P1	**P2**	**P3**	**P4**	**P5**
			Sowing Preparation		
Planting Time	8 Mar 2023	9 Mar 2023	9 Mar 2023	8 Mar 2023	9 Mar 2023
Planting Method	Direct seed sowing	Direct seed sowing	Direct seed sowing	Direct seed sowing	Direct seed sowing
Seed Variety	Inpari 32	Inpari 32	Inpari 32	Inpari 32	Inpari 32
Seed Quantity	70 Kg	70 Kg	70 Kg	70 Kg	70 Kg
			Application of Fertilizers		
1st Fertilization Time	20 Days after Planting	20 Days after Planting	20 Days after Planting	20 Days after Planting	20 Days after Planting
Fertilizer used	Urea	Urea	Urea and Phonska	Urea	Urea and Phonska
Fertilizer Amount	100 kg	150 kg	50 and 50 kg	150 Kg	100 and 100 Kg
2nd Fertilization Time	40 Days after Planting	40 Days after Planting	40 Days after Planting	40 Days after Planting	40 Days after Planting
Fertilizer used	Urea and Phonska	Urea and Phonska	Urea and Phonska	Urea and Phonska	Urea and Phonska
Amount of Fertilizer	50 dan 200 Kg	100 dan 200 Kg	50 dan 250 Kg	50 dan 200 Kg	100 dan 250 Kg
			Pets Controls		
Pest Type	Rat, Worms, Leafhoppers and Fungi	Rat, Worms, Leafhoppers and Fungi	Rat, Worms, Leafhoppers and Fungi	Rat, Worms, Leafhoppers and Fungi	Rat, Worms, Leafhoppers and Fungi
Time of Application	15 and 35 Days after planting	15 and 35 Days after planting	15 and 35 Days after planting	15 and 35 Days after planting	15 and 35 Days after planting

Description: P 1 − 5 =Plots 1 − 5.

machinery in the form of a Combine Harvester to facilitate the process (Figure 2). In addition, farmers hired a harvesting service with a fee based on the yield in a ratio of 10:1. The fee includes workers and the cost of transporting the grain, hence the net result of the agreed cooperation is received. The harvest is sold in a wet grain to the middlemen to prevent drying. In this context, the price of wet grain has a lower price considering the high water content, as shown in Table 3.

Figure 2. Combine Harvester Machine (A), Rice harvest (B), Post-harvest rice field (C)

Table 3. Harvesting activities of the second planting season

Variables	Observation Plots				
	P1	**P2**	**P3**	**P4**	**P5**
Time	18/6/23	20/6/23	20/6/23	18/6/23	19/6/23
Harvesting Technique	Combine Harvester	Combine Harvester	Combine Harvester	Combine Harvester	Combine Harvester
Operation Cost Harvest	10:1	10:1	10:1	10:1	10:1
Yield (tons/ha)	1.8	2	1.94	1.86	2.05

Description: P 1-5 = Plots 1-5.

From Table 3, harvest in second planting season P5 and P1 has the highest and lowest yields of 2.05 tons/ha and 1.8 tons/ha, respectively.

3.2 Relationship of Some Soil Chemical Properties to Rice Yield in the Second Farming Activity

The soil chemical properties observed were pH, CEC and C-Organic. The results of the analysis are carried out in multiple linear regression and correlation, as shown in Table 4.

Table 4. Results of pH, CEC, C-Organic and Yield Analysis

Variables	Observation Plots				
	P1	**P2**	**P3**	**P4**	**P5**
pH	4.47^{va}	3.93^{va}	4.43^{va}	4.37^{va}	4.35^{va}
CEC (Cmol(+)/kg)	20^{m}	22.5^{m}	20^{m}	20^{m}	22.5^{m}
C-organic %	2,47^{m}	3.87^{m}	2.86^{m}	2.82^{m}	3.01^{m}
Yield (tons/ha)	1.8	2	1.94	1.86	2.05

Description: P 1-5 = Plots 1-5; m = moderate; va = very acidic; h = high

Table 4 shows the analysis of several soil chemical properties and production results in the second cropping season. The value of the chemical properties tends to be different in each land but the classification class is similar. From the soil pH, each land is included in the very acidic class with the highest pH of only 4.43. Subsequently, the CEC value is categorized into the medium class with a value of 22.5 Cmol (+) /kg. The C-Organic value and P2 land are mostly found in the medium and high class with a value of 3.87%. Additionally, the three traits are tested for correlation and multiple linear regression to determine the influence of soil chemical properties and production yields. In this context, the correlation and multiple linear regression tests have normal data at 0.20 greater than 0.05. The data is included in the multi-coloniarity, with tolerance and VIF values of more than 0.1 and 10. Therefore, there is a relationship between soil chemical properties in the form of pH, CEC and C-Organic with a value greater than 0.05 and an R-value of 0.799. R-Squere is 0.639 since pH, CEC and C-Organic have a simultaneous influence on the production of rice.

3.3 Water Management System Operation and Water Table Dynamics

In this research, the operation of water management system network such as the use of the channel water gate in the tertiary block was observed. The upstream and downstream parts of water gates used a valve and gooseneck, as presented in Figure 3.

Figure 3. State of valve gate in the field (A), State of gooseneck gate in the field (B)

The working system of the two gates can help farmers in maintaining water availability. The use also supports the implementation of precision agriculture which is shown in the use of valve model sluice gates. The operational mechanism of this valve model allows the tide to push the sluice gate open, enabling water to enter the channel. During low tide, water is retained as the gate automatically closes, thereby retaining the tertiary channel, as shown in Figure 4.

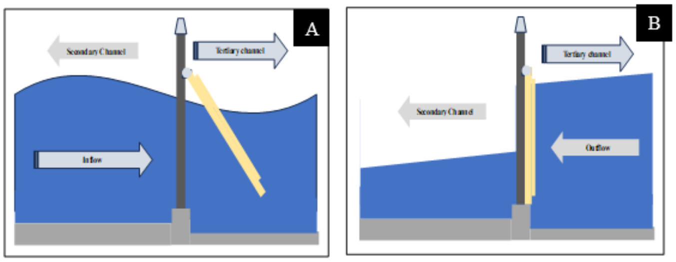

Figure 4. Valve water gate mechanism at high tide (A), Valve water gate mechanism at low tide (B)

Water gate observations were made at the vegetative, reproductive and maturation phases. Operation of the gooseneck model is also important since the second planting season coincides with El Nino phenomenon. This makes the weather climate of the region experience a long dry season, impacting the availability of water for agricultural cultivation. Consequently, farmers in tidal areas of typology B operate closed water gates for goosenecks in meeting the requirements of rice plants. The state of gooseneck water gate operation when open and closed can be seen in Figure 5, while the operation mechanism is presented in Figure 6. During rice cultivation, the operation of the sluice gate should be closed to prevent losing water in the tertiary channel (Imanudin et al., 2023b), as shown in Table 4.

Figure 5. Water gate operation when open (A), sluice gate operation when closed (B)

Table 5. Operation of gooseneck water gates during the growth phase

No	Growth Phase	Observation Results
1	Vegetative	Water Gate Closed
2	Reproductive	Closed Water Gate
3	Maturation	Open Water Gate

The gates are closed and opened at high and low tide to maintain water table depending on growth phase of rice (Imanudin et al., 2020b) as shown in Table 5. The operations at each growth phase are carried out according to the requirements of the farmers.

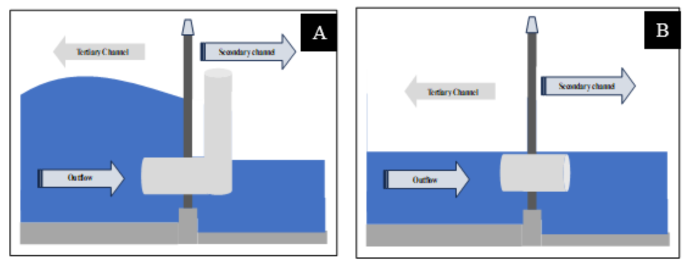

Figure 6. Swan neck water gate mechanism when closed (A), Swan neck water gate mechanism when open (B)

The second cropping season rice cultivation activities in typology B were carried out by observing water table in the channel and ground. Observations were made every day to overcome the problem of water availability for plants during the second cropping season. The average value of water table at each growth phase can be seen in Table 6.

Table 6. Average water table during the growth phase

Growth Phase	Channel Water Table	Ground Water Table
Vegetative	85.91 cm	+3.6 cm
Reproductive	81.56 cm	−8 cm
Maturation	94.89 cm	−4.85 cm

Table 6 shows the average value of water table in each growth phase. During the vegetative phase, the average height in the channel is 85.91 cm with the value of the groundwater table in a flooded state at +3.6 cm. In the reproductive phase, the average water table height in the channel and ground decreases slightly at 81.56 cm and −8 cm, respectively. For the maturation phase, the average value of channel and ground rises to 94.89 cm and −4.85, respectively. The minus value is because farmers when approaching the harvest will reduce the height of the groundwater table to facilitate the process using agricultural machinery in the form of a Combine Harvester. There is a relationship between channel and groundwater by observing water table using simple linear regression, as shown in Figure 7.

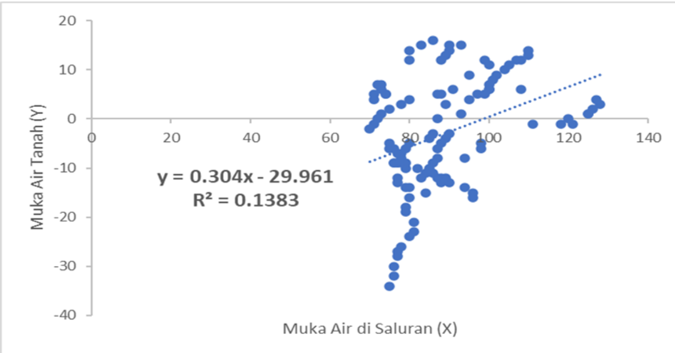

Figure 7. Simple linear regression between the groundwater table and water table in the channel

From Figure 7, there is a relationship between the groundwater and channel in the low category. Since the R-value is only 0.372 and the R Square value is 0.1383, the effect of water table is 13.83%. Meanwhile, the significance value is smaller than 0.05, namely 0.000 and the t-count is also greater than the t-table at $3.735 > 1.982$. The regression value $Y = 0.304x - 29.961$ shows that the groundwater and channel table coefficients are -29.961 and 0.304. Therefore, every 1% increase in water table in the channel will add the value of the groundwater by 0.304. Figure 8 shows the fluctuations in height between the two variables. At the time of the rise and fall of the line, the value tends to be the same, showing a relationship.

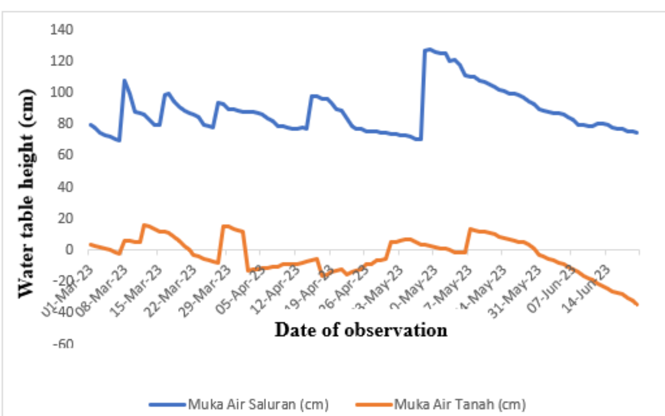

Figure 8. Dynamics of water table at the ground and in the channel

3.4 Surplus Excess Water -10 (SEW-10)

The height of water table at 10 cm can increase the growth of seed weight, and the number of leaves is high (Susilo et al., 2023). SEW-10 is an analysis to determine excess sufficiency with the limit of -10 as the assessment. Water table data are required during rice cultivation activities to conduct the analysis. During the second cropping season, rice cultivation activities have surplus water needs. This water table can also be adjusted according to the requirements of farmers (Figure 9). In the preparation of planting, the land is flooded to facilitate tillage. Meanwhile, during rice cultivation, farmers will set a sufficient water table. Since the second planting period is in the dry season, more effort is required for the efficient operation of floodgates. The expensive cost of using pumps makes farmers adopt the efficiency of sluice gate operations. During harvesting, the land will be made dry to facilitate the use of a combined harvester.

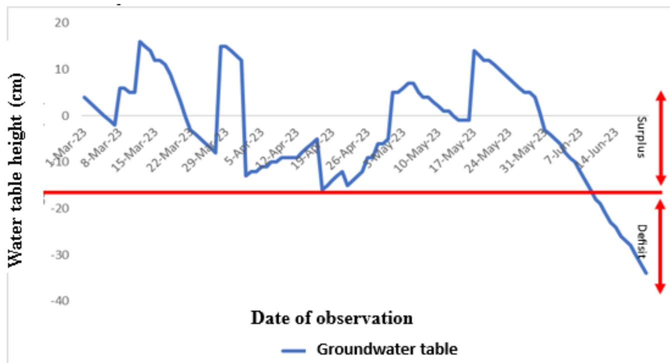

Figure 9. Dynamics of water table at the ground and in the channel

The SEW-10 value during cultivation activity is 778 cm due to a good value of water sufficiency. In this context, the value of the number of days above and below -10 reaches 84 and 28, respectively (Table 7).

Table 7. SEW-10 results of second planting season rice cultivation

No	Variable	Result
1	SEW-10	776 cm
2	Number of days above-10	84 days
3	Number of days below-10	28 days

4. CONCLUSION

In conclusion, the results of this research were reported to obtain a strategy for efficient rice cultivation in tidal lowland through precision farming practices. The strategy was initiated in the tertiary channel, such as optimizing the operation of sluice gates and monitoring the channel and groundwater table. In this context, the farmers were able to regulate water management according to the needs. The relationship between rice production and several soil chemical properties was represented by the equation $Y = 0.15 - 0.001$ pH + 0.000 CEC +0.000 C-Organic. Additionally, the SEW-10 value during cultivation activities in the second cropping season amounted to 778 cm, with the number of days above -10 reaching 84. The highest production yield in the second cropping season was 2.05 tons/ha. The farmers enhanced rice cultivation efficiency through agricultural practices, thereby optimizing rice cultivation activities in tidal lowland.

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