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Tidal Rice Yield Assessment in Central Kalimantan, Indonesia, under Different Cultural Practices

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Abstract: This research aimed to assess the performance of a technology package in relation to rice yield in a B-type tidal rice field in Central Kalimantan province (Indonesia). We selected four areas with different hydrological conditions, soil characteristics, and farmer management systems in Pulangpisau and Kapuas Regency. The introduced technology package covered water management, soil tillage, amelioration and fertilization, adaptive high-yielding varieties, and crop protection. The results showed that, on average, the rice yield of Terusan Karya was 5.52 t ha^{-1}, followed by Belanti B (3.75 t ha^{-1}), Belanti A (3.61 t ha^{-1}), and Talio Hulu (3.27 t ha^{-1}). Rice varieties that yielded more than 5 t ha^{-1} were Inpara 8 (6.28 t ha^{-1}), Suppadi 89 (5.54 t ha^{-1}), Inpara 3 (5.46 t ha^{-1}), and Inpara 2 (5.36 t ha^{-1}). The implementation of a site-specific technology package combined with intensive guidance for the farmer on its implementation is the key factor in increasing rice productivity in tidal rice farming.

Keywords: paddy soils; rice yield; rice variety; tidal rice farming; Central Kalimantan

1. Introduction

Food security and environmental sustainability are global concerns. Both are controlled by resource use and preservation. For food security reasons, wetlands have been reclaimed for agricultural lands in India, Bangladesh, Myanmar, Thailand, Vietnam, China, Malaysia, Egypt, Iraq, and Indonesia. Moreover, global analysis results indicate that agriculture, urbanization, aquaculture, and industry are primary causal factors in promoting the effective loss of wetlands [1]. Natural wetland ecosystems serve multiple ecological functions [1]: soil formation and stabilization support; food, water, and plant biomass supply; cultural/recreational services, landscape, and ecological tourism; climate regulation; and carbon sequestration. Wetland conversion leads to the loss of these functions. The remaining challenges are how to improve agricultural land productivity of this converted wetland, decrease further land degradation, and increase farmers' prosperity.

At present, tidal agricultural land is the center for agricultural production. For instance, in Vietnam, the Mekong Delta is one of Southeast Asia's most important food sources, contributing to more than half of the country's food production capacity and the majority of its rice exports [2]. Nevertheless, climate change and land degradation threaten resource use efficiency and land productivity, for example, in Mekong Delta, climate change-induced sea-level rise, delta-wide land subsidence, sedimentation reduction, and, more recently, riverbed mining [2]. Various approaches and technologies (soil, water, crop varieties, and farming systems) have been used to keep soils productive and boost crop yield while adapting to climate change. Sustainable intensification has been adopted as an approach to increasing land productivity in Red River Delta, Vietnam [3]. Climate change affects diversification opportunities in the Ganges–Brahmaputra–Meghna Delta [4]. In Bangladesh, the most critical factors for increasing crop productivity are increasing gross cropped area, fertilizer, labor, and pesticide input use [5]. In India, a changing cropping season is introduced to tailor variation in rainfall and river water salinity across the coastal zone of the Ganges Delta [6]. In Malaysia, sustainable amelioration of the acid sulfate soils area is used for growing crops [7]. Furthermore, promoting crop yields and sustainable intensification through balanced fertilizer use were adopted in a vulnerable saline region in Bangladesh [8]. Food system diversification, technological innovations and nature-based practices, and traditional and indigenous knowledge operationalized across the food system components have the potential for sustaining smallholder resilience in the face of natural hazards [9].

In Indonesia, tidal rice fields are among the rice production centers, primarily distributed in Sumatera's eastern lowlands and Kalimantan's western and southern lowlands [10]. In Central Kalimantan province, tidal rice fields are predominant and can be found in Pulang Pisau and Kapuas Regency. A food estate program has been developed in these areas to anticipate food crises caused by climate change. The program intensified agricultural production and optimized land utilization by increasing the planting index [11].

The average rice yield from tidal rice farming is about 4.0 metric tons of dried unmilled rice per hectare (t ha^{-1}). Nevertheless, with good water, soil, and crop management, a rice yield of 5 to 6 t ha^{-1} can still be attained [12]. It means that there is an opportunity to boost rice production in tidal rice farming by implementing suitable agricultural technologies.

In tidal rice farming, the rice yield is still low at the farmers' level due to soil-and water-related problems and low technology implementation. Very low soil fertility and a high onset of pests and diseases lead to low rice yield [13]. Meanwhile, tidal farmers are not implementing the recommended technology package of rice farming due to limited insight into such technology, unavailability of agro-input, and low budget for rice farming. Technical assistantships and technological support for farmers are some of the strategies designed to increase and sustain rice production.

In tidal rice fields, the sustainable intensification [14] of rice production is closely related to water, soil, and crop management. Precision and site-specific water, nutrient, fertilizer, and ameliorant management technology are required to provide favorable conditions for rice growth and production [15]. A sufficient irrigation and inundation period determines the rice yield in tidal rice fields [16,17]. In addition, tolerant and high-yielding rice varieties must be used, and crop protection must be implemented [18].

In soil fertility management, fertilizer application should consider rice varieties and soil characteristics, especially pH and toxic elements such as Fe, Al, and SO^{4-}. In addition, soil organic matter (SOM) content should be maintained and even added from local sources to maintain reductive conditions in which pyrite oxidation can be inhibited [19]. Local sources of organic matter such as crop residues, compost, and manure can be applied to increase SOM content [20]. Rotation of crop and rice varieties is also recommended to break the pest life cycle.

Rice productivity in tidal rice fields varies and is influenced by water management, rice varieties, soil management, and rice farming technology. This research aimed to

evaluate technology packages of tidal rice field management for increasing rice production of different rice varieties, water, and soil conditions. This study provides baseline data of soil and water characteristics and attainable yield of rice varieties once farmers had implemented the full technology package.

2. Materials and Methods

2.1. Study Area

The study area is part of a B-type tidal rice field located in 4 locations: (i) Talio Hulu Village on Ray 39, 40 and 41 of Pandih Batu District, Pulang Pisau Regency (Talio Hulu); (ii) Belanti Siam Village on Ray 19 (Belanti A); (iii) Belanti Siam Village on Ray 21 of Pandih Batu District, Pulang Pisau Regency (Belanti B), and (iv) Terusan Karya Village on Ray 27 of Bataguh District, Kapuas Regency (Terusan Karya). The location is part of the Talio Wetland Irrigation Region, the Belanti Wetland Irrigation Region, and the Terusan Wetland Irrigation Region. All are in the southern part of Central Kalimantan province, Indonesia (Figure 1).

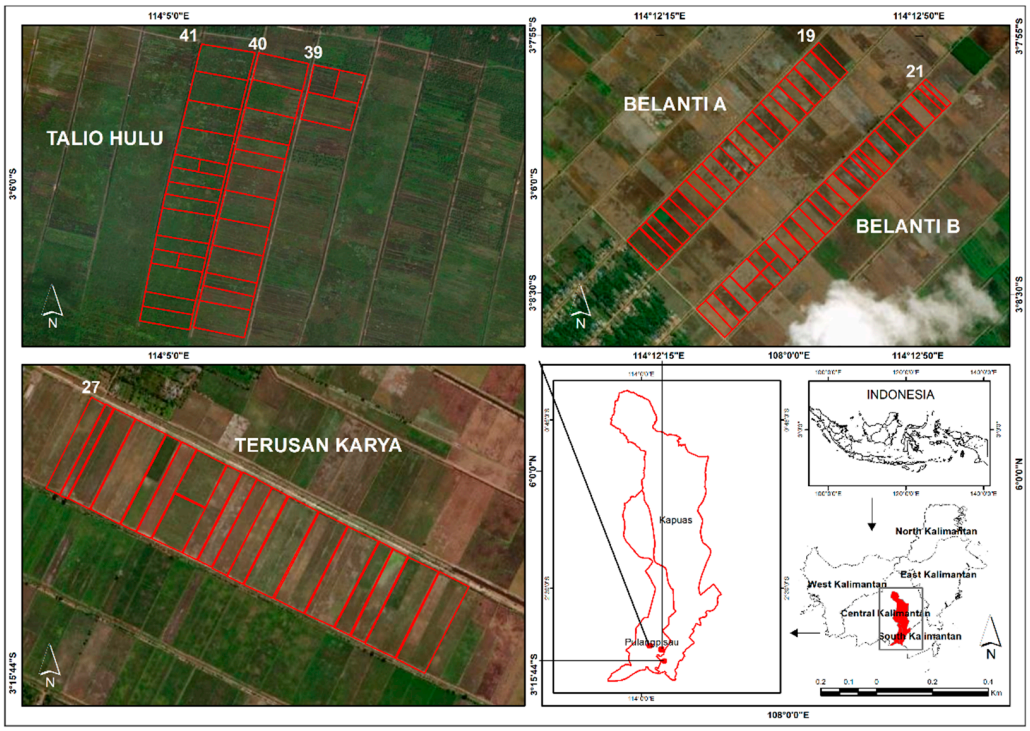

Figure 1. The location of the study area in Pulangpisau dan Kapuas Regency, Central Kalimantan, Indonesia.

In Talio Hulu, the study area extends from 3°05′43.75″ S to 3°06′19.00″ S and 114°04′56.76″ E to 114°05′23.02″ E, covering about 40 ha, with 1000 m length and 400 m width. In Belanti A, the study area extends from 3°08′00.06″ S to 3°08′31.71″ S and 114°12′14.77″ E to 114°12′45.36″ E, covering about 23 ha, with 1150 m length and 200 m width. In Belanti B, the study area extends from 3°08′09.05″ S to 3°08′47.67″ S and 114°12′27.03″ E to 114°13′03.29″ E, covering about 30 ha, with 1500 m length and 200 m width. In Terusan Karya, the study area extends from 3°15′23.13″ S to 3°15′43.78″ S and 114°13′57.98″ E to 114°14′29.53″ E, covering about 19.6 ha, with 980 m length and 200 m width.

Terusan Karya was first inhabited in 1979/1980, whereas Belanti was settled in 1981/1982. After that, the rice fields of both locations were intensively managed for rice production. Talio Hulu was first inhabited in 1980/1981. After that, from 1981 to 1996, the rice fields were used to produce maize and soybean. From 1997 to 1998, a long drought led to a land fire, and a monetary crisis also took place. Farmers experienced harvest failure

and loss of budget for farming. From 1999 to 2002, paddy fields were fallow, with farmers losing funding for agriculture and needing more time to return to the field. From 2003 to 2018, only 40 ha of 253 ha of rice fields were planted for rice. In 2019, the Peatland Restoration Agency rebuilt rice fields in Talio Hulu.

These study locations were formerly peatlands with various thick peat layers, and after 11 to 20 years of being managed for intensive rice production, these peatlands became mineral soils. During that period, drought, peat fire, and intensive tillage were undertaken to remove the peat layer and leave behind acid sulfate soil with a pyrite layer depth of 50 cm or more. Especially in the Talio Hulu area, peaty acid sulfate soils have been found in some plots.

The location is about 4 m above sea level for Talio Hulu and Terusan Karya and about 5 m above sea level for Belanti A and Belanti B. The mean temperature is between 26.5 °C and 27.0 °C, with a maximum temperature of 32.5 °C and a minimum temperature of 22.9 °C. The annual rainfall in the area is 2000 mm. The lowest monthly rainfall is 3 mm, occurring from April to September, and the highest monthly rainfall is 540 mm, occurring from October to March (Figure 2).

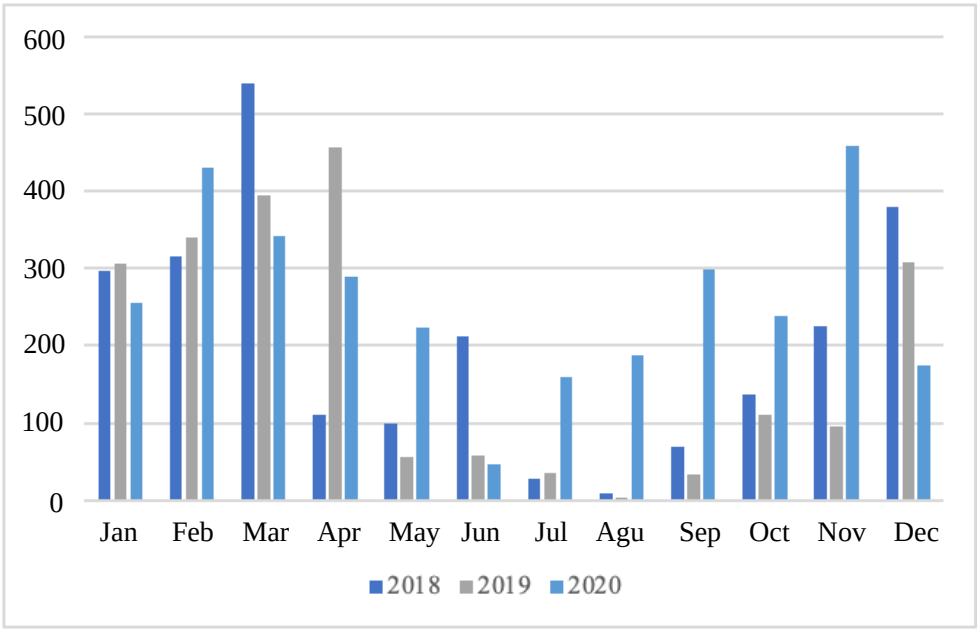

Figure 2. Monthly rainfall (in millimeters) in the study area, 2018-2020. Source: [21].

Ray is a secondary canal created to drain the area during reclamation. It divided the plots, i.e., fields where rice is planted, and was then used to irrigate them using spring tide water. The watergate has the function of controlling the water level in the rays and the farmer plots. In Indonesia, tidal rice fields are divided into A, B, and C types based on the inundation of rice fields. In the A type, the rice field is inundated during the diurnal spring tide and full-moon spring tide; in the B type, the rice field is submerged only during the full-moon spring tide, and in the C type is rice field is not flooded during the diurnal and full-moon spring tide. Nonetheless, the water table is influenced by spring tide.

In each rice field, canals and watergates were built and maintained to regulate water dynamics in canals and planting fields. Rice requires different water levels supplied by canal water during its growth phase. Canal water is influenced by tidal activity. The study areas are inundated twice a month during big spring tide so that rice grows twice during the dry and wet seasons. The total study area is about 112 hectares and is managed by 56 cooperative farmers. The study was conducted in 2019/2020. The rice cultivation schedule is presented in Figure 3.

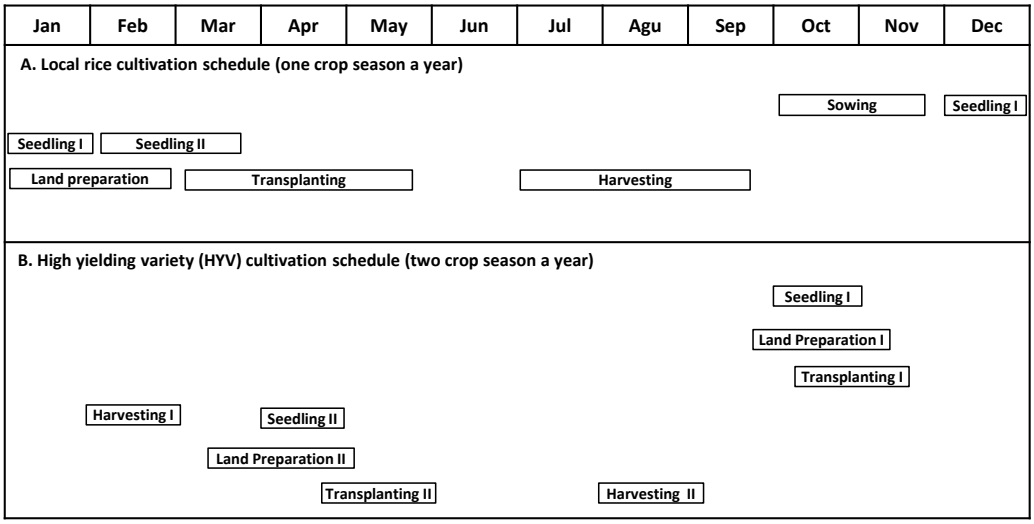

Figure 3. Rice cultivation schedule for one and two crop seasons a year.

2.2. Technology Package and Crop Management

Successful tidal rice farming depends upon better management of water, soil, and crops. Therefore, a technology package that integrated water management (water irrigation, and water drainage), soil management (fertilizer application, soil amendment application, and soil tillage), and crop management (planting distance, planting technique, crop protection, seed treatment, and the use of superior variety) was formulated to suit local conditions. This formulation considers initial soil water and soil properties, the advance of rice variety improvement, farmer knowledge, and rice preference by farmer and market. The formulation results in the recommended site-specific technology package being able to improve crop yield.

In this study, the introduced technology package comprised water management, amelioration and fertilization, soil tillage and seedling, planting distance, crop protection, and harvesting, as presented in Table 1. This package had already been developed by previous studies and tailored to local conditions of water quality and soil properties.

In this study, a complete technology package was applied by each farmer in their plot, as recommended, while the researcher team guided its implementation. Firstly, we improved micro water management in plots of the study location by using a TASEL system [12]. We installed a 3-inch-diameter PVC (polyvinyl chloride) pipe as water a channel and a 3-inch-diameter PVC knee at 90 degrees as a dam overflow both for water inlet and for outlet for a given plot. After that, land preparation and planting was performed by farmers following the rice cultivation schedule, as presented in Figure 3. The team made regular field visits to ascertain whether the technology was used correctly by farmers and to provide troubleshooting in the fields. Therefore, the rice yield in a given plot for a given location was determined by this technology package as the combined effect of water management, high-yielding rice variety, land preparation and planting, amelioration, fertilization, foliar fertilizer application, seed treatment, and pest control. This study focused on effect of the technology package on rice yield. We did not evaluate the effect of each technological component of the rice yield.

Table 1. Implemented technology packages on plots of the study area.

Component of Technology	Location			
	Talio Hulu	**Belanti A**	**Belanti B**	**Terusan Karya**
a. Water management	TASEL *	TASEL	TASEL	TASEL
b. Rice variety	Inpari 42, Inpara 2, Inpara 3, Inpara 8	Inpara 2, Inpari 3, Argopawon, Sembada, Suppadi 89	Inpara 2, Inpari 32, Inpari 42, MR-19, CL020, Sembada, Sertani, Suppadi	Inpari 32, Sembada, Sertani, Suppadi
c. Land preparation and planting				
Soil tillage	TR2	TR4; TR2	TR4; TR2	TR2
Planting technique	Tabela, Tapin	Tapin; Tabela	Atabela, Tapin	Tabela, Tapin
Planting distance	40 cm × 20 cm	25 cm × 25 cm; 20 cm × 20 cm	20 cm × 20 cm	25 cm × 30 cm
d. Amelioration (per ha)				
Lime	2.000 kg	1.000 kg	500 kg	700 kg
e. Fertilization (per ha)				
Urea	50 kg	50 kg	50 kg	50 kg
NPK	150 kg	250 kg	200 kg	250 kg
KCl		100 kg	-	100 kg
Rock phosphate	750 kg	500 kg	83 kg	-
TSP/SP36	50 kg	-	-	150 kg
Biotara	25 kg	25 kg	25 kg	-
f. Foliar fertilizer	-	Gandasil B 500g; Gandasil D 500 g	-	-
g. Seed treatment	Agrimeth 50 g	Claris 13 bottles	-	Claris 30 bottle
h. Pest control (per ha)				
Herbicide	Claris 5 L	Ally plus 5 packs; Nomine 3 bottles	Ally plus 5 pack	-
Insecticide	Furadan 5 kg; Temik 1 kg	Metro 1 L; Endure 0.2 L; Pexalon 225 mL; Furadan 10 kg; Plenum 100 g	Furadan 10 kg; Pexalon 225 mL; Plenum 100 g	Furadan 15 kg; Virtako 0.1 L; Regent 0.1 L; Klensect 0.2 L
Fungicide	Score 250 mL; Fungisida 59 mL	Filia 100 mL; Amistartop 250 mL	Filia 100 mL; Amistartop 250 mL	Filia 100 mL; Amistartop 250 mL

Note: TASEL * = canal blocking using PVC knee pipe (see [12]); TR2 = two-wheel tractor, TR4 = four-wheel tractor, Tabela = direct seeded rice; Tapin = transplanting.

2.3. Data Collection and Soil Laboratory Analysis

Water samples were taken from the secondary canal of 4 sites, namely, at 5 m, 500 m, 1500 m, and 4575 m from the primary canal. Water samples were analyzed for pH using a pH meter, while electrical conductivity (EC) was analyzed using an EC meter [22].

Composite soil samples were taken from each plot's tillage layer (0–25 cm). These samples were sent to a soil laboratory for sample preparation and then soil chemical analysis of soil pH, exchangeable cations (Ca, Mg, K, Na, Al, H) and cation exchange capacity (CEC), soil organic carbon, total nitrogen, available phosphorus, total P_2O_5, total K_2O, and electrical conductivity was carried out. The method of soil chemical analysis followed the instructions published by Balai Penelitian Tanah [22].

In the soil laboratory, soil pH was measured using a pH meter on an extraction solution using water (H_2O) and KCl. The ratio of soil to solvent used (H_2O or KCl) was 1:1. Soil electrical conductivity was measured using an EC meter. Exchangeable K, Ca, Na, and Mg and CEC were extracted using 1 M ammonium acetate (NH4OAc) at pH 7 and then measured using atomic absorption spectroscopy (AAS). Exchangeable Al and exchangeable H were extracted using 1 N KCl and then measured using the titration method. Soil organic carbon was measured using the ashing method for peat soils and the Walkley–Black method for mineral soils. Total N analysis used the Kjeldahl method. Available P was analyzed using the Bray I method. Total P_2O_5 and total K_2O used 25% HCl extraction, total P_2O_5

was measured using a spectrophotometer, and total K_2O was measured using AAS. Soil Fe was extracted using 1 M ammonium acetate at pH 4.8 and then measured using AAS.

We collected data on rice yield (in dried, unmilled rice) from each farmer (Yf) in metric ton per hectar (t ha^{-1}). The Yf could be used to indicate technology performance and farmer conduct. Higher yield means good technical performance and good management by farmers. Lower yield means either poor technology performance or poor management by farmers, or both. Several farmers grew the same varieties in a given location; accordingly, we averaged the yield of this variety (Yv). Then, we averaged Yv to calculate the average yield of rice variety from all locations (Yl).

We also calculated the average yield of rice for a given location (Yr) simply by averaging Yv in that location. Moreover, we calculated the environmental productivity [23] of a given rice variety (Ye) by averaging Yr for the location where the variety was grown. Finally, we subtracted Yl from Ye to evaluate the adaptability of rice variety, expressed as a percentage (%). The positive difference means that the yield of a given variety is higher than the average yield of all varieties planted in the same location. In contrast, the negative difference shows that the yield of a given variety is lower than the average yield of all varieties.

2.4. Statistical Analysis

The rice and soil data were subjected to statistical descriptive data analysis. In addition, analysis of variance (ANOVA) was conducted to assess the effect of rice varieties and technology package implementation in a given location on rice yield variation. A least squares difference (LSD) test at alpha 0.05 was conducted to evaluate the difference between average of soil property and the average of rice yield. All data analysis was assisted by the R program [24]. In addition, ANOVA by the Sum of Square type III was used to study the correlation between category trait (technology package and variety) and numeric trait (rice yield). A Tukey–Kramer test at alpha 0.05 was conducted to evaluate the difference average rice yield. This analysis was assisted by the online version of SAS on Demand for Academics.

3. Results

3.1. Water Quality

In tidal rice farming, the sea/river spring tide is used to irrigate the right and left plots of a secondary canal (Ray), and the neap tide is used to leach acids and toxic elements from paddy soils. Hence, water quality is one determining factor for successful tidal rice farming. In Indonesia, this water quality is indicated by the electrical conductivity of water (EC_w) and water pH (pH_w) values. Both values, measured during full-moon spring tide, are shown in Figure 4. Ray 39, 40 and 41 are in Talio Hulu, Ray 27 in Terusan Karya, and Ray 21 in Belanti.

The pH_w ranged from 3.0 to 6.1 in Talio Hulu, from 3.2 to 4.7 in Terusan Karya, and from 3.5 to 4.4 in Belanti. The pH_w of Ray 39, 40 and 41 in Talio Hulu and the pH_w of Ray 27 in Terusan Karya increased compared to canal edge, whereas the pH_w of Ray 21 in Belanti decreased compared to canal edge. Paddy soils from Talio Hulu and Terusan Karya had a deep pyrite layer. Paddy soils of Talio Hulu were dominated by organic layers, whereas Belanti paddy soils were dominated by river clay sediment. Hence, such conditions lead to relatively low pH_w in all locations.

In addition to soil properties, the distance of a secondary canal inlet from the main river also determines pH_w. The inlet position of the secondary canals of Talio Hulu is about 8 km from Kahayan River, and for Terusan Karya, it is about 21 km from Kapuas Murung River. This position affected the pH_w at the inlet, which was low (pH_w 2.7–3.2) compared to the existing pH_w of the secondary canal (pH 4.3–6.0) during spring tide. As a result, the pushing power of water in the primary canal and estuary of the secondary canal decreases the pH_w of the canal. The estuary position of the secondary canal obtained much of the

water supply from the primary canal, hence experiencing a pH_w decrease compared to the canal edge.

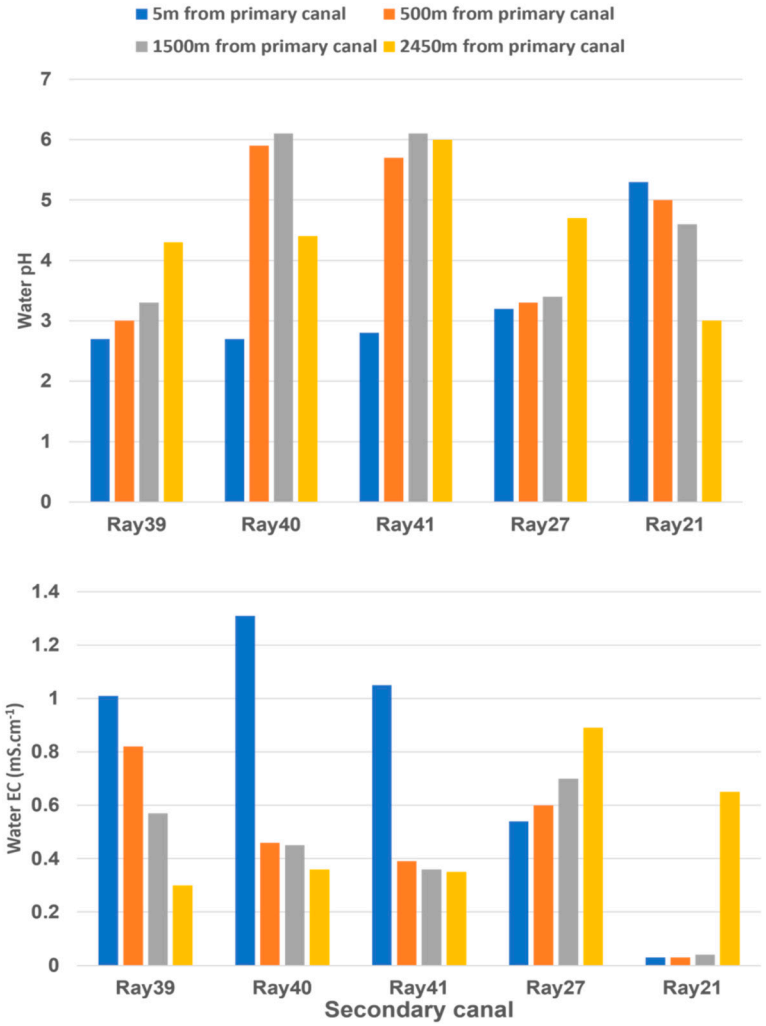

Figure 4. Water pH and EC of the secondary canal in the full-moon period. Note: Talio Hulu: Ray 39, 40 and 41; Terusan Karya: Ray 27; Belanti: Ray 21.

Meanwhile, the inlet position of Ray 21 is about 5 km from Kahayan River; therefore, spring tide has a higher pushing power in the primary canal with higher pH_w than that of the secondary canal (pH 3.0). Thus, the pH_w of the secondary canal near the primary canal is higher than that of the canal edge. Finally, the pH_w was also controlled by the performance of the macro water management system of the wetland irrigation region (WIR). Good performance causes a higher pH_w value due to good water circulation [25]. The pH_w becomes an indicator of other soil properties in tidal areas having pyrite layers and poor drainage.

The EC_w of secondary canals in Talio Hulu showed a similar pattern to those of Terusan Karya, where the EC_w decreased from the estuary to the canal edge. In contrast, the EC_w of Belanti increased from the estuary to the canal edge. In the meantime, the pattern of this EC_w value was the reverse of the pattern of the pH_w value. Such a pattern is commonly found in acid sulfate areas with poor micro water management and far from a river/sea estuary. Pyrite oxidation decreases soil pH (pH_s) value to 2 or 3. This extreme soil acidity dissolves soil minerals and increases soluble salts in the canal, leading to a higher measured EC_w value. Cations (Ca, Mg, K) content increased with the decrease in pH_w in the primary and secondary canals of the acid sulfate area [25].

3.2. Variation of Soil Properties among Plots

A rice field is composed of plots, where each plot covers 1 to 2 hectares. One farmer commonly has 1 to 3 plots, or more. Rice growth and yield differed among rice hills in a given plot, suggesting variation in soil characteristics. Hence, understanding soil variation among plots could be essential to selecting soil-management strategies and priorities in tidal rice farming.

Table 2 shows the variation of soil pH (pH_s), soil EC (ECs), and Fe content of tidal paddy soils. Terusan Karya paddy soils, on average, had higher pH_s (5.25) than Belanti paddy soils (4.27) and Talio Hulu paddy soils (4.39), indicating that Terusan Karya paddy soils had better soil fertility status. Nevertheless, considering the variation of plots, Terusan Karya paddy soils show relatively high variation in pH_s, ranging from 4.60 to 5.83 with a standard deviation (sd) = 0.45, compared to Talio Hulu paddy soils (3.42 to 5.31, sd = 0.35) and Belanti paddy soils (3.67 to 4.58, sd = 0.20). These data are in agreement with data from other tidal paddy soils. For instance, in Sungai Nipah (Mempawah, West Kalimantan), the pH_s was 4.7 [26], whereas in Sungai Daun (Sambas, West Kalimantan), the pH_s is 5.9 [27]. These data suggested that lime requirements differed among plots within each location.

Table 2. Brief statistics of initial paddy soil properties from farmers' plots at a depth of 0–20 cm.

Soil Property	Talio Hulu					Belanti					Terusan Karya				
	n	Min	Max	Avg	SD	n	Min	Max	Avg	SD	n	Min	Max	Avg	SD
Soil pH, H_20	22	3.42	5.31	4.39 b	0.35	26	3.67	4.58	4.27 b	0.20	13	4.60	5.83	5.25 a	0.45
Soil pH, KCl	22	3.27	5.11	3.97 b	0.33	26	3.53	3.99	3.80 c	0.11	13	3.90	5.02	4.55 a	0.38
Soil organic carbon, %	18	20.1	51.8	41.1 a	10.8	26	3.88	7.94	5.53 b	1.04	-	-	-	-	-
Total Nitrogen, %	13	0.51	1.34	0.87 a	0.26	26	0.3	0.59	0.45 b	0.07	13	0.24	0.44	0.35 c	0.07
C/N	13	35	71	44 a	9.26	26	9	17	12.5 b	2.39	-	-	-	-	-
Total K_2O, mg 100 g^{-1}	18	16.4	47.5	30.5 a	9.47	24	25.3	62	33.9 a	8.23	-	-	-	-	-
Total P_2O_5, mg 100 g^{-1}	18	9.41	255	38.3 b	57.0	24	5.2	150	86.4 a	34.6	-	-	-	-	-
Available P_2O_5, ppm P	18	5.75	73.4	20.1 a	17.0	26	8.63	52.6	18.0 a	9.97	13	6.06	112	17.8 a	28.8
Exch. Ca, cmol kg^{-1}	17	2.22	14.3	8.15 a	3.90	26	0.71	1.6	1.14 b	0.24	13	1.86	3.02	2.28 b	0.35
Exch. Mg, cmol kg^{-1}	17	30.4	93.7	59.0 a	17.0	26	3.96	7.59	5.90 c	0.90	13	15.5	23.9	19.2 b	2.43
Exch. K, cmol kg^{-1}	17	0.01	1.13	0.38 a	0.29	26	0.12	0.51	0.20 b	0.78	13	0.18	0.53	0.40 a	0.11
Exch. Na, cmol kg^{-1}	17	3.05	9.45	6.15 a	1.86	26	0.66	1.98	1.22 b	0.29	-	-	-	-	-
Exch. Al, cmol kg^{-1}	8	0.54	1.69	0.88 b	0.39	26	5.67	18.6	10.0 a	3.11	13	0.98	4.68	2.19 b	0.98
Exch. H, cmol kg^{-1}	17	0.16	0.96	0.52 b	0.24	26	0.39	6.1	1.6 a	1.17	-	-	-	-	-
Soil CEC, cmol kg^{-1}	17	11.3	78.3	44.8 a	17.5	26	11.4	75.7	34.6 b	17.2	13	30.6	52.5	42.7 ab	6.47
Fe, ppm	16	69	661	266 c	158		828	1947	1318 a	256	13	413	1857	1070 b	499
Soil EC, mS cm^{-1}	22	0.31	2.22	1.30 a	0.47	24	0.16	0.80	0.32 b	0.15	-	-	-	-	-

Note: n = number of sample, Min = minimum value, Max = maximum value, Avg = average, SD = standard deviation, EC = electrical conductivity of the soil, CEC = cation exchange capacity, (-) = not analyzed. In the same row, numbers that are followed by the same letter are not significantly different according to LSD test of $\leq$0.05.

The EC_w and EC_s should be considered to assess the soil salinity problem. The soil electrical conductivity (EC_s) was higher in Talio Hulu paddy soils (0.31 to 2.22 mS cm^{-1}) than in Belanti paddy soils (0.16 to 0.80 mS cm^{-1}). In this work, the EC_s of Terusan Karya paddy soils were not sampled. However, there was high variation among plots of EC_s in Talio Hulu paddy soils (sd = 0.47 mS cm^{-1}) compared to Belanti paddy soils (sd = 0.15 mS cm^{-1}). This suggests no salinity problem in Talio Hulu and Belanti paddy soil plots.

Iron toxicity is a significant problem in tidal paddy soils, especially for plots experiencing stagnant water circulation due to poor water management. Soil Fe content was determined to assess iron toxicity and to select the appropriate technology for its mitigation. On average, Talio Hulu paddy soils showed the lowest Fe content of all the soils, ranging from 69 to 661 ppm, much lower than Belanti paddy soils (828 to 1947 ppm) or Terusan Karya paddy soils (413 to 1857 ppm). Among plots within the location, high variation was shown in Terusan Karya paddy soils (sd = 499 ppm) and Belanti soils (sd = 256 ppm). Lower iron (II) content in Talio Hulu paddy soils was due to chelating iron by soil organic matter, which is remarkably higher in Talio Hulu. Iron (II) was complexed and chelated

by humic material in peat soils [28]. Liming, improving water management, and selecting adaptive crop varieties are the technology options for mitigating iron toxicity problems.

Table 2 shows the soil organic carbon (SOC), total nitrogen (TN), and phosphorus content in tidal paddy soils. For Terusan Karya paddy soils, only available phosphorus and TN were determined. The SOC content ranged from 3.88 to 7.94% in Belanti paddy soils and from 20.1 to 51.8% in Talio Hulu paddy soils. Formerly, either Terusan Karya, Belanti, or Talio Hulu was a peatland forest area. These forests were cleared, and water infrastructure was developed as the following step in wetland development [10]. Over time, with a peat fire and intensive use, the peat layer was removed and mineral soils remained. Moreover, plots in Talio Hulu were abandoned for almost 11 years, leading to higher SOC content, whereas plots in Terusan Karya and Belanti were planted with rice intensively. High SOC content in the tidal paddy soils is typical because inundation prevents intensive mineralization and humification.

The TN content ranged from 0.24 to 0.44% with sd = 0.07% in Terusan Karya paddy soils, from 0.30 to 0.59% with sd = 0.07% in Belanti paddy soils, and from 0.51 to 1.34% with sd = 0.26% in Talio Hulu paddy soils (Table 2). Thus, due to high soil organic matter, Talio Hulu paddy soils showed the highest TN content. In addition, the C/N ratio of Talio Hulu paddy soils was high (on average, 42), compared to Belanti paddy soils being only 12. Thus, adding N fertilizer is crucial for better rice yield.

On average, Belanti paddy soils showed higher total P_2O_5 (86.4 mg $100g^{-1}$) than Talio Hulu paddy soils (38.3 g $100g^{-1}$). However, Belanti soils showed lower available phosphorus (18.0 ppm) than those of Talio Hulu paddy soils (20.1 ppm). Belanti soils contain high Al that complexes phosphorus so that it is not available for crops. This amount of available P suggested that the P fertilizers were required to attain a high rice yield.

Table 2 presents the exchangeable cations and cation exchange capacities (CEC) of tidal paddy soils. On average, the Talio Hulu paddy soils showed the highest exchangeable Ca (8.15 cmol kg^{-1}), exchangeable Mg (59 cmol kg^{-1}), and exchangeable Na (6.15 cmol kg^{-1}) compared to the Terusan Karya paddy soils and Belanti paddy soils. The CEC of Talio Hulu paddy soils (44.8 cmol kg^{-1}) was higher than that of Terusan Karya paddy soils (42.7 cmol kg^{-1}) and Belanti paddy soils (34.6 cmol kg^{-1}). Paddy soils of Talio Hulu were re-used for rice after being abandoned by farmers for 11 years. In contrast, Terusan Karya and Belanti's intensive tillage was perhaps responsible for these low figures.

On average, Belanti paddy soils show higher exchangeable Al (10 cmol kg^{-1}) than Terusan Karya paddy soils (2.19 cmol kg^{-1}) and Talio Hulu paddy soils (0.88 cmol kg^{-1}). The lower Al content in Talio Hulu is due to the chelation of Al by humic material. The high Al content in Belanti paddy soils could be toxic for rice and complex phosphorus, but liming can control it.

Kalium (K) is the major soil nutrient required for rice. In the study area, on average, the exchangeable K of Belanti paddy soils (0.20 cmol kg^{-1}) was lower than Terusan Karya paddy soils (0.39 cmol kg^{-1}) and Talio Hulu paddy soils (0.38 cmol kg^{-1}). This suggests that paddy soils in the study area are grouped as medium K status, where the response to K fertilizer is probable [29]. Nevertheless, Belanti paddy soils showed higher total K_2O (33.9 mg $100g^{-1}$) than Talio Hulu paddy soils (30.5 mg $100g^{-1}$), which indicated that paddy soils are grouped as medium status, with content of between 20 and 40 mg $100g^{-1}$ [30]. Thus, the addition of K fertilizer should be at a low rate.

3.3. Yield Variation

Table 3 contains brief statistics of the rice yield in Talio Hulu, Belanti A, Belanti B, and Terusan Karya and of the rice yield of selected and common varieties in the study area. In Talio Hulu, the rice yield varied, ranging from 1.23 to 6.31 t ha^{-1} with an average of 3.27 t ha^{-1} due to variation in rice varieties and farmer conduct because all plots experienced full agro-input. Planted varieties in Talio Hulu include Inpara 2, Inpara 3, Inpara 8, and Inpara 42. Inpara 2, Inpari 3, and Inpara 8 were specific tidal rice fields, whereas Inpari 42 was a particular variety for irrigated rice fields.

Table 3. Brief statistics of the rice yield by selected rice variety and location.

Parameter	Yield (t ha^{-1})				
	n	Min	Max	Avg	SD
By location					
Belanti A	8	1.78	5.54	3.61 b	1.23
Belanti B	25	1.78	5.57	3.75 b	1.11
Talio Hulu	15	1.23	6.31	3.27 b	1.96
Terusan Karya	13	4.50	6.75	5.52 a	0.78
By selected rice variety					
Inpara 2	3	4.37	6.31	5.36 a	0.97
Inpari 32	7	2.71	6.75	4.69 a	1.26
Inpari 42	24	1.23	5.60	3.19 b	1.46
Sembada	9	2.95	6.63	5.06 a	1.06

N = number of farmer, Min = minimum value, Max = maximum value, Avg = average, SD = standard deviation. Numbers that are followed by the same letter are not significantly different according to LSD test of $\leq$0.05.

This yield variation in Talio Hulu was perhaps related to organic acids from peat material. Organic acids, mainly phenolic acids, influence nutrient absorption by the crop, hence determining rice growth and yield. High phenolic acids decrease the crop sorption of P, K, Cu, and Zn [31]. In addition, this yield variation was due to low available nutrients in the crop generative phase. Phosphorus is crucial to accelerating flowering and grain ripening [32]. The low P availability during the grain filling period decreases grain weight and harvested grain. Moreover, Cu is vital in grain filling; very low available Cu will lead to empty grain or harvest failure.

In Belanti A, rice yield varied, ranging from 1.78 to 5.54 t ha^{-1} with an average of 3.61 t ha^{-1} (Table 3) due to used varieties, whereas the planting technique did not affect this yield variation. The planted varieties in Belanti A included Inpara 2, Inpari 3, Argopawon, Sembada, and Suppadi 89. Inpara 2 and Inpari 3 were improved varieties of tidal rice fields that were tolerant to iron toxicity and showed a slightly high yield. Argopawon was an improved variety due to the purity of local varieties from tidal swampland in West Kalimantan.

In Belanti B, rice yield varied, ranging from 1.78 to 5.57 t ha^{-1}, with an average of 3.75 t ha^{-1} (Table 3). The planted varieties in Belanti B included Inpara 2, Inpari 32, Inpari 42, MR-19, CL020, Sertani, Sembada, and Suppadi. In terms of rice production, there was no significant difference between Belanti B and Belanti A. Nevertheless, farmers' performance was higher in Belanti B in that they tried to plant new varieties. Farmers in Belanti B are mostly younger than Belanti A, but Belanti A is more compact than Belanti B. Hence, although their rice field has not improved so far, the dynamics of the farmer groups are different.

The iron content of Belanti paddy soils is high, even more than 1000 ppm Fe (Table 2). This condition causes iron toxicity that greatly influences crop growth and yield. Yield decreases due to iron toxicity ranging from 30 to 100% depending on the variety's tolerance, toxicity intensity, and soil fertility status [33,34]. The influence of iron toxicity on rice yield is determined by the selected variety's resistance, toxicity intensity, crop growth phase, and soil fertility level [32]. In the tidal rice field of Belawang (South Kalimantan), rice having severe iron toxicity produces only 160 kg ha^{-1}. Even during the rainy season in 2018, farmers of Tamban Baru Tengah Village of Kapuas Regency (Central Kalimantan) did not harvest their rice due to severe iron toxicity. Applying lime and controlling water circulation mitigate this iron toxicity problem

In Terusan Karya, the rice yield was high, ranging from 4.50 to 6.75 t ha^{-1}, with an average of 5.52 t ha^{-1}. Farmers planted Inpari 32 and hybrid rice varieties (Sertani, Sembada, and Suppadi). Sertani, which was planted using direct seedlings, showed a higher yield than other varieties.

The Terusan Karya paddy soils contained high iron content, ranging from 413 to 1857 ppm, potentially toxic for rice. However, liming was common practice in Terusan

Karya paddy soil. In addition, Terusan Karya paddy soil's pH was also high, ranging from 4.60 to 5.77. Good management, better conditions, and the selected hybrid rice were responsible for the higher yield in Terusan Karya.

Although, in the study area, as many as 13 soil varieties were planted, the preference among farmers was different. Every farmer freely opted for a rice variety, and several selected the same varieties. The preferred varieties by most farmers were Inpara 2, Inpari 42, Inpari 32, and Sembada for price and taste (Table 3). Inpara 2 is adaptive wetland rice, and its yield ranged from 4.37 t ha^{-1} to 6.31 t ha^{-1}, with an average of 5.36 t ha^{-1}. However, Inpara 2 was not so popular because of the relatively low price. It is also non-sticky; however, farmers in the study area like sticky rice.

Inpari 32 and Inpari 42 are sticky rice and have a good price. In the study area, these Inpari were planted by most farmers. Inpari 32 yielded between 2.71 t ha^{-1} and 6.75 t ha^{-1} with an average of 4.69 t ha^{-1}. The yield of Inpari 42 was between 1.23 t ha^{-1} and 5.60 t ha^{-1} with an average of 3.19 t ha^{-1}. The varieties of Inpari are traditionally grown in irrigated rice fields but performed better in the tidal rice fields.

Most farmers in the study area recently changed to planting hybrid rice, Sembada and Suppadi, yet most farmers prefer Sembada due to its high yield and good price. The Sembada ranged from 2.95 t ha^{-1} to 6.63 t ha^{-1}, averaging 5.06 t ha^{-1} (Table 3). Field observation of other farmers (non-cooperative farmers) showed that they did not provide input as recommended due to affordability. Hence, their yield tends to be lower than cooperative farmers, who applied all technology recommendations.

3.4. Rice Variety versus Agri-Environmental Growth

Table 4 presents the average yield of each rice variety from each location. In Talio Hulu, Inpara 2 showed a higher yield (6.31 t ha^{-1}), followed by Inpara 8 (6.31 t ha^{-1}), Inpara 3 (5.46 t ha^{-1}), and Inpari 42 (2.56 t ha^{-1}). In Belanti A, Inpara 2 demonstrated a higher yield (4.37 t ha^{-1}), followed by Inpari 3 (3.94 t ha^{-1}) and Argopawon (2.11 t ha^{-1}). In Belanti B, Inpara 2 displayed a higher yield (5.40 t ha^{-1}), followed by Inpari 42 (3.80 t ha^{-1}) and MR19 (3.37 t ha^{-1}). In Terusan Karya, Sertani indicated a higher yield (6.67 t ha^{-1}) than Inpari 32 (5.28 t ha^{-1}). For hybrid rice, Suppadi 89 showed a higher yield (5.54 t ha^{-1}) than Sembada (2.95 t ha^{-1}) in Belanti A; however, Sembada disclosed a higher yield in Belanti B (4.62 t ha^{-1}) and Terusan Karya (5.55 t ha^{-1}) than Suppadi. The ANOVA type III also gave us information that the technology package and variety were gave a significant effect to the rice yield. This yield variation of rice variety suggested that location or environmental growth conditions and farmer practice (such as planting technique and crop protection) controlled rice yield in the study area.

Table 4 also presents the average yield of each variety by location (Yl). For example, the average yield of Inpara 2 was 5.36 t ha^{-1}, as the result of the yield averaging of Inpara 2 from Talio Hulu (6.31 t ha^{-1}), Belanti A (4.37 t ha^{-1}), and Belanti B (5.40 t ha^{-1}). For other examples, the average yield of Inpari 32 was 3.99 t ha^{-1}, as the result of the yield averaging of Inpari 32 from Belanti B (2.71 t ha^{-1}) and Terusan Karya (5.28 t ha^{-1}). If a given variety was planted in one location, no averaging was calculated, and the yield of that location was used. The average yield by location was Inpara 8 > Inpara 3 > Inpara 2 > for inbred rice and Suppadi 89 > Suppadi > Sembada for hybrid rice. The average yield by location indicated the overall performance of rice varieties in the study area. The average yield of a rice variety in a given location specified an attainable yield in that location.

In addition to the average yield of each variety by location (Yl), Table 4 also shows the average rice yield of each location from all rice varieties or location productivity (Yr). Rice farming in Terusan Karya showed a higher yield (5.73 t ha^{-1}), followed by Talio Hulu (5.15 t ha^{-1}), Belanti A (3.78 t ha^{-1}), and Belanti B (3.58 t ha^{-1}), where the average was 4.56 t ha^{-1}. The environmental index subtracted the average yield (4.56 t ha^{-1}) from location productivity. Hence, Terusan Karya showed a higher environmental index (+1.17), followed by Talio Hulu (+0.59). Locations showing a high environmental index indicated high productivity, and vice versa [35]. Accordingly, the order of productivity was Terusan

Karya > Talio Hulu > Belanti A > Belanti B. Thus, each location has a maximum capacity for supporting a rice variety to express its genetic potential.

Table 4. Yield of rice variety from four locations of Central Kalimantan, 2019/2020.

No.	Name of Variety	Yv of Talio Hulu	Yv of Belanti A	Yv of Belanti B	Yv of Terusan Karya	Yl	Ye	(Yl-Ye)
		(. . . . . t ha^{-1} . . . . .)						%
1	Inpara 2 [a]	6.31 ab	4.37 abcd	5.40 abc	-	5.36	4.21	28.28
2	Inpara 3 [a]	5.46 abc	- [d]	-	-	5.46	5.15	6.02
3	Inpara 8 [a]	6.28 ab	-	-	-	6.28	5.18	21.94
4	Inpari 3 [a]	-	3.94 bcd	-	-	3.94	3.78	4.23
5	Inpari 32 [a]	-	-	2.71 cd	5.28 abc	3.99	4.65	−14.19
6	Inpari 42 [a]	2.56 d	-	3.80 cd	-	3.18	4.36	−27.06
7	Argopawon [a]	-	2.11 d	-	-	2.11	3.78	−44.18
8	MR-19 [b]	-	-	3.37 cd	-	3.37	3.58	−5.86
9	CL020 [b]	-	-	2.74 cd	-	2.74	3.67	−23.46
10	Sertani [a]	-	-	2.23 d	6.67 a	4.45	4.65	−4.30
11	Sembada [c]	-	2.95 cd	4.62 abc	5.55 ab	4.37	4.36	0.23
12	Suppadi [c]	-	-	3.81 bcd	5.42 abc	4.61	4.65	−0.86
13	Suppadi 89 [c]	-	5.54 abc	-	-	5.54	3.78	46.56
	Yr	5.15	3.78	3.58	5.73			
	Environmental index	*+0.59*	*−0.78*	*−0.98*	*+1.17*			

Note: [a] inbred variety; [b] rice traits; [c] hybrid variety; [d] **Ya** = average of **Yr** from all locations = **4.56** t ha^{-1}. **Yf** = yield of a given rice variety from a given farmer for a given location; **Yv** = the average of **Yf** for a given variety in a given location; **Yl** = average of **Yv** for all locations; **Yr** = the average of **Yv** in a given location of all varieties; **Ye** = the average of **Yr** for the location where a given rice variety grew. Environmental Index is the difference between **Yr** and **Ya**. Numbers that are followed by same letter are not significantly different according to LSD test of ≤0.05.

In addition to location productivity, each variety has an environmental yield (Ye) calculated by averaging location productivity where the variety was planted. For instance, the environmental yield of Inpara 2 was 4.21 t ha^{-1}, as the result of averaging location productivity (Yr) of Talio Hulu (5.15 t ha^{-1}), Belanti A (3.78 t ha^{-1}), and Belanti B (3.58 t ha^{-1}) because Inpara 2 was planted in Talio Hulu, Belanti A, and Belanti B. In another instance, the environmental yield of Sertani was 4.65 t ha^{-1}, as the result of averaging the location productivity of Belanti B (3.58 t ha^{-1}) and Terusan Karya (6.67 t ha^{-1}). If a given variety was only planted in one location, the environmental yield was the location productivity of a given location. For example, the environmental yield of Inpara 3 was 5.15 t ha^{-1}, which is the location productivity of Talio Hulu (5.15 t ha^{-1}), as Inpara 3 is planted only in Talio Hulu.

The environmental yield of each variety was input to identify the adaptability of a given variety. The difference between average yield by location and environmental yield was the indicator of adaptability. Inpara 2 showed a higher positive difference (28.08), followed by Inpara 8 (21.94), suggesting that these varieties were highly adapted to environmental growth conditions. Meanwhile, Agropawon showed very low adaptation to the different environment, as indicated by the highest negative difference (−44.18). For hybrid rice, Suppadi 89 was highly adaptive (48.56), followed by Sembada (0.23). Thus, varieties with high adaptability in tidal paddy soil were Inpara 2 > Inpara 8 > Inpara 3 > Inpari 3. Selecting the right variety for the right location could be a determining factor for high production. Nevertheless, the choice of planted variety was determined by rice variety adaptability, farmer preference, rice milling preference, local culture, and price.

4. Discussion

4.1. Practical Implications

This study confirms that the rice yield of tidal rice fields varied, although these varieties/traits were planted in the same environment and with the same farming technology package. A technology package used for a given land will influence nutrient availabil-

ity. Various technology packages result in different rice yields because the soil fertility varies. A technology package that can contribute nutrients optimally leads to maximal rice yield. This is why yield differences are observed for different technology packages. Thus, as shown in the results, a superior technology package for tidal rice farming requires flexibility and adaptability in its implementation. Flexibility and adaptation are related to environmental conditions and farmers' conduct. Therefore, the improvement of the environmental condition is also important despite the implementation of the technology package.

Development and dissemination of specific rice varieties being tolerant to the tidal rice field environment are essential for increasing rice productivity; however, farmers' adoption of new varieties is relatively slow in Central Kalimantan. Typically, plant breeders develop varieties isolated from active farmers [36]; however, the released varieties were tested in the target region, albeit mainly conducted under ideal conditions. Participatory varietal selection (PVS) facilitates the identification and understanding of the criteria of smallholder farmers for selecting and adopting new rice varieties. Burman et al. [37] reported significant correlations between the preferences of male and female farmers in most trials. It was indicated that both groups have similar criteria for selecting rice varieties, but the preferred criteria of farmers are not the same as those of the researchers. Grain yield was the most important but not the sole reason. There were other criteria for variety selection by farmers, such as plant height, panicle length, lodging resistance, iron and submergence tolerance, and maturity. The determining factors for farmers in adopting a rice variety include maturity duration, grain shape, and good quality for better market value. Therefore, PVS facilitates farmers' feedback to the breeders for variety improvement for marginal soils by providing information on critical traits.

Seed availability is the most important factor in disseminating rice varieties. In our study, farmers could not afford seeds easily. The sub-optimal environment, including the tidal and inland rice regions, is large and spreads outside the Java island. However, rice producers are primarily located on those islands, and seed transportation has become a bottleneck for the dissemination and adoption of wetland rice varieties. Seeds are the most crucial input and must be available before any business activities in agriculture can take place. With high-quality seeds, crop productivity will increase, and our technology package will significantly support the productivity of rice varieties. Therefore, it is essential to fulfill the good-quality seed criterion and produce the seeds on the farm.

Factors affecting the development of self-reliance capabilities were rice seed production experiences, income, cost, rice seed field tenure, belonging to a group, farm media perception, public activities participation, and the number of native knowledge applications [37]. Therefore, it was essential to campaign for native knowledge application for rice seed production, promote cultivation techniques, and enhance local farmers' capabilities to produce rice through training courses and intensive technical assistantships. The Indonesian Ministry of Agriculture launched Seed Smart Village or *Desa Mandiri Benih* as a supportive program for local producers. However, the program still needs improvement, primarily to support seed producers in sub-optimal regions. These programs significantly shorten transportation lines/tracks and provide good-quality seed distribution outside Java island. In collaboration with the seed certification unit in each province, the program will be beneficial in increasing the farmers' capabilities and income.

4.2. Future Directions

Researchers have been developing various technological components for tidal rice farming. Different technology packages for tidal rice farming have been formulated to increase rice production. Nevertheless, the tidal paddy soils are marginal and fragile due to the availability of toxic elements, water and soil dynamics, and low soil fertility; hence, the development of rice in the larger region needs to be carried out precisely and carefully. Technology selection and implementation patterns should be tailored to a region's characteristics.

In wetland development, water management systems are vital to control water availability in a given area and region. Drainage canals would overcome water logging, and understanding water management with pyrite position is essential [20]. Although the implementation of water management technology to support agricultural land rehabilitation and farming show promising results, it is only partial, does not cover a whole region, and is only slightly satisfactory. It requires the improvement of water infrastructure to control water, especially in drain areas, operationalization and maintenance of canals and ditches, coordination in land management, including farming knowledge and capability, and the institutional system to empower infrastructure in the wetland region.

In this study, we improved micro water management in each study location by applying TASEL two weeks before planting. The main objective of this improvement was to ensure good water circulation and to ascertain whether water was available for soil tillage and crop growth stage. Water in tidal rice farming becomes a key factor because whole implementation of each technological component needs water arrangements to be effective. Applying fertilizer, ameliorant, and herbicide needs water inundation of about 0.1 cm to 0.5 cm so that fertilizer and ameliorant can be adsorbed by soil colloids to prevent loss by drainage water. Sprayed systemic herbicide will not experience dilution and hence works more effectively. A water table of the plots' surface needs arranging so that it does not dry or sink. Dryness triggers pyrite oxidation, which causes high soil acidity, accelerates peat subsidence, and makes peatland more prone to fire. Long inundation without drainage can inhibit crop growth and show iron toxicity.

Generally, in terms of the soil, in several locations, the reclamation process is not fully completed, as can be seen from land that is always in acidic condition in the dry season. Key factors to successful tidal rice farming include water and land management, adaptive variety selection, amelioration, fertilizer application adapted to crop need, and soil nutrient status. In addition, a large area is to be managed while limited labor requires the introduction of machinery designed for site-specific wetland conditions in order to be productive and effective.

From a socio-economic perspective, the development of mixed farming is potentially a good alternative but requires serious discussion. Local knowledge proves the resiliency of mixed farming in wetland development, that is, mixing and synergizing between on-farm and off-farm in improving farmers' income. In several cases, the value of off-farm can contribute up to 40% of the income source of the farmer. A study on resource management, accessibility, capital, and human resource education is required [38].

5. Conclusions

In conclusion, our study confirms variations among plots in soil properties, leading to variation in environmental growth. These plots reflect the treatment by farmers historically of their soil to attain good rice crops, but the treatment differs between farmers. This study found that four varieties have higher yields of more than 5.0 t ha^{-1}, namely, Inpara 8, Suppadi 89, Inpara 3, and Inpara 2. Rice productivity in tidal rice fields depends on the variety and package of cultivation technology, soil and water characteristics, and farmers' conduct. Water management is a key factor, followed by the use of a high-yielding variety, amelioration, and fertilizer application. Selecting and implementing technology must be adapted to the water and soil characteristics and the farmers' social, cultural, and economic conditions.

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