Rice productivity on the swampland flooded tide: the case of Terusan Karya Village

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Abstract. Sustainability of agricultural development in swampland is required considering its fragile nature. The objective of research is to study the impact of tides on rice productivity in the flooded tidal swampland type B of Terusan Karya Village in July-October 2021. This research was a demonstration plots on the Rei 27 with an area of 14 ha that applied water management systems, soil tillage, application of ameliorant and fertilizer, use of improved rice and integrated pest management. The result showed lower water acidity with increasing distance from the Rei estuary, pH 3.16 to pH 4.71 at 2.3 km. Electrical conductivity (EC) and total dissolved solids (TDS) increased with increasing distance, from 0.54 to 0.89 mmhos cm^{-1} and 272 to 446 ppm. The further away from the estuary the more acidic the soil, from pH 5.49 to pH 4.63. Other soil chemical properties such as Al, Fe, Mg, K, and CEC showed an irregular pattern. Rice yield showed a range of 4.3 – 5.2 t ha^{-1} in the estuary of Rei (0 km), increased (5.7 – 6.3 t ha^{-1}) in the middle (1.0-1.5 km), then decreased (4.2-4.5 t ha^{-1}) at the end (2.3-2.5 km). Soil pH and Fe concentration significantly impact to rice productivity.[*]

1 Introduction

Tidal swamplands are influenced by two powerful forces: gravity, which pulls seawater towards the moon and sun, causing tides in seas and rivers, and centrifugal force, emanating from the center of rotation of three celestial bodies (sun, moon, and earth), pushing outwards. These forces together give rise to the periodic occurrences of spring tides and neap tides. In swamp areas, particularly in Central Kalimantan, local farmers have given specific names to these tidal forces. They refer to full moon tides (single pairs) as spring tides and call neap tides (double pairs) *pindua* [1, 2]. Swampland is classified into four types based on hydrotopography or high tide levels for agricultural purposes. These types are: tidal type A, flooded by water during both spring and neap tides; tidal type B, flooded

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only during spring tides; tidal type C, not flooded by water tide but with a ground water table < 50 cm depth; and tidal type D, not affected by water tide but with a ground water table > 50 cm depth, often referred to as rainfed swampland (Figure 1) [10, 11].

The farmers in the swamp area of Central Kalimantan choose flooded areas for rice cultivation due to several beneficial factors. Firstly, they gain easy access to rice fields and cultivated land. Secondly, during the high tide period, irrigating the rice fields becomes effortless. Thirdly, the inundation inhibits weed growth, contributing to better crop yields. Lastly, the tidal action facilitates a more intensive leaching process, effectively removing acids and toxic ions from the soil [3, 4].

The utilization of swampland for agriculture in Indonesia saw significant growth and expansion following the implementation of the Tidal Rice Opening Project (*Proyek Pembukaan Persawahan Pasang Surut-P4S*) from 1969 to 1985 in various regions, including Kalimantan, Sumatra, Sulawesi, and Papua. During this project, approximately 2 million hectares of swampland were cleared, with a particular focus on Kalimantan and Sumatra. As a result, some of these areas transformed into productive rice production centers, while others faced degradation over time. Regrettably, about 4 million hectares of swampland have been classified as degraded, nearly equivalent to the total area that underwent rice cultivation [5, 6]. This indicates the complex challenges and consequences associated with the ambitious agricultural expansion in these regions.

Rice cultivation in swampland has evolved from the rich local knowledge of farmers, exemplified by the Banjarise System in Kalimantan [7, 8]. The farmers' approach entails an adaptive mechanism, where technology is carefully tailored to the unique environmental conditions, particularly the water system's characteristics and the varying flood or water levels [9]. To enhance rice crop productivity, a proven and effective strategy is the implementation of sustainable intensification in tidal rice fields, complemented by mentoring programs. Demonstration plots play a role in this process, serving as platforms for researchers and extension workers to showcase and control the application of technology and innovation. Additionally, these plots offer valuable opportunities for farmer training, guidance, and learning. Considering the delicate and vulnerable nature of swampland, sustainable agricultural development requires the adoption of adaptive and environmentally friendly technologies.

This study aims to investigate study the impact of tides on rice productivity in the flooded tidal swampland, focusing on the case of the swamp irrigation area (SIA) in Terusan Karya Village, Bataguh District, Kapuas Regency, Central Kalimantan. By understanding the dynamics of this unique ecosystem, we can work towards more efficient and ecologically conscious rice cultivation practices.

2 Materials and methods

2.1 Study approach

In this study, a field experiment was conducted on tidal type B swampland, covering an area of 14 ha, with the implementation of agricultural technology. Each farmer's plot, ranging from 1 to 2 ha in size, acted as a micro water management unit. This approach allowed for precise control and management of water levels, optimizing rice cultivation in the tidal environment.

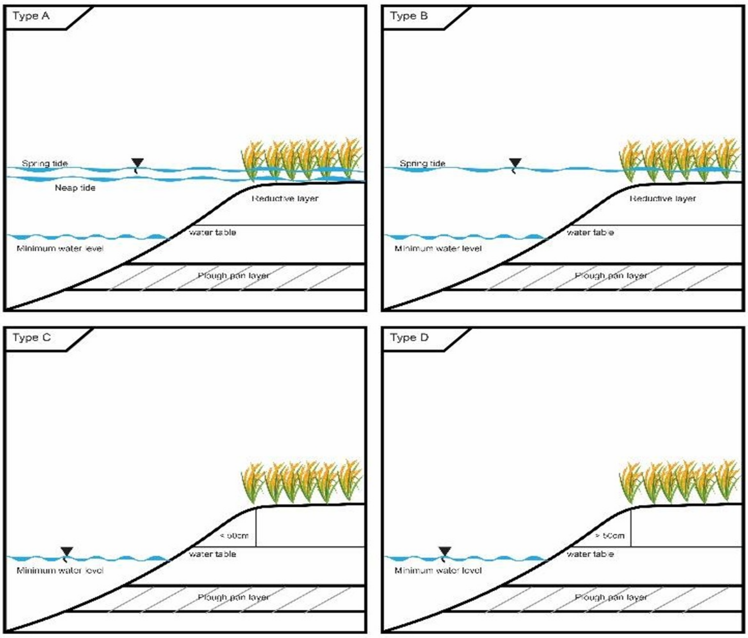


Fig. 1. Illustration depicting the different types (A, B, C and D) of tidal swamplands categorized according to the influence of tides and ground water table levels.

Rice productivity in tidal swampland is influenced by many of factors, encompassing soil type, water management, production facilities such as fertilizers and seeds, types of rice varieties, land preparation, soil tillage, and effective control of weeds, pests, and plant diseases. Within the specific context of tidal type B, including the study site in Terusan Karya Village, rice productivity stands out as the most favorable compared to types A and C. In tidal type A, although rice productivity can be high, cropping intensity is generally limited to once a year (IP 100). The high water level during the rainy season prevents rice cultivation, while in the dry season, the intrusion of sea water causes abnormal growth due to increased salinity. For tidal type C, rice crops often face drought and Al toxicity in the dry season, posing challenges to productivity. However, advancements in swamp rice varieties have made significant improvements. Varieties released between 1980 and 1990, such as Kapuas, Barito, Batanghari, and Margasari, had a potential yield of 4-5 t ha^{-1}. More recently released varieties between 2010 and 2015, like Inpara 2, Inpara 3, and Inpara 8, have shown higher potential yields of 6-8 t ha^{-1}, with actual productivity reaching 7-8 t ha^{-1}. Apart from the choice of high-yielding rice varieties, the productivity of rice is also influenced by the employed rice management and cultivation systems, such as spacing, fertilization, and other essential treatments [9, 12, 13, 14]. These factors collectively contribute to the success of rice cultivation in tidal swamplands.

2.2 Study area

Terusan Karya Village, a tidal swampland, was established in 1983 and features a Comb System that connects two rivers, the Kapuas Murung River and the Kahayan River. The system includes primary, secondary, and tertiary canals to regulate water flow effectively. In accordance with the Qomariah calendar, the area experiences full moons during spring tides on the 13th, 14th, and 15th of the month, followed by dead moons on the first and second days. Subsequently, neap tides occur, characterized by two daily tides within 24 hours, each with varying flooding heights between the first and second tide. This intricate tidal pattern shapes the unique ecosystem of Terusan Karya Village, influencing agricultural practices and land management in the region.

Terusan Karya Village has 23 tertiary canals, known locally as *Rei*, numbered from *Rei* 18 to *Rei* 41 (see Figure 2). Considering the good functioning of the irrigation infrastructure, as well as a relatively flat and uniform land topography. Moreover, the active participation of local farmers adds to the overall effectiveness of the agricultural practices in the region. For the dry season of 2021, during from July to October, the demonstration plot was chosen at *Rei* 27 in tidal type B, within the Terusan Karya Village of Bataguh District, in Central Kalimantan's Food Estate area. This selection ensures a suitable environment for conducting the experiment and studying rice productivity in the specific tidal swampland conditions of the region.

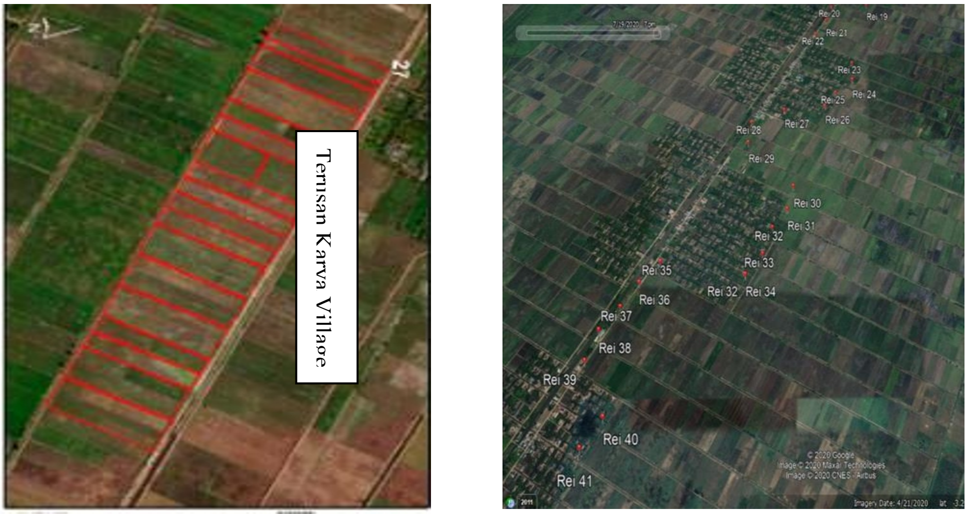


Fig. 2. The irrigation network in Terusan Karya Village

2.3 The introduced technology

The water management in the area adopts a pumping system in conjunction with an elbow system. The elbow plays a role in regulating the inflow and outflow of water into the rice fields, making this approach particularly suitable for tidal types A and B. To facilitate land preparation, a mechanization system utilizing a hand tractor was employed (see Figure 3a). To enhance soil fertility and nutrient levels, a comprehensive approach to amelioration and fertilization was implemented. This involved assessing the soil's nutrient status and utilizing a combination of organic fertilizers and bio-fertilizers to optimize crop growth and productivity.

Improved rice variety is one of the main components of technology that have been proven to increase rice productivity and is quickly adopted by farmers because it is cheap and more practical to use. In this study, hybrid and Inpara rice varieties were used due to their good performance and were in accordance with farmer's preferences (Figure 3b).

(a) (b)

Fig. 3. (a) Land preparation, and (b) rice crop performance at harvest

The integrated pest disease control approach is implemented through a combination of various strategies, including simultaneous planting, utilizing resistant varieties, adopting biological control methods, employing bio-pesticides, implementing physical and mechanical pest management techniques, using pheromones, and maintaining natural enemy populations. Chemical pesticides are considered as a last choice, to be used only if other control measures are unable to effectively manage pests and diseases. The technology and cultivation components employed in this integrated approach are detailed in Table 1.

Table 1. Introduced technology at demonstration plot of *Rei* 27

No	Technology components	Introduced technology
1	Water management	Elbow system, small canal in the edge of the surrounding rice field (locally called *kemalir*), pumping irrigation
2	Land preparation	Hand tractor
3	Amelioration and fertilization	Amelioration: 1. Lime (500 kg ha^{-1}) 2. Rice straw (5 t ha^{-1})
		Biofertilizer: 1. Biotara 25 kg ha^{-1}
		Chemical fertilizer: 1. NPK Phonska 250 kg ha^{-1} 2. SP36 150 kg ha^{-1} 3. KCl 100 kg ha^{-1} 4. Urea 50 kg ha^{-1}
4	Adaptive varieties	Hybrid: Suppadi, Sembada Inbrid: Inpari 32
5	Pest management	Control based on integrated disease and pest concept

The observed parameters are water (pH, EC, and TDS), initial soil condition (pH, N, P, K, Ca, Mg, CEC, Al, and Fe), and rice grain yield at every 0.2 km distance from *Rei* estuary.

3 Results and discussions

3.1 Water quality

Water quality in tidal swamplands is a dynamic factor influenced by various elements, including canal dimensions, distance from the estuary, seasonal variations, tidal strength, and the infrastructure of the swamp irrigation network. In general, water quality is found to be better during high tide compared to low tide. This improvement is attributed to the inflow of water from rivers that carry good quality (Table 2). For the specific case of *Rei* 27, the water quality at the estuary is notably better during low tide. This enhancement is attributed to the intrusion of fresh water from the oil palm plantation collector canal in the Southern part. Interestingly, this contrasts with other locations like Sidodadi Village in Tamban Catur District, Kapuas Regency, Central Kalimantan, where water quality is poor due to runoff from oil palm plantations [15].

Table 2. Water quality of *Rei* 27

Water quality	**Distance from estuary (km)**											
	0	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**	**2.3**
pH	3.16	3.26	3.27	3.29	3.30	3.34	3.40	3.44	3.58	3.58	3.84	4.71
EC (dS m^{-1})	0.54	0.57	0.60	0.61	0.69	0.68	0.70	0.78	0.78	0.78	0.80	0.89
TDS (ppm)	272	284	300	324	334	338	351	389	384	384	400	446

Source: [16]

3.2 Soil properties

The research site in Terusan Karya Village predominantly consists of acid sulphate soil with a pH range of 4.6 to 5.8. As we move further away from the estuary, at a distance of 2.3 km, the pH level tends to decrease from pH 5.49 to pH 4.63. The iron content, which is a characteristic feature of acid sulfate soils, exhibits an irregular pattern. Similarly, other chemical properties such as available phosphorus (P), exchangeable cations, cation exchange capacity (CEC), and Al-exchangeable also display irregular patterns (Table 3).

Table 3. The chemical properties of the initial soil in *Rei* 27

Distance from estuary (km)	**pH H_2O**	**N (%)**	**P-available (ppm)**	**K-exch.**	**Ca-exch.**	**Mg-exch.**	**CEC**	**Al-exch.**	**Fe (ppm)**
				(cmol(+) kg^{-1})					
0	5.49	0.39	8.11	0.53	2.80	23.81	44.61	2.91	975.66
0.2	5.83	0.44	6.29	0.45	2.18	16.76	41.26	2.32	1710.85
0.4	5.70	0.29	13.21	0.50	2.64	17.45	40.55	4.68	1857.12
0.6	5.48	0.32	6.49	0.50	3.02	23.88	46.48	2.11	771.42
0.8	5.77	0.38	6.06	0.21	2.36	18.31	52.49	2.69	774.08
1.0	5.37	0.44	12.98	0.48	2.31	20.23	33.30	1.22	1202.13
1.2	4.66	0.43	12.45	0.41	1.86	15.48	43.30	2.26	505.79
1.4	5.63	0.30	8.25	0.37	2.20	19.37	40.76	1.36	1151.58
1.6	5.02	0.33	7.47	0.37	2.08	17.82	47.56	2.56	1429.14
1.8	4.97	0.24	22.37	0.40	2.12	19.62	36.29	2.07	412.91
2.0	5.13	0.27	7.32	0.41	1.93	18.73	30.57	0.98	1798.33
2.2	4.60	0.30	9.16	0.18	2.02	19.16	47.90	2.23	626.23
2.3	4.63	0.37	10.70	0.38	2.07	18.44	49.81	1.09	689.70

Exch. = exchangeable
Source: [16]

3.3 Rice Productivity

Most of the existing infrastructure in Terusan Karya Village has not been successful in controlling water levels in the canal or rice fields. The secondary and tertiary canal infrastructure primarily serves to facilitate the inflow and outflow of tidal water from the river, but the floodgates have not been functioning as intended. To address this issue, farmers have adopted a micro-level water management model. They installed several PVC pipes connected to an elbow at the end of each pipe, effectively serving as substitutes for sluice gates, allowing one-way flow. As a result of these water management efforts, the water acidity in the demonstration plot demonstrated a favorable soil pH (> 5.0). This improvement can be attributed to the application of dolomite to the rice fields, which effectively enhanced soil acidity. The addition of 1.0-1.5 tons ha^{-1} of manure, remaining straw from the previous season, 25 kg ha^{-1} of bio-fertilizer (Biotara), and inorganic fertilizers (250 kg Phonska + 150 kg SP36 + 100 kg KCl) ha^{-1} also contributed to the increased rice productivity. These combined agricultural practices and inputs have positively impacted the rice cultivation in the demonstration plot.

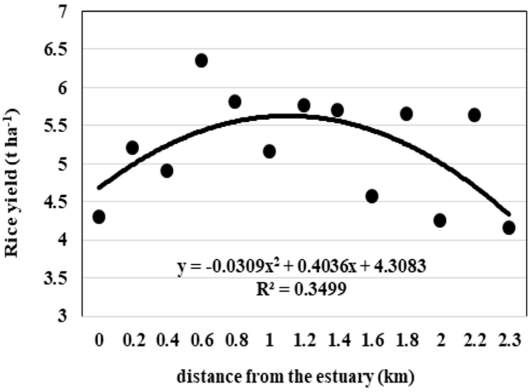
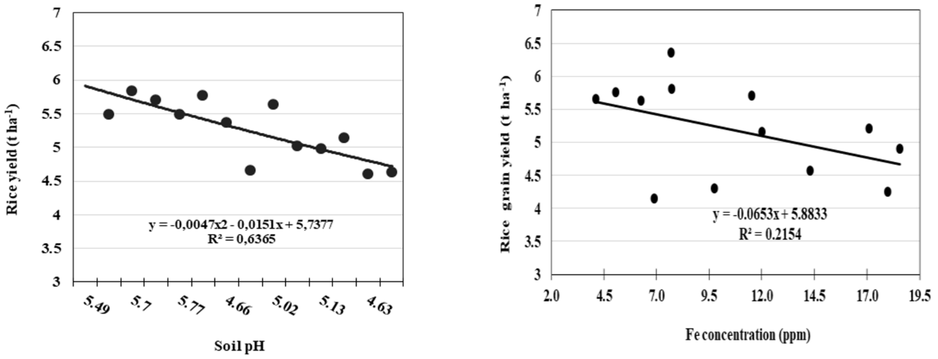


Fig. 4. Rice grain yield at the distance from the estuary



(a) (b)

Fig. 5. Rice grain yield at soil pH (a) and Fe concentration (b)

The rice problem in tidal swampland with acid sulphate soil is primarily attributed to iron toxicity. This condition is caused by various factors, including high soil iron (Fe) concentration, low soil pH, nutrient deficiencies, nutrient imbalances, poor drainage, reduced Fe^{2+} exclusion capacity due to the accumulation of respiratory inhibitors such as H_2S, FeS, and organic acids, along with the addition of non-decomposable organic matter [19, 20]. The research results clearly demonstrate the correlation between rice grain yield and soil pH (Figure 5a), with an R-squared value of 0.64, and iron content (Figure 5b), with an R-squared value of 0.22. As soil pH decreases and soil Fe concentration increases, rice grain yield decreases. Excessive Fe absorption enhances the activity of the polyphenol oxidase enzyme, leading to the production of highly oxidized polyphenols and resulting in leaf bronzing. Therefore, iron toxicity significantly impacts rice growth in acid sulphate soil. The reduction in yield due to iron toxicity varies between 30-100%, depending on the variety's tolerance, the intensity of toxicity [21], and the soil fertility status [22].

The normal range of Fe concentration in rice leaves is considered to be 100-200 ppm, while levels exceeding 300 ppm are toxic to rice plants [23]. During the tillering phase until panicle initiation, the critical limit for iron toxicity in young leaves of rice plants is >300-500 ppm, with an optimum limit of 100-150 ppm. In plants with high toxicity, the Fe concentration can reach 300-2,000 ppm. However, the critical Fe concentration varies based on the plant's age and nutrient status [19, 24]. To effectively manage iron toxicity in rice, several approaches can be employed, including soil and water management, amelioration, appropriate fertilization, and the use of tolerant rice varieties [25].

Implementing intermittent water management resulted in a 13.6% increase in rice growth and yield compared to continuous flooding, while the flushing system contributed to a 13.2% increase. Although the intermittent system required a delay in planting of 14 to 21 days after flooding, the benefits were evident. Additionally, applying 5 t ha^{-1} straw compost and 5 t ha^{-1} *purun tikus* (*Eleocharis dulcis*) compost led to a 16.4% increasing in rice growth and yield, surpassing the results obtained with dolomite at a rate of 2 t ha^{-1}. Fertilization with 90 kg ha^{-1} P_2O_5 and 100 to 125 kg ha^{-1} K_2O, along with seed treatment using CaO at 75% of the seed's weight, enhanced rice growth and grain yield. Similarly, a fertilizer application of 90 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5, and 60 kg ha^{-1} K_2O also resulted in increased rice yield. Furthermore, using adaptive and high yielding rice varieties such as Margasari, Lambur, Indragiri, Air Tenggulang, Mendawak, Inpara 1, 2, 3, 6, 7, 8, and 9 demonstrated up to a 31% increase in rice grain yield compared to the Margasari variety. By combining water management, amelioration and fertilizer application, and utilizing tolerant rice varieties, rice production in acid sulphate soil of tidal swamplands can be significantly enhanced, leading to a substantial increase in rice grain yield [25, 26]. The impact of Fe concentrations in growth media on rice growth varies significantly. Even at relatively low concentrations of 50 ppm Fe, rice growth was negatively affected [27]. However, higher concentrations of 500 ppm or 1,000 ppm Fe did not show any significant impact on the plants [28].

According to a report by [29], Fe concentrations in the soil ranging from 300-1500 ppm were considered growth media that led to iron toxicity. Surprisingly, despite the iron content in some rice fields reaching levels of 1,000-1,800 ppm (as shown in Table 3), the growth and condition of the rice leaves did not exhibit any symptoms of iron toxicity (Figure 6). This apparent contradiction can be explained by the fact that the cultivated rice varieties in Terusan Karya Village are tolerant to high iron content [30]. As a result, even when exposed to elevated Fe levels, these tolerant rice varieties continue to thrive without manifesting any adverse effects on their growth.

Fig. 6. The growth performance of the Inpari 32 variety (on the left) and Sembada variety (on the right) in the demonstration plot of Terusan Karya Village was observed (Photos by M. Alwi, 2021)

4 Conclusion

The swamp irrigation area of Terusan Karya Village has a potency for the development of rice crops due to its good irrigation network, which is directly connected to the Kapuas Murung River, enabling the controlled inflow of tidal water to inundate the rice fields. The productivity of rice in this area is significantly influenced by soil pH and soil Fe concentration. By implementing agricultural technologies that encompass water management, plant and nutrient management, and effective pest and disease control, rice productivity in the region has shown considerable variation, ranging from 4.15 to 6.35 t ha^{-1}. To further enhance rice productivity on the swampland, it is essential to focus on improving the network infrastructure of the swamp irrigation area (SIA). This improvement will facilitate better water distribution and management, contributing to the overall success of rice cultivation in the flooded tidal zone.

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