

Lesson learned from the development of sustainable rice farming in peatland

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Abstract. Future food production is expected to meet the capacity in providing food for 9.7 billion people in the world by 2050. As the population rises, the demand for rice cropping areas in Indonesia will double to approximately 16.5 million ha by 2040. Deploying arable land intensification alone would hardly fill the gap. In Indonesia, around 140,000 – 187,000 hectares of agriculture areas have been lost due to residential or industrial purposes every year, especially in Java Island. This research attempted to explore the viable farming method to improve rice production in peatland which has the potential to be cultivated as arable land. Three main issues hindered the development of rice growth: acidic soil and water, irrigation, and rice variety adaptation. Despite these constraints, the experiments in Pulau Burung District, Indragiri Hilir Regency, Riau using rice varieties Mekongga, IR 64, and Cilamaya Muncul managed to yield an average up to 4-ton/ha of rice grain. This number is close to the Indonesian average productivity of 5-ton/ha. In practice, the experiments leverage on an integrated water resource management and the selected ameliorant. The yield range in peatland is often limited by productivity factors such as pest, fertilizer, water, next to the cost of providing ameliorant. By further developing the practice, sustainable rice farming can contribute in securing staple food production.

1. Introduction

The future of food production is expected to meet the capacity in providing food for 9.7 billion people in the world by 2050. Food security in Indonesia is highly associated with rice production. *Oryza sativa* is the first domestication type of wild rice species. The early use of rice for staple food began from 7500 - 8500 BC in China, and around 4000 BC in Java [1]. Over the years, the escalating number of rice consumption has raised concerns to Indonesia's production capacity to meet the national demand. In 2019, the total number of rice field areas in Indonesia is approximately 7.46 million hectares [2]. As the population rises, the demand for rice cropping areas is predicted to double to approximately 16.5 million hectares by 2040 [3].

Promoting food security by increasing food production is among the feasible solutions, although it requires millions of hectares of crop fields. Agriculture intensification became the main strategies for providing food since it was introduced in the mid-nineteenth century. However, this approach also comes with challenges. If the yield is already near to achieve its maximum potential, it would be even harder to raise production [4]. This intensification system may degrade the land because they exceed its capacity and need more fertilizer and water. Pollution, soil erosion, and water scarcity are adding the problem. Further, globally, 24.3 million hectares of arable cropland has been converted into urban area in just twenty years observation (1992-2015) [5]. In Indonesia, around 140,000 – 187,000 hectare



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of agriculture areas have been lost to residential or industrial purposes every year, with two-third land conversion taking place in Java [6,7].

Intensification has a limit in generating the maximum yield; thus, extensification is inevitable. Extensification means increasing food production through the expansion of new agricultural land. This farmland expansion must not be translated into deforestation. In fact, the practice should utilize the abandoned and degraded land that can be enhanced for farming. One of the potential areas to create the new farmland is located on suboptimal land type. The "sub" is a prefix indicating the characteristics that inhibit the growth of crops due to less optimum water, light, or nutrients. The "suboptimal land" term was started to be used widely to describe the typical character of land with low productivity, reduced economic return, and/or severe limitations for agricultural use.

One of suboptimal land that can serve for rice farming purpose is peatland. Peatland is among suboptimal land types that are technically modifiable for agriculture due to its soil and water characteristics [8]. In Indonesia, peatland covered ~20 million hectares of area in Sumatra, Kalimantan and Papua [9]. There are 8.28 million hectares of potential paddy fields across Indonesia. The number consists of 2.98 million ha of swamp paddy fields and 5.30 million ha of non-swamps. The potential for developing rice fields are located in Papua, Kalimantan and Sumatra, where each province has 5.19 million ha, 1.39 million ha and 0.96 million ha, respectively [10].

The peatland conversion into paddy fields is part of the government's effort to meet the nation's future rice demand. It is projected that by 2025 and 2040, Indonesia needs to develop additional 1.4 and 9 million ha of rice cultivation [3,11]. Nevertheless, the peatland utilization has always been controversial, especially since the failure of the Mega Rice Project (MRP) in 1996, and the concurrent massive peatland fire [12,13]. Irresponsible soil drainage and poor canalization system have significantly contributed to these calamities [14]. Insufficient technology to address acidic soil and nutrient deficiency also exacerbate the situation. Hence, peatland utilization for rice farming must be implemented carefully to ensure the optimum yield of productivity. To that end, many studies have been conducted to identify ways in modifying peat soil to grow paddy fields with minimum environmental damage effectively [15-17].

Due to several restrictions, rice farming on peatland became less developed. The research related to rice cultivation on peatland is also limited despite its opportunity to contribute to long-term food security. Farming extensification, if well managed, can reduce the negative effect of intensive agriculture and boost food production [18]. Rice farming is considered as a tool of development intervention on degraded peatland besides for plantation [8]. In the long run, the practice will help to meet the local rice demand along with the reduction of CO₂ emission [19]. Study conducted by Furukawa et al. [20] suggested that lowland rice demonstrated a higher carbon reduction in peatland in terms of C sequestration and greenhouse gas emissions compared to other upland crop systems. Additionally, this practice is an effective way to reduce subsidence due to high groundwater table maintenance which inhibits oxidation of peat substrate [21].

This paper attempted to explore viable farming methods to improve rice production in a sustainable manner. Three main issues hamper the development of rice farming in peatland: acidic soil and water, water management, and rice variety adaptation. The pH of peat soil is below 4, while the optimum pH for rice farming is 5 – 8. Multiple studies were conducted using ameliorant to increase pH that is suitable for rice farming [22]. Ameliorant is a chemical material with alkali characteristic to compensate acidic water on peatland. Next, determining the rice varieties that adapt to acidic condition is vital for productivity because the plants will be grown in deficient settings. The following experiment tested the growth and productivity of several rice varieties such as Pak Tiwi, Mekongga, Cilamaya Muncul, IR 64, Kalimasada, Serai Wangi, and Pandan Wangi.

2. Method

2.1 Study location

The research site is located at Pulau Burung District, Indragiri Hilir Regency, Riau Province (0° 22' 42.708" N 103° 33' 12.564" E) (Fig.1). It lies on Sungai Kampar - Sungai Gaung Peatland

Hydrological Unit, a 711,000 ha peatland ecosystem. The land use in Pulau Burung is dominated by coconut plantations. Its practices are primarily managed by local farmers and a local company named Sambu Group. Since 1986, Sambu Group has built and maintained an integrated water resource management called Water Management Trinity (WMT) within the 22,000 ha of coconut plantations in the region. The trinity system consists of canals, dikes, dams and water gates. Besides WMT's core function to regulate the water resource, the canals also serve as the waterways transportation for the community.

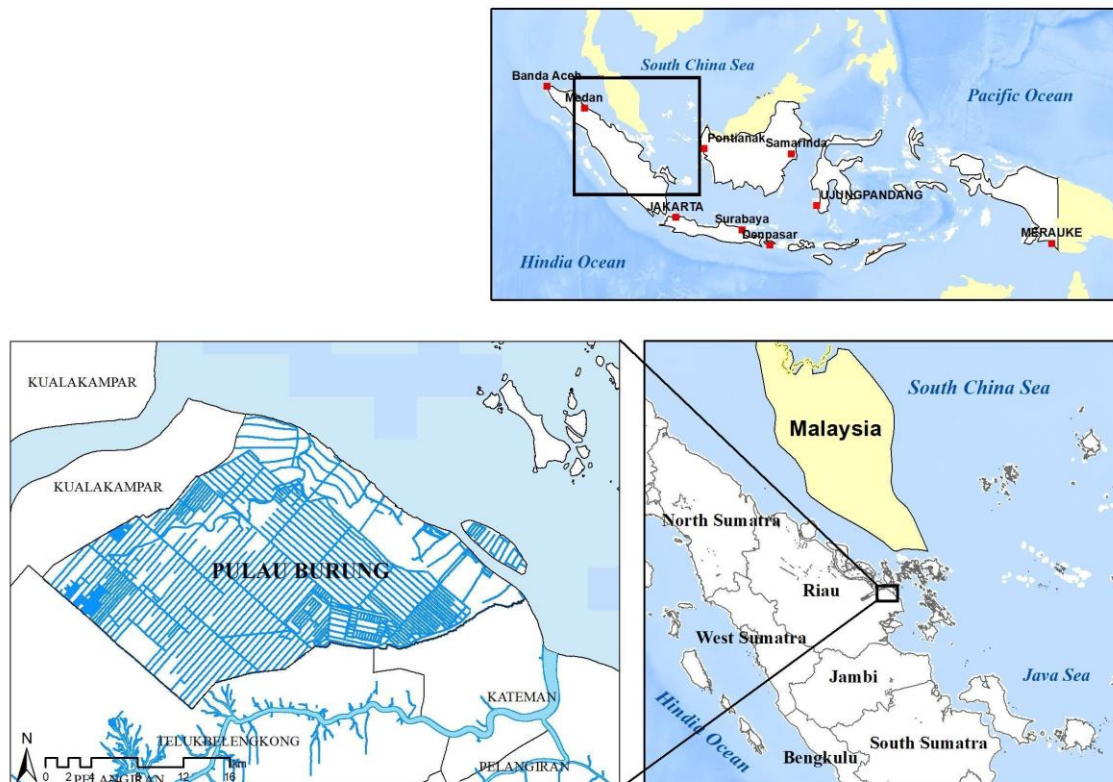


Figure 1. The research location in Pulau Burung, Riau, Indonesia. The blue lines represent the canal network within the district.

This rice farming research was implemented inside the area where the irrigation system is managed by the existing WMT. Four hectares of paddy field were used for the experiment in 2018 - 2019. The field was divided into 13 blocks within an area range from 750 – 5000 m². The study was divided into two parts: The test using Sambu Group laboratory and the field experiment.

2.2 Data and analysis

2.2.1 Soil and water acidic improvement. The study used four ameliorants, namely dolomite ($\text{CaMg}(\text{CO}_3)_2$), cement, ash, and BioPeat to improve soil and water pH in peatland. Dolomite contains Calcium (Ca) and Magnesium (Mg) contains alkali characteristics. Dolomite applications also increased mineral Ca and Mg for crop growth on water and soil. Cement ($\text{Ca}(\text{OH})_2$) is the second ameliorant since it is able to enhance pH of 12.5 at normal temperature. The third ameliorant is ash which derived from litter and wood burning. And the last is BioPeat that was made from mixing an inoculant and pineapple waste. BioPeat is a compost or organic fertilizer, “Bio” term derived from microbial inoculant of *Trichoderma* sp. fungi that improves “Peat” fertility. These four ameliorants are easily found in the district so the local farmers can easily replicate the method to grow on their own.

The laboratory experiment involved 100 mL peat water + 5 mg ameliorant (each for dolomite, cement, ash, and BioPeat). The chemical combination was used to identify the most suitable ameliorant to increase the peatland pH in soil and water. The pH was then measured after application.

2.2.2 Water management. Water management is the most crucial aspect that determines the crops survival on peat. Maintaining water both in the dry and wet season to sustain rice farming requires efficient irrigation. Irrigation in peatland means controlling the desirable water table. Rice farming needs a constant flooded rice to prevent weed development. The water table data was obtained from field measurement of 106 points in the surrounding area in 2018 and 2019; and acquired every two weeks.

2.2.3 Rice variety. Seven paddy varieties were used for the experiment in 9 plots. This research used 4 ameliorants to increase pH in water and soil of peatland. The dose for each ameliorant is 4 ton per ha and 8 ton per ha. Before the rice was planted, soil improvement was applied. The specific water treatment was set as follows: 2 weeks flooded, one week drained, with two-cycle (one-month preparation). Afterward, all varieties were planted the *jajar legowo* method with 6:1 (25 x 12.5 x 50) cm intervals. They were treated under the same irrigation system according to age – water height at germination phase is 3 cm, 0 – 30 days is 5 cm, 31 – 90 days is 10 cm with two days drainage every two weeks. Lastly, water height was drained again during 10 days before harvest. After the harvest season, the total productivity is recorded by considering the contributing factors to analyze the result.

3. Result

3.1 Soil and water acidic improvement

It should be noted that not all peat soil is suitable for cultivation. Some types in particular locations only support the fruit plantation, native species, or even unable to grow any crops. The soil suitability is determined by the level of maturity and thickness of the peat, the mineral soil beneath the peat layer, and water quality. It categorized the soil into three types: Land with most optimum condition (S1), land quality below optimum but can be improved (S2), and less suitable (S3). Outside these categories the lands are physically unsuitable (N) [23]. This research took place in S2 type of peat soil where it requires additional soil fertility improvement.

Soil fertility improvement in peatland is largely affected by the water management. The first step to improve soil fertility is by increasing pH. The peat water pH without treatment is only 3.5 - 4.8. The desirable pH for optimal agriculture is around 7. Adding the alkali substance will increase the pH. The result from the laboratory experiment indicated that the application of BioPeat increased the pH to 7.6. Higher pH were resulted from following ameliorants, dolomite 8.6, ash 9.3, and cement 11.9.

The experiment in the paddy field revealed different results compared from the laboratory. **Fig. 2** showed the water pH is higher than soil pH. The different result of pH level from lab and field was because on the field, the ameliorant spread into soil and water. There is a slight difference between the application of 8 ton and 4 ton/ha. The use of dolomite and cement is effective to increase the water and soil pH. If the soil improved, it would increase productivity. The experiment commensurate with research from Septiana et al. (2017) that highlighted the application of ameliorant could increase dry weight of rice grain [24]. Besides, ameliorant application should be combined with fertilizer. Practically, using fertilizer is common to boost soil fertility. The problem is peat soil has a higher porosity which requires 10% more fertilizer use. The cation exchange capacity (CEC) of peat soil in this study area is >40 me/100 gr with low base saturation, which drives lower nutrient content. In non-peat soil with higher pH and base saturation, the nutrient is high without additional application of ameliorant.

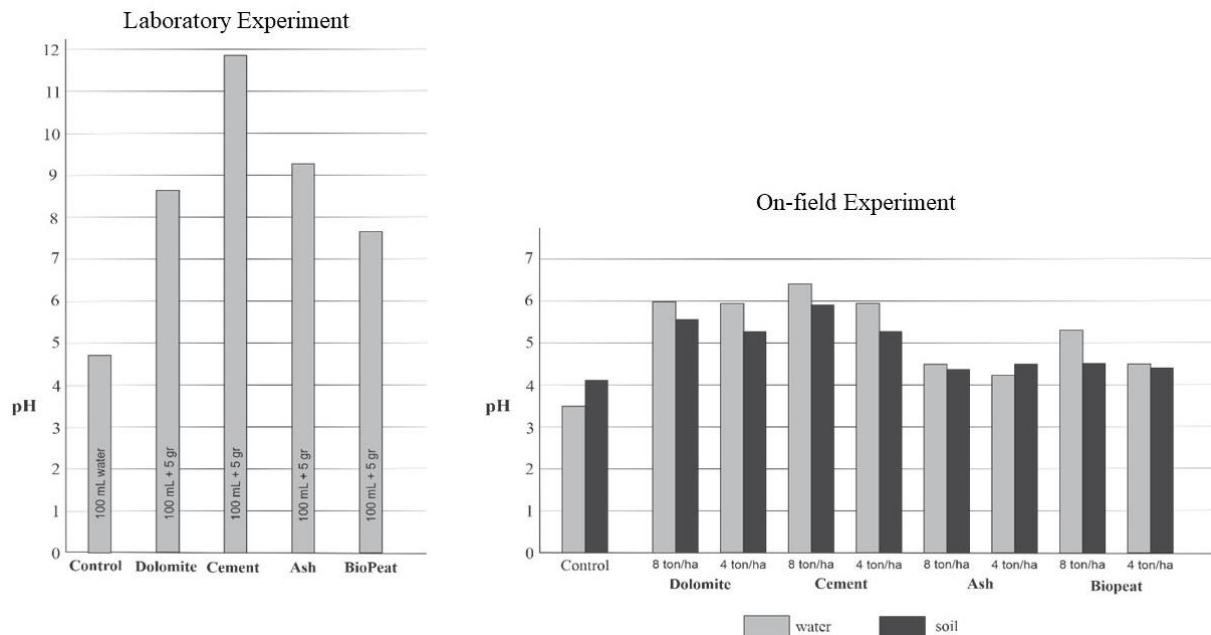


Fig. 2. pH increment comparison resulted from four different ameliorant

3.2 Water management

Rice is originally a wetland species although the upland types already developed and planted. Thus, water availability is a critical factor of rice production. Highest productivity occurred on alluvial plains with rich water supply from rivers or reservoirs. Hence, proper irrigation is crucial since rice farming needs all year water supply. Likewise, the high water level on peatland farming must be maintained. It is even more vital to prevent carbon loss from peat oxidation. Conventionally, the purpose of canal creation in peatland is to drain peat water and optimize the plant growth. This method must be changed to conserve the water in peatland. The canal network should be designed as a close system to store water, and to prevent water deficit and flood in any season. Introducing dams and water gates to this system is important to control water flows.

The plantation in Pulau Burung deploys the WMT that is able to maintain the water table at 40 – 70 cm depending on the season (**Fig. 3**). WMT is a close system to maintain and regulate water in peatland using three components: canal, dike, and dam with water gate. This system can conserve water for plantations and its surrounding areas, including rice farming production fields in all following years.

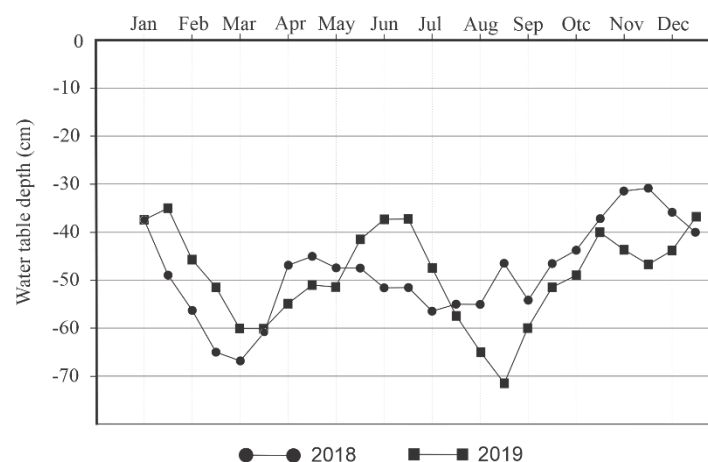


Fig. 3. Water table data year 2018-2019

Water management during the rice growth is the key element to enable the growth of the crops as well as minimizing the peat fire risk. Since the water is set to be over the land surface, it will reduce the CO₂ release, slow down the subsidence, and mitigate the forest fire. Maintaining peat to be constantly moisturized will prevent the irreversible peat soil characteristic that is severely drained and cannot hold water anymore.

3.3 Rice variety

The experiments result indicated that there is no strong correlation found between high dose of ameliorant (4 and 8 ton per ha) with productivity per hectare (**table 1**). Paddy varieties play a more important role to adapt with acidic condition and pest occurrence. The recorded pests during experiments were green planthopper (*Siphanta acuta*), white stemborer (*Scirpophaga innotata*), blast disease (*Pyricularia oryzae*), and bird (*Estrildidae familia*). Intense pest attacks made the productivity decrease up to 50%. Each variety has a different pest resistance level and productivity rate as shown in the following table.

Table 1. Comparison of rice varieties and average grain productivity rate

Variety	Plot	Ameliorant	Average Grain Productivity per Ha (kg)	Pest Occurrence	Harvest days
Pak Tiwi	7 A,13 B	dolomite 8 ton/ha	2.480,2	low	104
Mekongga	23 B	dolomite 4 ton/ha	4.771,9	low	114
Cilamaya Muncul	20 B	dolomite 4 ton/ha	3.394,1	medium	90
IR 64	5 A,12 B	dolomite 8 ton/ha	4.266,8	medium	101
Kalimasada	17 B	dolomite 8 ton/ha	2.142,9	high	121
Serai Wangi	19 B	dolomite 4 ton/ha	650,5	high	97
Pandan Wangi	19 B	dolomite 4 ton/ha	188,0	high	90

Table 1 indicates that Mekongga is the variety with highest productivity that reached 4,771.9 kg/ha, closest to its optimum yield of 6,000 kg/ha. This is because Mekongga is not only able to tolerate the acidic water and soil, but also resistant to brown planthopper (BPH, *Nilaparvata lugens*), bacterial leaf blight (BLB, *Xanthomonas oryzae*), and tungro (*Rice tungro bacilliform virus*). Compared to the average yield of national productivity of 4,600 ton/ha, the result is quite promising [25]. Under the same treatment with low occurrence of pests, Pak Tiwi variety earned only 2,480 kg/ha, although its average yield is 8,000 kg/ha in an optimum scenario. It managed to tolerate brown planthopper, bacterial leaf blight, and tungro, but it could not stand the acidic water even though the dolomite dose was 8 ton/ha. The second highest productivity rate was IR 64 with 4,266 kg/ha. IR 64 variety has proven can stand in acid condition (pH 5) with productivity 3.6 – 3.9 ton/ha [22]. This is supported by its resistance to blast disease and green planthopper, also medium resistant to stemborer. With the same occurrence of pests, the Cilamaya Muncul variety only produced 3,394 kg/ha.

Due to high occurrence of pests, Kalimasada generated the highest productivity only at 2,142 kg/ha, although it could produce 12,000 kg/ha on optimum yield. Kalimasada can tolerate low pH conditions, but is relatively weak to pests. Likewise, Serai Wangi and Pandan Wangi are vulnerable to brown planthopper, bacterial leaf blight, and tungro. The combination of poor adaptation toward acidic condition and pests made Serai Wangi and Pandan Wangi have productivity of only 650 kg and 188 kg/ha, respectively. Originally, the Pandan Wangi variety was designed for the paddy field at Cianjur, West Java. Thus, these are premium rice types that are not compatible with acidic conditions. Based on the experiment, it is concluded that IR 64 and Mekongga are the most suitable to peatland rice farming.

The experiment result implies that rice farming in peatland, although complex, is promising, and the productivity level is close to Indonesian average of 5-ton of rice grain per hectare. The main

obstacle that hampers productivity is pests as they constantly attack the crops regardless of the season. There are two options to address the pests: preventive and curative. During the experiments, prevention is conducted using pesticide or liquid smoke, while curation involves manual work to revoke the plant diseases. The one that causes the most harvest loss is bird pests since they cannot be controlled by pesticides. The lack of preparation in addressing birds has undermined the experiment process.

4. Discussion

4.1 High-cost investment: Limitation in preparing peatland farming

The peatland rice farming research revealed several obstacles to achieve the optimum yields. These include the low pH level which drove the large amount of ameliorant utilization. It also means additional expense in land preparation as indicated in the table below. But in the long term, when the soil has improved with a higher pH level, the amount of ameliorant use will be reduced. Gultom & Mardaleni [22] concluded dolomite as ameliorant with dose 2.5 – 4 ton/ha can bring optimum results. **Table 2** pointed out the cost of ameliorant for rice farming. With around 4-ton dose will add more IDR 4 million on land preparation.

Table 2. The cost of ameliorant application per hectare

Ameliorant	Cost of 8-ton Application per ha (in IDR)	Cost of 4-ton Application per ha (in IDR)
Dolomite	8,000,000	4,000,000
Cement	9,200,000	4,600,000
Ash	1,600,000	800,000
BioPeat	12,800,000	6,400,000

In intensive farming, the necessity for ameliorant will slowly decrease to 1 – 2 ton/ha over the years [26]. Meanwhile, this research was only using dolomite for ameliorant purpose. The combination of ash and dolomite can be applied for cheaper land preparation. If the cultivation were conducted in a more intensive and larger scale setting, it would reduce the ameliorant cost.

Other than ameliorant, the high cost of peatland agriculture also comes from the water management that requires canals, dikes, dams and water gates construction. For a region like Pulau Burung, it can manage to leverage the already existing WMT to enable the paddy to thrive. Oftentimes, it takes either large-scale private business or government intervention to build an advanced water management system that effectively maintains the water table and the soil condition. Since it requires large capital to make the production possible, this kind of farming activities are usually terminated after five years. Hence, it is difficult to measure the sustainability level as it needs a long-term observation to draw a scientific conclusion.

4.2 Sustainability of rice farming in peatland in the long run

Peatland agriculture offers both food production opportunities and challenges in managing the fragile ecosystem. The sustainability of rice farming in peatland is shaped from the combination of technologies, policies, and best practices to integrate and to balance the environmental and socio-economic principles. There are multiple parameters to be considered to support sustainable land management on rice farming. First, maintaining or enhancing rice production [1]. The experiment above indicated that varieties like Mekongga and IR 64 are resistant to acidic water and pests. In the long run, the findings could contribute to the food self-sufficiency in Indragiri Hilir regency as this region is dominated by peat. Other than planting rice, the activities also involved planting species that can sequester carbon and reduce carbon loss [19]. Crops like pineapple, corn, tubers, and horticulture are commonly cultivated in the area to enhance food diversification.

Second, contributing as alternatives for the decreasing croplands. In the past half-century, the world lost one-third of its arable land [27]. It is an alarming problem since the global demand for food is constantly increasing. The intensive modern farming methods modified from the green revolution have been producing larger and cheaper food. Yet, it also leads to excessive farming practice or over-farming. Hence, the alternative land utilization must ensure the cultivation activities will not exceed the area carrying capacity.

Third, protecting natural resources and preventing degradation on peat soil and water. The main environmental issue on peatland comes from carbon emission from land subsidence and fires [28]. The Indonesian government regulates peatland farming should be implemented on shallow peatland. The water table also must not be below 70 cm – if exceeded, it will exaggerate carbon emission from peat oxidation. Ideally, farmers should be trained to prevent fires and to grow more plants to sequester carbon for carbon neutral.

Fourth, providing economically efficient food production. Peatland farming requires higher cost and more complicated maintenance compared to one in arable lands. It is a more reasonable solution under some circumstances: when the arable regions are densely populated and the existing croplands are converted to non-agricultural purposes. Especially in a region that is largely covered by peatland, such as in Indragiri Hilir Regency, developing farming practice would build a more efficient rice supply chain, instead of sourcing the commodity from outside the area. Eventually, it can strengthen the local food security as well as improve the farmers livelihood.

Lastly, in terms of social aspect, the practice should benefit the local community. The cultivation process should involve the knowledge transfer among the farmers. It equipped them with skills in cultivating peatland, water management, and ways to prevent carbon emission. The research findings may become a reference to develop larger paddy fields in the area. In Pulau Burung, the district heavily relies on food supply from other regions since 90% of its land is covered by peat soil. The rice farming practice can help the community to produce their own staple food. Local rice will create a more efficient supply chain that leads to a more affordable price.

5. Conclusion

Under certain conditions, rice farming on peatland is a promising opportunity to strengthen food security. This study found that each rice variety brought a different productivity level depending on its adaptation to acidic situations and pests. Among others, Mekongga and IR 64 were proven to be able to generate the highest productivity with average grain yields of 4,771.9 kg/ha and 4,266.8 kg/ha, respectively. In general, to meet the sustainability parameters, peatland cultivation should deploy a comprehensive water management system, set up a proper water table, find effective and efficient ameliorants, and select the variety types that are suitable to peat characteristics. Finally, the practice must be ensured as economically and socially viable.

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