The environmentally friendly technology: A framework for the development of tidal swampland to promote food production in Indonesia

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Abstract. High yield and low methane emission are two goals in tidal swampland management systems. In tidal swampland, draining converts soil organic matter to be oxidized and release emission of CO$_2$ into the atmosphere. Organic matter has been used as a soil amendment to improve the properties of this soil. Methane is produced by anaerobic soil bacteria, methanogens, and methanotrophs, by utilizing organic matter from the soil and rice root exudates, and it is transported to the atmosphere through aerenchyma. In wetland soil, rice straw incorporation with and existing vegetation are a source of organic matter to improve soil fertility. However, management of organic matter with a traditional system called "Tajak, Puntal, Ampar" often increase methane (CH$_4$) emissions, one of the main sources of anthropogenic CH$_4$. A portion of organic matter decomposition in saturated soils yielding methane (CH$_4$) rather than CO$_2$. Methane is one of the main greenhouse gases and is known to be a major cause of global warming. We analyze each of the components of technology and its relation to lessons learned. The environmentally friendly technology in tidal swampland includes: water management, land preparation and land management, amelioration and fertilization, use of low-emission varieties, and intercropping. Implementation of this technology in swamps can reduce greenhouse gas emissions. This paper presents a framework for environmentally friendly farming in the wetland for food production, which includes (1) the characterization and problem of soil; and (2) environmentally friendly technology. Implementation of this technology in swamps can reduce GHG.

1. Introduction

The characteristic of tidal swampland is the presence of sulfidic material which contains lots of pyrites. The presence of pyrite in acid sulfate soils is a serious obstacle in the development of swamps for rice cultivation. Sulfidic material is mineral or organic soil material that contains easily oxidized sulfur compounds, has a pH of ≥3.5, and if incubated with a thickness of 1 cm at field capacity, aerobic and room temperature conditions for eight weeks, will experience a decrease in pH ≥0.5 unit and the decrease in pH reaches a value of ≤4.0 [1]. According to Purnomo et al. [2] that there are several problems found in tidal swampland in terms of soil fertility, namely: (1) Low soil pH and nutrient content, especially P, (2) high availability of Fe and Al nutrients and (3) Uncontrollable standing water. Pyrite is generally found in tidal swampland which is rich in sulfidic materials resulting from marine deposits.

Methane is the result of the methanogenesis process and root biomass is a source of carbon and energy for methanotrophic bacteria in the root zone. The results of the study Annisa and Maas [3], and Annisa and Nursyamsi [4] show that the quantity and quality of the available carbon source either from
organic matter is significantly influenced by the methane production fluxes. Application of the combination of 30% of composted straws and 30% composted rush weed and 40% composted cattle manure in lower methane emission than the combination of 50% of composted straws and 50% composted rush weed. Composting is the most common way to ripen organic matter and has been shown to reduce greenhouse gas emissions and increase rice yields. The results of the research of Setyanto et al. [5] show that rice cultivation in paddy fields with intermittent irrigation can reduce methane emissions by 46.5% compared to continuous inundation.

The efforts to mitigate CH$_4$ and CO$_2$ emissions from agricultural land have been carried out through several cultivation techniques such as water and organic matter management to reduce greenhouse gas emissions. Wihardjaka et al. [6] showed that providing rice straw compost in lowland rice land released emissions of $73.2 \pm 6.6$ kg CH$_4$ ha$^{-1}$ season$^{-1}$ lower than giving fresh rice straw of $93.5 \pm 4.0$ CH$_4$ ha$^{-1}$ season$^{-1}$. In addition, the addition of litter decomposition also affects CO$_2$ production at the soil surface. The results of the study Sampanpanish, (2012) in [7] that CO$_2$ emissions from paddy fields in Thailand with manure organic matter were 377.35 mg/m$^2$/day, lower than rice fields treated with chemical fertilizers, CO$_2$ emissions released were 534.11 mg/m$^2$/day.

This paper presents a framework for environmentally friendly farming in the wetland for food production, which includes (1) the characterization and problem of soil; and (2) environmentally friendly technology.

2. The characteristic and problem of soil in tidal swampland

Based on soil type (soil taxonomy), swamp soils can be included in a great group (1) alluvial marine soils (Sulfaquent, Sulfaquept Hydraulquent, Fluvaquent), (2) river alluvial soils (Endoaquent, Endoaquept), and (3) peat soil (Haplofibrist/hemist, Sulfofibrist/saprist, Sulfohemis/saprist) [8]. Decreasing pH results in an increase in Al levels. Nutrient deficiency in acid sulfate soils is generally caused by the low pH of the soil solution so that the environment becomes acidic. Since before independence, the Bugis people have devoted swamps in various places on the East coast of Sumatra and the South coast of Kalimantan with varying degrees of success. Although with low yields ranging from 0.8 to 1 ton ha$^{-1}$ of rice, with a cropping index of once a year, it is sufficient to meet family food needs and the area of land cleared is also limited, only reaching 1-2 km inland [9].

Organic matter contains organic acids which are able to chelate the toxic elements in the soil so that they are harmless to plants [10]. The binding of metals or ions in the soil solution is influenced by the presence of humic acid and fulvic acid. According to Bourbonniere and Creed [11], the decomposition of organic matter will produce humic and fulvic acids which can contribute to the negative charge of the soil and function as organic colloids. Based on the research of Indrayati and Jumberi [12], giving rice straw compost can suppress toxic elements in the rhizosphere of rice plants and increase rice yields.

3. History and framework development of tidal swampland

For hundreds of years, indigenous people living in swamp areas have utilized swamplands for agriculture. Banjar people use these two areas for nipah cultivation [14]. Since 1969-1972 swamp areas were opened with a target of 5.25 million ha supported by the transmigration program, namely the placement of residents from densely populated areas of Java, Nusa Tenggara, and Bali to sparsely populated areas on the islands of Kalimantan, Sumatra, Sulawesi, and Papua. Including swamps as the location of placement. The cleared swamp land is then printed into swampy fields by the government to be planted with superior varieties of rice which are shorter-lived and have higher productivity. Swamp rice cultivation technology which is commonly practiced by local people with local rice varieties that have a long life has gradually shifted. The introduction of superior varieties of rice cultivation technology opens opportunities for farming communities in swamplands to increase production through intensification such as the use of high yielding and relatively short-lived high yielding varieties, balanced fertilization, amelioration, tillage using tractors, spacing, seed maintenance, weed control, pests, and plant diseases.
The conceptual framework for the development of swampland in Indonesia is composed of four stages, which can be considered as steps to be followed for its application: (1) Characterization of land and problem of development, (2) Analysis of historical development and lessons learned, (3) Technology development, (4) Optimization of development [14].

4. Indigenous knowledge in tidal swampland
The indigenous tribes living along the flow of large rivers such as Barito, Kapuas, Kahayan (in Kalimantan), Musi, Batanghari, Indragiri, Rokan, Siak, and Kampar (in Sumatra) have shown their success in cultivating various food crops, horticulture, and plantations, however, in general, their utilization is still limited by using traditional methods (indigenous knowledge) with a narrow stretch scale. In simple terms, these local people dig channels called handil, tatah, or trenches protruding from the mouth of a large river so that water irrigate and drainage following the rhythm of the tide and nipe (Figure 1 and Figure 2). Soil and water conditions that depend on tides lead to a nursery system called taradak ampak, and tracer; land preparation system called tajak, puntal, balik, and ampar (tapulikampar). The “tajak-puntal-balik-hamparr” system is the preparation of land for the cultivation of rice plants in tidal swamplands in the South Kalimantan area. tajak), after that the weed pieces are left in the water for ± 15 days which is called the “planting period”. The conventional method of preparing the land is simple, safe but still inaccurate because it has an impact on greenhouse gas emissions, especially methane. Annisa and Mass [3] reported that the application of undecomposed organic matter in tidal swamplands increased the cumulative CH\textsubscript{4} and CO\textsubscript{2} fluxes to 41.05 μg CH\textsubscript{4}.g\textsuperscript{-1}/day\textsuperscript{-1} and 1273.5 μg CO\textsubscript{2}.g\textsuperscript{-1}/day.

5. Impact of rice cultivation on greenhouse gas emissions in tidal swamp land
All organic carbon that enters the soil is a source of greenhouse gas emissions. The amount of organic carbon stored in paddy soil is greater than dry land because the decomposition process takes place anaerobically due to inundation [15]. Liu et al. [16] reported that methane is produced by methanogenesis bacteria under anaerobic conditions, and the results of their research show high methane (CH\textsubscript{4}) emissions from irrigated rice fields. The addition of organic matter in the form of straw to paddy fields, especially those that still have a high C/N ratio, will increase methane emissions into the air [6]. The results of the study Song et al. [17] showed that CO\textsubscript{2} and CH\textsubscript{4} emissions in two types of inundated land in Sanjiang Plain, China, namely on continuously inundated swamps, the CO\textsubscript{2} emissions released were 548 mg.m\textsuperscript{-2}. day\textsuperscript{-1} lower than CO\textsubscript{2} emission from seasonally inundated swamps is 713 mg.m\textsuperscript{-2}.day\textsuperscript{-1}. Khosa et al. (2010) in [18] reported that the application of organic matter in paddy fields significantly increased methane emissions compared to controls with different methane emission percentages from various types of organic matter depending on the quality of organic matter, namely: wheat straw by 4.07%, fertilizer green by 2.06% and rice straw compost by 1.51%. The higher methane emissions released from wheat straw associated with lower organic matter quality are seen from the higher C: N
ratio of 120:1. Apart from methane released from lowland rice cultivation, carbon dioxide will also be released. Zou et al. [19] also reported that the pattern of CO$_2$ emissions at the beginning of high growth then decreased until the final period of rice growth because inundation would increase the CO$_2$ flux at the beginning then continued to decline. The same thing was also reported by Annisa and Nursyamsi [4] stated that the highest methane emissions were shown from intensive acid sulfate land, namely 30.40 kg ha$^{-1}$ season$^{-1}$ with 100% NPK fertilization treatment at the recommended dose.

6. Management of environmentally friendly on tidal swampland

Constraints on tidal land can be overcome by the application of qualified technology which consists of five main components and assembled into five land management systems called PANCA KELOLA Technology. In brief, the components are as follows: (1) Water management using a one-way flow pattern (one follow system) and conservation blocks (SISTAK) aims to improve the quality of water entering tertiary channels or paddy fields that can improve soil conditions so that increasing cropping index and productivity of swamps (Figure 2); (2) Land arrangement depending on the type of overflow A, B, C and D is directed to the paddy field and support systems. The objectives of land planning are to: reduce the risk of total failure in farming, increasing the diversity of farming through crop diversification, increasing farm income through crop diversification, maintaining soil fertility; (3) Balanced Fertilization and Amelioration. Fertilization using the Tool Tool Swamp Soil Test (PUTR), while the supplementary N fertilizers use Chart Leaf Color (BWD).

![Figure 2](image1.png)  
**Figure 2.** One flow direction water management system for tidal swampland [14].

![Figure 3](image2.png)  
**Figure 3.** The Land arrangement with tukungan in tidal swampland [14].
General recommendations for fertilization in swamps based on soil nutrient status; (4) New superior varieties with high yield potential. New high yielding rice varieties specific to swamps that are tolerant of Fe poisoning and acid sulfate are Inpara (inbred swamp rice), which is a variety of rice released for adaptation to land. There are several recommended varieties of swamp rice, namely Inpara 2,3,4,8 and 9; (5) Integrated Pest Management. Pest and disease control is carried out using IPM technology in an integrated manner through the use of resistant varieties, natural enemies, application of good cultivation techniques and environmental sanitation while the use of pesticides chemical is done as a last resort.

7. Conclusion
The production and productivity in tidal swampland can be increased by optimizing existing reclaimed and abandoned swamplands. Implementation of PANCA KELOLA Technology will further improve crops and friendly environmentally reduce greenhouse gas emission. Local wisdom is important for the development and management of swamplands. Water management and organic matter management are key to using the land sustainably, which includes keeping the potential acid sulfate soil inundated, removing excess surface water, providing fresh water for leaching and diluting acidity and composting. These technology efforts can increase crop production and productivity, as well as community welfare in tidal swampland.

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