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REVIEW

Freshwater swampland as food buffer during El Niño: Case study in South Kalimantan, Indonesia

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ABSTRACT

The freshwater swampland in Indonesia covers an area of 13.28 million hectares, with approximately 8.88 million hectares suitable for agriculture. However, only 1.55 million hectares are utilized for paddy field. These lands are predominantly found in several provinces such as South Kalimantan, Central Kalimantan, West Kalimantan, East Kalimantan, South Sumatra, Jambi, Riau, Lampung, and Papua. The impact of El Niño on Indonesian freshwater swampland has positive effects. During extreme El Niño climatic conditions in 2015, there was an expansion in the utilization of freshwater swamplands compared to normal climate conditions. In the region of South Kalimantan, the influence of El Niño led to an 11.06% increase in the rice planting area, which consequently resulted in an overall harvested area increase of 13.20% and a 12.49% rise in rice production compared to a normal year. In order to optimize the potential of freshwater swamplands as a food buffer during El Niño, it is imperative to intensify efforts by focusing on the improvement of water management infrastructure and the implementation of integrated crop management such as cultivating adaptive varieties, applying the *Legowo* planting system with ratios of 2:1 or 4:1, utilizing fertilization practices to meet crop requirements, adopting integrated pest management practices, and embracing mechanized harvest techniques.

Key words: El Niño, food buffer, freshwater swampland, *Oryza sativa*, rice.

INTRODUCTION

Freshwater swamplands (*lebak*) in Indonesia cover a total area of 13.28 million hectares (Chozin and Sumardi, 2019). These freshwater swamplands are primarily found in South Kalimantan, Central Kalimantan, West Kalimantan, East Kalimantan, South Sumatra, Jambi, Riau, Lampung, and Papua, (BBSDLP, 2015; Sulaiman et al., 2019). Among these areas, 8.88 million hectares are suitable for cultivating food crops and horticulture, but only 1.55 million hectares have been utilized for paddy field (Hairani and Anwar, 2022). This underutilization of freshwater swampland presents a vast potential for increasing and diversifying agricultural production, especially food crops (Chozin and Sumardi, 2019).

In South Kalimantan, the freshwater swampland area extends over 208893 ha, comprising shallow freshwater swampland (46918 ha), medium freshwater swampland (106076 ha), and deep freshwater swampland (55899 ha). Among these, a total of 76634 ha has already been utilized (Alwi and Tafakresnanto, 2017). The development of freshwater swampland in South Kalimantan traces back to 1930 when the implementation of a polder system commenced. Notably, the Alabio Polder in North

Hulu Sungai Regency, covering an area of 6000 ha, was among the early endeavors. However, due to insufficient water management infrastructure, only 3000 ha are presently utilized for paddy fields, leading to suboptimal yields (Anwar and Susilawati, 2017).

El Niño stands as a compelling illustration of the ever-changing dynamics within Earth’s atmospheric system, highlighting the intricate interplay between oceanic and atmospheric circulation patterns (Rosenzweig and Hillel, 2008). This global-scale phenomenon disrupts cloud formation and modifies precipitation patterns, leading to a notable decrease in rainfall and the onset of drought conditions in affected regions (Sulaiman et al., 2018). In certain parts of Indonesia, El Niño influences the duration of dry seasons or delays the arrival of the rainy season. One positive consequence of El Niño is the expansion of planting areas in freshwater swamplands, particularly in medium and deep freshwater swamplands that were previously utilized solely for fishing and raising swamp buffalo. The El Niño event in 2015, for instance, resulted in a 42% increase in paddy rice cultivation across four provinces with substantial freshwater swampland: South Kalimantan, South Sumatra, Lampung, and Riau. On a national scale, the impact of El Niño becomes evident through a decline in rice production, prompting the government to import rice to fulfill food supply requirements. In 2016, during the 2015 El Niño period, Indonesia’s rice imports reached 1.28 million tons (Julianto, 2016), consequently affecting global rice prices and agricultural products.

The successful rice harvest in South Kalimantan, for example rice ‘Mekongga’, exemplifies the potential for increasing rice production on freshwater swampland, with a productivity rate of 6.5 t ha^{-1} (Subagio et al., 2015). Considering that there is approximately 8.88 million hectares of suitable freshwater swampland for food crops and horticulture, a mere 40% increase in either planting area or planting intensity, coupled with a productivity rate of 6.5 t ha^{-1}, could result in an additional yield of 23.09 million tons of paddy. This highlights the crucial role that freshwater swamplands can play as a significant national food production buffer during El Niño periods when other agricultural ecosystems face constraints in crop cultivation (Naylor et al., 2001; Murayama et al., 2003). This paper presents a review of research on the potential of freshwater swampland as a food production buffer during El Niño events, with a focus on the region of South Kalimantan.

EL NIÑO PHENOMENON

The El Niño Southern Oscillation (ENSO) phenomenon comprises two oceanic phases: The warm phase known as El Niño and the cold phase referred to as La Niña. These phases are connected by variations in atmospheric pressure over the South Pacific, known as the Southern Oscillation (Shrestha and Kostaschuk, 2005). During an ENSO event, the surface temperature of the Pacific Ocean along the west coast of Ecuador and Peru experiences abnormal warming, leading to significant global repercussions.

The consequences of ENSO events are often characterized by flooding in coastal regions of Peru and Ecuador, while regions such as Indonesia, New Guinea, and Australia experience drought conditions (Cane, 2005). In Indonesia specifically, ENSO events primarily result in reduced rainfall and lowered sea levels (Supriatin and Martono, 2016). These conditions lead to an extended dry season accompanied by increased water evaporation, a shortened rainy season with heightened surface runoff, and ultimately a decline in both ground and surface water storage (Susilo et al., 2013).

Over the past few decades, there has been a notable increase in the frequency and intensity of El Niño and La Niña events, particularly in Indonesia. From 1990 to 2022 (32 yr), Indonesia experienced El Niño occurrences 10 times, including two strong El Niño events in 1997-1998 and 2015-2016 (Sarvina and Sari, 2017; Yuniasih et al., 2022; NOAA, 2023). According to National Oceanic and Atmospheric Administration (NOAA), the 2015 El Niño event began in February-March-April 2015 and concluded in March-April-May 2016 (Athoillah et al., 2017). In contrast, the La Niña events in 2020, 2021, and 2022 were classified as weak to moderate. During the years 2013, 2014, 2016, 2017, and 2018, Indonesia experienced normal weather conditions without significant El Niño or La Niña effects (Yuniasih et al., 2022). Figure 1 illustrates the climate conditions, specifically rainfall distribution and evapotranspiration, in South Kalimantan during normal (2013), La Niña (2010), and El Niño (2015) years. In these years, the annual rainfall recorded was 3006, 3326, and 1713 mm, respectively, providing a visual representation of the variations in precipitation associated with different climatic phases.

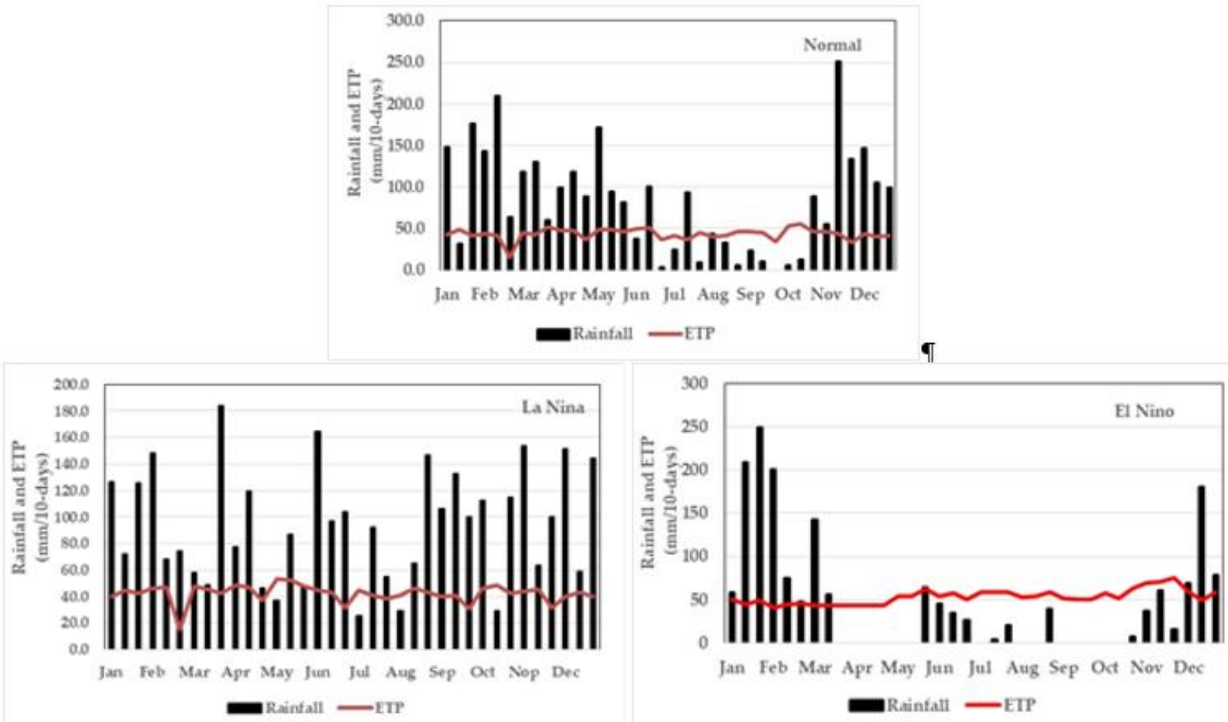

Figure 1. Distribution of rainfall and evapotranspiration (ETP) in the 10 d period during normal, La Niña, and El Niño years in North Hulu Sungai Regency, South Kalimantan.

The occurrence of El Niño, particularly from the first 10 d of April to the first 10 d of December, characterized by low rainfall ranging from 0 to 50 mm, can lead to dry conditions in the land. El Niño events have the potential to increase the planting area for rice cultivation in freshwater swamplands (Noor, 2007). When evapotranspiration exceeds rainfall, drought conditions can arise. The intensity of evapotranspiration is not primarily determined by the amount or intensity of rainfall, but rather influenced by the land cover. Factors such as rainfall, river tides, and runoff play a crucial role in determining the availability of water in a given region (Puspitahati et al., 2017).

LAND CHARACTERISTICS

Freshwater swamplands, found within the broader wetland ecosystem, are characterized as low-lying depressions with distinct hydrological dynamics that exhibit fluctuations in water levels between the wet and dry seasons (Tubtim and Hirsch, 2004; Mukhlis, 2013; Mitsch and Gosselink, 2015). These swamplands undergo periodic inundation during the wet season, which can last throughout the year or for duration sufficient to stress vegetation (Tiner, 2005; Mitsch and Gosselink, 2015). Conversely, in the dry season, the water levels gradually recede, triggering a shift from an aquatic environment to a predominantly terrestrial one. This transition exposes the soil and vegetation to varying degrees, as the once-submerged land becomes visible (Mitsch and Gosselink, 2015).

Freshwater swampland classification

Freshwater swamplands are typically located in lowland areas where natural drainage is hindered by river barriers. The classification of these swamplands is based on specific criteria such as vegetation, habitat, and various hydrological factors, including water quantity, depth, and duration of inundation (Subagyo, 2006). There are three distinct types of freshwater swamplands based on these criteria. The first type is shallow freshwater swampland, characterized by water depths ranging from 25 to 50 cm and a minimum inundation duration of 3 mo. The second type is medium freshwater swampland, with water depths ranging from 50 to 100 cm and an inundation duration of 3 to 6 mo. The third type is deep freshwater swampland, featuring water depths exceeding 100 cm and an inundation duration exceeding 6 mo (Subagyo, 2006; Alwi and Tafakresnanto, 2017). These classification distinctions help to differentiate and characterize the unique hydrological characteristics of different freshwater swampland ecosystems.

Soil type

Freshwater swamplands consist of two main types of soil: Mineral soil and peat soil (Mitsch and Gosselink, 2015; Vepraskas and Craft, 2016). Mineral soil is formed through the weathering of parent rock, either *in situ* or after being transported from another area. This process is influenced by climate and pedogenesis. In many cases, mineral soil contains a peat layer that is less than 20 cm thick. Peat soil, on the other hand, is created by the gradual accumulation of organic material over hundreds of years in anaerobic and waterlogged conditions. It typically has a composition of more than 65% organic matter and a thickness exceeding 50 cm (Page et al., 2011; Anda et al., 2021). Peat soil is most prevalent in the medium and deep freshwater swamplands and exhibits varying degrees of sapric and hemic decomposition. In freshwater swamplands, it is common to find peat layers interspersed with mineral soil layers (Mitsch and Gosselink, 2015). This heterogeneous composition contributes to the unique characteristics and diversity of the soil profiles found in these freshwater swamplands.

The mineral soils found in shallow freshwater swampland include Epiaquepts and Endoaquepts, as well as Fluvaquents. In medium freshwater swampland, there are Hydraquents, Endoaquents, and Endoaquepts. Conversely, deep freshwater swamplands are characterized by the presence of Hydraquents and Endoaquents. Peatlands, characterized by the dominance of peat accumulation, exhibit a range of soil types, including typic Haplofibrist, terric Haplofibrist, typic Haplohemists, terric Haplohemists, typic Haplosaprists, terric Haplosaprists, sulfic Haplohemists, and sulfic Haplosaprists (Soil Survey Staff, 1999; Subagyo, 2006). These soil types reflect the diverse chemical and physical properties associated with peat soils formed in different conditions. Overall, the soil composition within freshwater swamplands is influenced by mineral deposition and peat accumulation, resulting in a range of distinct soil types.

Water dynamic

The water level dynamics within the freshwater swampland exhibit variability based on local rainfall and upstream precipitation (Furukawa, 1994; Mitsch and Gosselink, 2015). In a typical year, the largest rice cultivation area is situated in the shallow freshwater swampland, primarily from May to October. However, during a dry year characterized by El Niño, rice cultivation can persist year-round due to the water level being below 40 cm. A similar pattern of rice cultivation can be observed in the medium freshwater swampland, but the duration is shorter, occurring from June to October. In a wet year, specifically from January to May, rice cultivation is not feasible in the shallow and medium freshwater swampland due to water inundation exceeding 50 cm. The deep freshwater swampland generally does not support year-round rice cultivation except during an extended dry season (Noor, 2007). Figure 2 provides a simulation illustrating the dynamics of water levels during El Niño dry years, normal years, and La Niña wet years for shallow freshwater swampland (a), medium freshwater swampland (b), and deep freshwater swampland (c).

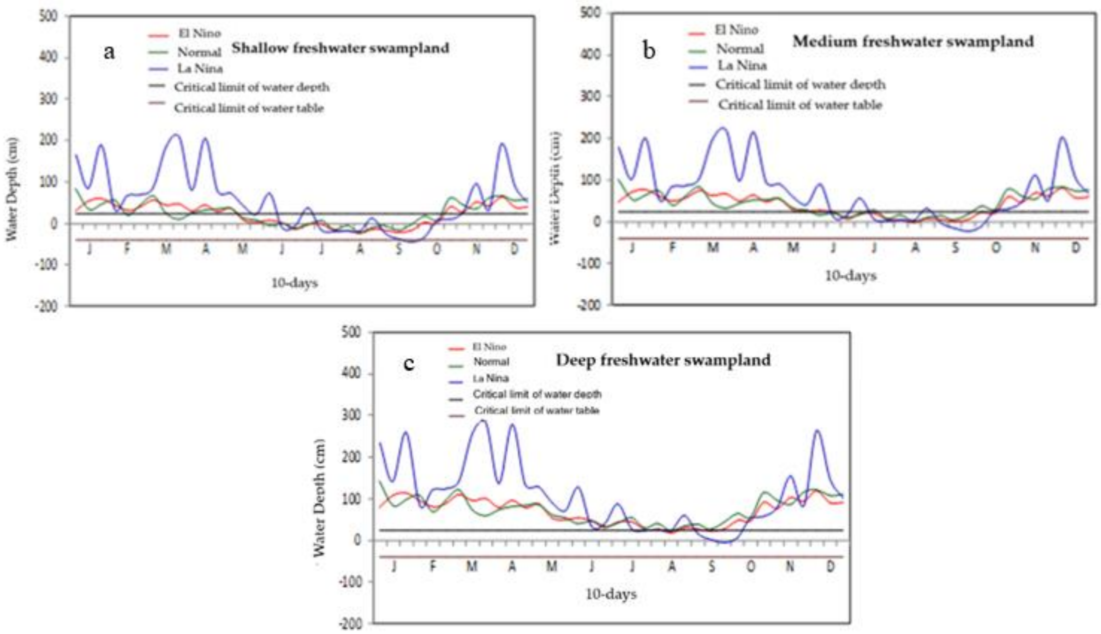

Figure 2. Simulation of the dynamic of water level during 2010-2011 in freshwater swampland at North Hulu Sungai Regency, South Kalimantan for shallow freshwater swampland (a), medium freshwater swampland (b), and deep freshwater swampland (c) (Wakhid et al., 2015).

RICE PRODUCTION DURING EL NIÑO

Rice farmers currently face a range of climate change uncertainties, including droughts, floods, changes in rainfall patterns, and outbreaks of pests and diseases, all of which pose a threat to their harvests (Sekaranom et al., 2021). To address these challenges, the government has provided financial support for sustainable agricultural development, encouraging innovation in the sector (Budiman et al., 2020). Climate change refers to the deviation of several climate elements from the average towards a certain direction, with indicators including rising temperatures, sea level, shifting rainfall patterns, and extreme weather events such as El Niño and La Niña (Wassmann et al., 2009; Boer et al., 2011; Surmaini and Faqih, 2016). In Indonesian freshwater swamplands, El Niño has positive impacts. During El Niño, there is an increase in the planting area in the medium and deep freshwater swampland. Figure 3 shows the impact of the 2015 El Niño, which resulted in a 48% increase in rice planting area in the medium freshwater swampland, from 16223 ha in normal years to 23958 ha, and a 294% increase in the deep freshwater swampland, from 1528 ha in normal years to 6024 ha. Under normal conditions, some of these areas are unsuitable for rice cultivation. The expansion of planting areas and planting index (PI) during El Niño has the potential to boost rice production. Conversely, during La Niña, the planting area in freshwater swampland has decreased (Haryono et al., 2013).

During the El Niño year (2012-2014), the impact of El Niño on the rice planting area with a planting index of 100 (PI 100) in South Kalimantan led to an increase from an average of 87667 ha in normal years to 94625 ha (7.94%). However, the rice planting area with a planting index of 200 (PI 200) decreased to 2710 ha during the El Niño year, compared to an average of 3109 ha in normal years (a decrease of 12.83%). As a result, the rice-unplanted areas reduced to 7190 ha during the El Niño year from 15300 ha in a normal year, representing a decrease of 53.01%. Overall, this led to a 13.20% increase in the harvested area and a 12.49% increase in rice production compared to a normal year (Figure 4).

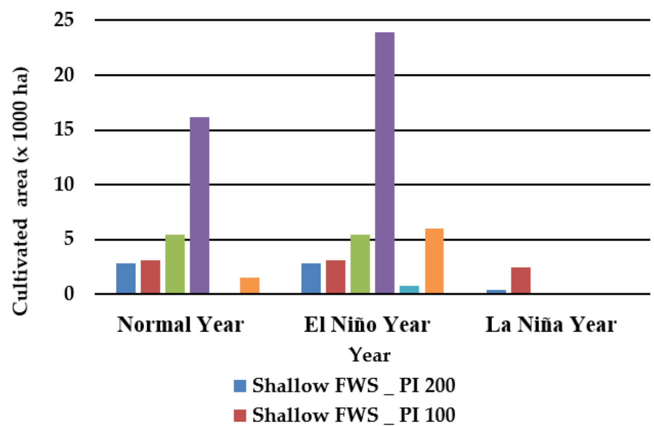

Figure 3. Impact of climate change to cultivated area and planting index (PI) of rice in Indonesian freshwater swampland (FWS) (Nursyamsi et al., 2014).

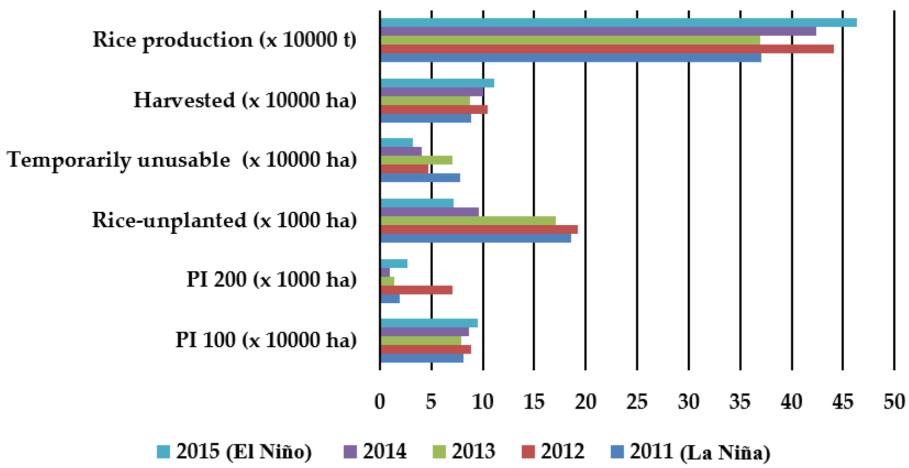

Figure 4. Impact of climate change on planting area, rice-unplanted, harvested, and rice production in freshwater swampland of South Kalimantan during 2011 to 2015. Source: Data were processed from BPS-Statistics of South Kalimantan Province (2012a; 2012b; 2013; 2014a; 2014b; 2015a; 2015b; 2016a; 2016b).

INTRODUCED TECHNOLOGY

To enhance rice productivity in freshwater swampland, there are two key approaches: Improving water management infrastructure and implementing integrated crop management practices. The improvement of water management infrastructure involves the construction of embankments, farm roads, canals, water gates, and water management networks within the polder or mini polder system. These infrastructure enhancements enable better control over water levels, drainage, and irrigation, providing favorable conditions for rice cultivation.

In addition to the polder system, farmers in freshwater swampland also utilize a simple yet effective water management technique known as terraced fields (Noor, 2007; Nursyamsi et al., 2014). Terraced fields are constructed along the channels with a distance of 50-100 m between each terrace. This system plays a crucial role in regulating water levels within the channels and agricultural lands. It serves multiple purposes such as facilitating the transportation of agricultural products, preserving groundwater, and maintaining soil moisture levels in the surrounding areas. The terraced fields not only enhance water management but also contribute to sustainable agriculture practices in freshwater swampland.

The arrangement of land in freshwater swampland should be carefully designed, taking into account the specific type of swampland and the composition of the soil, to optimize productivity and ensure sustainable agricultural practice. For shallow freshwater swampland, a sunken-bed system is suitable for rice fields, while raised-beds (known as *surjan*) are recommended for horticulture and secondary crops. Implementing the *surjan* system in rice farming has shown to enhance yields and increase farmers' income (Jumakir and Endrizal, 2017; Yulia, 2017). Medium freshwater swampland is best utilized for rice cultivation or supporting embankment systems, except in cases where the soil is peat. Deep freshwater swampland, due to its regular flooding, is typically left in its natural state. However, during the dry season, it can be utilized for growing food or horticultural crops. To determine the appropriate land arrangement approach for different types of freshwater swampland, refer to the guidelines provided in Table 1.

Table 1. Cropping pattern and land arrangement for agriculture in freshwater swampland (Nursyamsi et al., 2014).

Nr	Type of freshwater swampland	Cropping pattern	
		Sunken-bed	Raised-bed
1	Shallow freshwater swampland	Rice-rice Rice-rice-secondary food crops Rice-rice-horticulture crops Rice-secondary food crops Rice-horticulture crops	Secondary food crops-secondary food crops Secondary food crops-horticulture crops Horticulture crops-horticulture crops
2	Medium freshwater swampland	Rice-fallow-rice Rice-Secondary food crops Rice-horticulture crops	Secondary food crops-secondary food crops Secondary food crops-horticulture crops Horticulture crops-horticulture crops
3	Deep freshwater swampland (inundation duration < 3 mo)	Rice-fallow Secondary food crops-fallow Horticulture crops-fallow	- - -
	Deep freshwater swampland (inundation duration > 3 mo)	Secondary food crops/a short duration horticulture crops	-

Integrated crop management practices play a crucial role in optimizing rice cultivation in freshwater swamplands. These practices include utilizing adaptive varieties, implementing planting systems such as *Legowo* 2:1 or 4:1, applying fertilizers based on crop requirements, adopting integrated pest management strategies, and employing machinery for harvesting (Helmi, 2015; Gribaldi et al., 2016; Yulia, 2017; Hatta et al., 2018). Table 2 provides an overview of the introduced technologies for rice cultivation in freshwater swamplands.

In the region of South Kalimantan, farmers utilize the terms *sawah barat* and *sawah timur* to distinguish rice fields in freshwater swamplands that are cultivated during the rainy and dry seasons, respectively. These fields are planted with two distinct types of rice, known as *padi surung* and *padi rintak*. *Padi surung*, also referred to as deep water rice, demonstrates an exceptional ability to elongate its stem in response to rising floodwaters, allowing it to withstand lodging due to continuous root growth. Notable varieties of *padi surung*, including Nagara, Tapus, Alabio, as well as local varieties like Pandak, Bayar, and Siam Arjan, have a potential yield range of 2.0-2.5 t ha^{-1} (Saleh and Khairullah, 2022). Conversely, *padi rintak* is cultivated when water levels begin to recede during the dry season. Prominent *padi rintak* cultivars, such as Mekongga, Ciherang, Cisokan, Cisanggarung, and IR 42, exhibit potential yields exceeding 6 t ha^{-1} (Khairullah and Mawardi, 2021).

The *Legowo* planting system is a transplanting technique that involves alternating two or four rows of plants with empty alleys that run parallel to the plant rows. Within each row, the plants are spaced at half the distance between rows. This planting system enhances plant density, provides an ideal growing environment for optimum growth and development, and simplifies plant cultivation practices. The PATRA software is utilized to determine the appropriate dosages of ameliorants and NPK fertilizers for rice cultivation in swampland areas (Alwi and Fahmi, 2016). This specialized software is designed to calculate the precise fertilizer requirements customized to the specific needs of each location. One of the notable advantages of PATRA is its ability to provide location-specific fertilizer recommendations. These recommendations are formulated by considering factors such as the specific nutrient requirements of the plants, soil nutrient content, water management system, and the presence of *in situ* organic materials in the field.

Table 2. Introduced technology for rice cultivation in freshwater swampland (Rina et al., 2017). *Jajar legowo* is a planting system that alternates between two or more (usually two or four) rows of rice plants and one empty row.

Technology components	*Padi surung* (wet season)	*Padi rintak* (dry season)
Adaptive cultivars	Nagara, Tapus, Alabio, Pandak, Bayar, and Siam Arjan	Mekongga, Ciherang, IR 42, Inpari 13, Inpari 17, Inpari 20, Inpari 32
Seedbed preparation and seedling management	30 kg seed 150 m^{-2}, 1 kg rice husk ash m^{-2}, 5 g urea and KCl m^{-2} respectively. 10-15 d after sowing, seedlings are transferred to rice field until 25-30 d, then planted	Same as *padi surung* nursery, however the nursery will be prepared again if the water level is still high and the seedlings are old
Land preparation	Herbicide application and soil tillage by hand tractor	Manual weed control and without soil tillage
Planting system	Transplanting system with *jajar legowo* plant spacing 2:1, 4:1	Transplanting system with *jajar legowo* plant spacing 2:1, 4:1
Fertilization	NPK fertilizer and amelioration dosage used PATRA software	NPK fertilizer and amelioration dosage used PATRA software
Pest management	Control based on integrated pest management concept	Control based on integrated pest management concept
Harvest	Using sickle and thresher	Using combine harvester

CHALLENGE AND FUTURE DIRECTION

The vulnerability of the freshwater swampland ecosystem to floods and droughts, effective management and utilization strategies are crucial to ensure the sustainability of freshwater swampland ecosystem. To accomplish these objectives, a comprehensive and collaborative approach involving all sectors of society and intergovernmental cooperation is essential (Noor and Sosiawan, 2018).

Despite the availability of technological innovations for freshwater swampland farming from various research institutions (Nursyamsi et al., 2014; Cahyana et al., 2017; Koesrini and Saleh, 2017; Saleh and William, 2017; Nurita et al., 2017; Yulia, 2017; Wandansari and Pramita, 2019), their adoption has not met the expected levels due to several factors. These factors include the limited impact of technologies in increasing income, the lack of social, cultural, and environmental feasibility, and inadequate institutional management (Efendy and Hutapea, 2010; Rina and Subagio, 2017; Widuri et al., 2020; Kabir et al., 2022).

The model for accelerating the development of freshwater swampland agriculture is driven by innovation and comprises four interconnected subsystems. The first subsystem, land development, conservation, and regional infrastructure, aims to ensure environmental sustainability while improving transportation and accessibility of goods and services within the region. The second subsystem, cultivation development, focuses on integrated cultivation practices for rice, suitable commodities, and swamp buffaloes, following the principles of Low External Input Sustainable Agriculture (LEISA) and adopting zero waste practices. The third subsystem, the mechanization and post-harvest subsystem covering land preparation, planting, harvesting, and post-harvest processes, as well as and utilizing agricultural waste as livestock feed mechanization and post-harvest. The fourth subsystem, farmer institutional subsystem is designed to empower farmers engaged in rice farming, suitable commodities, and livestock, providing them with rapid and accurate access to information, technology, capital, and markets (Effendi et al., 2014). Together, these subsystems form a comprehensive framework that promotes sustainable and efficient freshwater swampland agriculture while supporting the socio-economic well-being of the farming community.

CONCLUSIONS

El Niño in Indonesian freshwater swampland has positive impacts, requiring a smart approach that optimizes production while maintaining sustainable economic, social, and ecological environments. The introduction of technology should be done through a participatory approach, taking into account the specific characteristics of each type of freshwater swampland and the diverse behavior of farmers. The occurrence of El Niño in South Kalimantan amplifies the planting area and planting index in the medium and deep freshwater swampland, leading to increased rice production and improved farmer incomes. This highlights the importance of harnessing the potential of climate patterns for agricultural development. The model for accelerating the development of freshwater swampland agriculture is driven by innovation and consists of four interconnected subsystems: Land development, cultivation development, mechanization and post-harvest, and farmer institutional. These subsystems work together to create a comprehensive framework that fosters progress, enhances efficiency, productivity, and sustainability in farming practices. The advanced agricultural innovations provide a foundation for the development of accelerated agricultural models in freshwater swampland. Assuming a rice productivity rate of 6.5 t ha^{-1} and a 40% increase in planting area in freshwater swampland, it would result in an additional yield of 23.09 million tons of rice. These innovative approaches can drive progress and enhance the efficiency, productivity and sustainability of farming practices in such regions.

Author contributions

Conceptualization: A.H., M.N., M.A. Methodology: Y.R., I.K., H.S., M.M. Data curation: A.H., M.N., M.A., Y.R., H.S., N.H, M.M., I.L. Writing-original draft: A.H., M.N., M.A., M.S., Y.R., I.K., H.S., N.H., M.M., I.L. Writing-review & editing: A.H., M.A., M.M., I.K. Visualization: H.S., N.H., I.L., M.S. All co-authors reviewed the final version and approved the manuscript before submission.

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