The potential of intercropping citrus and rice to improve the productivity of swamp land in Indonesia

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Abstract. Appropriate and integrated land management technology in utilizing swamp land with optimal and sustainable productivity is needed because the swamp ecosystem is naturally fragile. The development of intercropping rice and citrus on tidal land needs to be supported by the application of cultivation technology and institutional strengthening of farmers so that the results obtained can be optimum and sustainable. Common problems that arise in the use of tidal land for agriculture include a variety of overflow and inundation conditions, very diverse types of soil with varied and low fertility levels, soil acidity and high potential for pyrite toxicity, variety of peat thickness and maturity level, and the condition of farmers who are still weak both in terms of skills and capital. This paper discusses the intercropping potential of citrus and rice to increase the productivity of swamps in Indonesia, the environmental and technical constraints, and strategies in proper and integrated land management.

1. Introduction
The availability of dry land and rice fields in Indonesia for agricultural development declined significantly, among others, due to land conversion for non-agricultural purposes. On the other hand, the production of agricultural commodities needs to be increased to meet the increasing needs of the population. Swamp land in Indonesia reaches 34.1 million ha, consisting of 11 million ha of tidal land, 9.2 million ha of swampy wet land, and 14.9 million ha of peat land [1]. The key to the success of tidal farming in Indonesia is how farmers control water at the tertiary level for plant water supply [2]. Almost 91% of the total swamp land that has been cultivated for agriculture is cultivated for rice farming with a one-time cropping pattern of rice in a year. Thus, opportunities for intensification in swamp land are still possible. Appropriate and integrated land management technology in utilizing swamp land with optimal and sustainable productivity is needed because the swamp ecosystem is naturally fragile. Currently, citrus cultivation in swamp land is increasing along with the opening of tidal swamp land for agricultural purposes. Citrus and rice intercropping systems in swamps allow farmers to obtain optimal yields and to increase income. This is also an effort to achieve national food security. This paper discusses the intercropping potential of citrus and rice to increase the productivity of swamps in Indonesia, the environmental and technical constraints, and strategies in proper and integrated land management.

2. Current tidal swamp land condition
Indonesia has a land area of 189.1 million ha, of which 157.2 million ha are included in the suboptimal land category. Tidal swamp land is included in the suboptimal wetland group. It is always wet or
runny due to the influence of tidal overflows from the sea or river around it which takes place periodically. This land has an area of 11.0 million ha, with 3 of the largest areas being Papua, South Sumatra and East Kalimantan, respectively. Of the total 11.0 million ha of tidal swamp land, 9.3 million ha is included in the land that has the potential for agricultural development. The rest is suggested to be a conservation area with natural vegetation because the area is not suitable for agricultural development due to various limiting factors [1].

Tidal swamp land is a swamp area that is affected by the presence of spring tide and neap tide from the river or sea, both directly and indirectly. Based on the effect of tidal overflow, especially in the rainy season, tidal swamp areas are divided into 4 overflow types, namely overflow types A, B, C, and D. The overflow type A land is always overflowed with tide, both in the rainy season and in the dry season; land with overflow type B is only overflowed during rainy season; the overflow type C is not affected by tide but is influenced by the groundwater level with a depth of less than 50 cm; while overflow type D is like type C but the depth of groundwater is more than 50 cm [3]. Different technological inputs are needed to support the development of agriculture in this area, including the use of varieties that are resistant to inundation, salinity and acidity. In addition, drainage, water management, fertilizer management and pest and disease control are also needed. Various food crops (rice), secondary crops (soybeans, corn, peanuts and sweet potatoes), plantations (coconut, rubber and oil palm), and horticultural crops (mustard, eggplant, watermelon, citrus, and pineapples) have been successfully developed in tidal swamp land with regard to appropriate cultivation technology [4–6].

3. Potential development of intercropping citrus and rice in tidal swampland

Citrus production centres grow very dynamically on tidal land, such as in Sambas District (West Kalimantan), Barito Kuala and Banjar Districts (South Kalimantan), Kapuas District (Central Kalimantan) and North Mamuju District (West Sulawesi) [7–9]. Citrus on tidal land has planted either monoculture or intercropping with rice. Farmers plant Siam Banjar citrus in Barito Kuala District by intercropping with rice. Farmers who grow citrus and rice on tidal land with the sorjan system get higher income from citrus, while rice is planted to meet household consumption [9–12]. Farmers grow Siam citrus together with rice in raised beds in Kapuas District, Central Kalimantan. However, citrus production is still not optimum because farmers still have not applied good cultivation technology [8,13]. Citrus fruits grown on tidal swamp land, especially the overflow type A, have a higher ratio of total soluble solids: acidity than those planted in swamp land [9,14].

The importance of developing citrus in tidal land includes: potential tidal land that is suitable for citrus is widely available; longer exposure to sunlight and abundant water supplies can accelerate fruit growth and production; citrus has high economic value; citrus plants are carbon sink that helps reduce greenhouse gases in the tidal land environment. The development of citrus on tidal land needs to be supported by the application of cultivation technology and institutional strengthening of farmers so that the results obtained can be optimum and sustainable.

4. Citrus development issues in tidal swamp land

Utilization of tidal land for citrus-rice farming is a wise choice in supporting the Ministry of Agriculture program, namely Indonesia as the world food barn in 2045. This is because, in addition to maintaining rice production, it can also increase farmers’ income on tidal land. Compared to dry land, citrus cultivation in tidal land often experiences health problems. Common problems that arise in the use of tidal swamp land for agriculture include a variety of overflow and inundation conditions, very diverse types of soil with varied and low fertility levels, soil acidity and high potential for pyrite toxicity, variety of peat thickness and maturity level, and the condition of farmers who are still weak both in terms of skills and capital.

The use of tidal swamp land often faces barriers to ferrous iron and dihydrogen sulfide toxicity. Iron poisoning is caused by high concentrations of dissolved iron in the soil [5]. Another obstacle due to high acidity is the increased susceptibility of citrus plants to two soil-borne diseases, namely Diplodia stem rot (Botryodiplodia theobromae) and stem/root rot (Phytophthora sp). Diplodia disease...
threatens the damage and death of 63,431 ha of citrus land in the country [15]. Loss of yield due to Phytophthora in annual crops in Indonesia by 6-12% with an average loss of US $ 23,400,000 [16]. A complex of Diplodia stem rot and Phytophthora root rot disease is often found in the field, thus accelerating the death of citrus plants. The rapid development of the disease occurs due to the flow of irrigation, splashing of water, and type of host. If the problem is not overcome, it can lead to a shorter productive life of citrus plants, lower land productivity, and poor fruit quality. In addition, the results of surveys at citrus production centers in West Kalimantan, South Kalimantan, and West Sulawesi showed that most citrus plants at the age of 10 years had experienced health setbacks that led to death. The problem of the low productivity of citrus land on tidal land is not only due to low soil fertility, but also due to the application of inadequate cultivation technology and low plant population per hectare in the citrus-rice intercropping system (around 250 trees/ha).

5. Development strategy of citrus-rice intercropping in tidal swamp land

To realize food barns in swamps, during 2015-2019 the Indonesian Ministry of Agriculture has carried out land optimization for the expansion of planting areas, improvement of agricultural infrastructure, procurement of seeds and introduction of new superior varieties, procurement and optimization of the use of agricultural tools and machinery, the development of organic agriculture, and the development of farmer corporations [17]. Development of tidal swamp land for citrus-rice intercropping requires good planning and appropriate strategies because each region has a different character. The overall approach relating to the implementation of ideas, planning, and execution within a certain period of time must be appropriate so as not to damage the environment and provide maximum benefits to farmers. This is important to do so that farmers are encouraged to continue to strive further on the tidal land. Utilization of tidal swamp land for integrated farming is very possible by using integrated and sustainable technology. The strategy that needs to be carried out for the success of intercropping of citrus and rice in tidal land includes site selection based on land suitability, proper soil and water management, liming technology (amelioration) and balanced fertilization, selection of adaptive variety in swamps, use of disease-free seeds, the application of high density planting system for citrus plants, and also disease control.

5.1. Land suitability

Based on soil properties and constraints in agricultural development, swamp land is divided into four land typologies, namely: potential land, acid sulphate land, peat land, and saline land. Intercropping of citrus-rice cannot be done in all areas of tidal land because the character of the land needed by citrus plants to grow and produce optimally is not necessarily in accordance with the needs of rice plants, and vice versa. The maximum yield from intercropping the two commodities will be achieved if the farming is carried out on the land with character in accordance with the growing requirements of the two commodities. The ideal soil physical character for citrus plants is minimum solum of 100 cm and uniform, effective depth more than 75 cm, texture of sandy to sandy clay, good drainage and aeration, ground water level at a depth of about 100 cm, no pyrite layer to depth of 1500 cm, a small amount of crude material (rock) (<15%). Ideal soil biochemistry, namely soil pH of 5.5-6.5, cation exchange capacity more than 25 me/100 g, base saturation more than 50%, salinity more than 2 mmho/cm, and organic C content of 3-5%, while for the best peat soil is sapric.

Among the four swampland typologies, potential land is the main location suggested for the development of citrus-rice intercropping because of the lightest limiting factor (Table 1). The pyrite layer on this land is located at a depth of more than 100 cm so that with proper soil treatment, this land is quite safe for rice and citrus. The potential constraints on tidal land use for agriculture include moderate soil acidity (soil pH > 4.0-4.5) [3]. This obstacle can be overcome by the application of soil ameliorants [18–20]. On the other hand, although acid sulphate land is quite suitable for rice plants, careful intercropping of citrus and rice on this land needs to be especially concerned with the depth of the pyrite layer. The development of citrus and rice in acid sulphate fields that have a pyrite layer at a
depth of <100 cm is quite risky for citrus plants if proper land and water management is not carried out. Raising bed is carried out gradually so that pyrite oxidation does not occur [20].

In general, citrus plants can be cultivated on peat land [21,22]. However, intercropping citrus-rice can only be done in shallow peat (less than 100 cm thick peat) [23] because medium peat land (1-2 m thick peat) is less suitable for rice, while thick peat (2-3 m peat thickness) and very thick peat (more than 3 m peat thickness) are not suitable. Rice plants in thick and very thick peat cannot form grain due to the lack of micronutrients [24].

Table 1. Land suitability for citrus, rice, and intercropping citrus and rice in swamps [25,26]

| Land characteristic   | Citrus | Rice | Citrus – rice |
|-----------------------|--------|------|---------------|
| Water table           | 60 – 100 cm below the ground | vary | 60 cm below the ground: Citrus is grown on raised beds |
| Salinity              | < 2 mmho/cm | < 2 mmho/cm | < 2 mmho/cm |
| Soil acidity          | 5.5 – 6.5 | 5.5 – 8.0 | 5.5 – 6.5 |
| Depth of pyrite layer | > 100 cm | > 50 cm | > 100 cm: Citrus is grown on raised beds |
| Peat thickness        | < 100 cm | < 100 cm | < 100 cm |
| Peat types            | Sapric – hemic | Sapric – hemic | Sapric – hemic |

5.2. Land and water management

Inundation and pyrite layers on tidal swamp land are heavy restrictions for citrus plants if land management is not conducted properly. The most important aspect that must be considered in the tidal swamp land management is to keep the roots of the citrus plant away from the tidal inundation and the pyrite layer and its negative influence.

The best land management for citrus-rice farming on tidal swamp land is sorjan system, using raised bed and sunken bed to cultivate crops [27–29]. In this system, citrus is grown in the raised bed, while rice is planted in the sunken bed. The width of the sunken bed can be made around 10-15 m, while the effective width of the raised bed is recommended at around 2 m. Height of raised beds varies depending on the depth of the pyrite level and the tide. In principle, sorjan system must be able to prevent plants from overflowing water and keep pyrite to not disturb the roots. The ideal groundwater level is maintained at 60-100 cm below the ground. A water surface that is too shallow (<60 cm below the ground) disrupts root growth and has the potential to cause root rot.

Sorjan can be done directly on potential land because the position of the pyrite layer is quite deep. The production of sorjan in acid sulphate fields must be carried out in stages by forming raised beds. This has to be done carefully as to not open or transport pyrite layers. In addition to forming raised beds, the entry and exit of water on this land must be controlled. Water management in tidal land for citrus-rice farming aims to regulate water supplies according to the needs of both plants, prevent oxidation of pyrite so as not to increase soil acidity, purify toxic compounds, and prevent the danger of salinity and flooding. High salinity is not good for citrus plants because it limits growth and fruit production [30–32]. The irrigation system that has been tested well on tidal land is a controlled one-way flow system using flap-gate and stop log. The water management system that combines the one-way flow system and the conservation system provides an opportunity to improve yields and improve soil properties[6].

5.3. Use of adaptive varieties and disease-free seeds

The selection of rootstock and scion varieties will affect the adaptation of plants in tidal land which is known to be often flooded. Troyer and Carrizo citrange, as well as Poncirus trifoliata varieties, are resistance to Phytophthora sp. [33,34] so that it is a good choice for citrus in tidal swamp land.
However, these rootstocks are difficult to obtain in Indonesia, so Japansche Citroen (JC) and Rough Lemon (RL) varieties are mainly used to produce citrus seeds. JC and RL rootstocks support the most vigorous stem growth, while the Carrizzo citrange variety gives a dwarf effect on the upper stem [35].

In order to support citrus revitalization, Indonesian Citrus and Subtropical Fruits Research Institute has developed Technology for Disease-Free Citrus Seed Production, and currently has around 250 accessions of citrus. Siam citrus with various varieties is the main citrus developed on tidal swamp land on the islands of Borneo and Sulawesi. In addition to Siam citrus, Terigas mandarin is also suitable for tidal land because they are resistant to the excess water conditions that are the main character of this land [36]. Aside from being fruitful, the juice of this mandarin tastes sweet, the peel is easily peeled and the selling price reaches 2-3 times the price of Siam citrus. The survey results on type B tidal land in South Kalimantan showed that the size of Terigas mandarin could reach a diameter of 6-7 cm, which was greater than the average fruit produced on dry land (4-5 cm in diameter).

5.4. Control of Diplodia and Phytophthora disease
Selection of rootstock and application of environmentally friendly pesticide and fungicide are vital to control Diplodia and Phytophthora disease. The utilization of rootstock that is resistant to Phytophthora disease is suggested in tidal swamp land agriculture. Japansche Citroen, Rough Lemon, Cleopatra Mandarin, or Poncirus trifoliata are recommended varieties [37]. Clove extract and lemongrass as vegetable agents are able to control Phytophthora [38,39], while the recommended Diplodia disease control is the application of Trichoderma asperellum in the form of suspension or secondary metabolite formulas. It is proven to be best in controlling Diplodia disease in tidal land of South Kalimantan compared to California porridge (bubur California), diptheronazole or copper fungicide [40] with a decreased disease intensity from 12-30% at week 3 to 0% at week 7.

5.5. Balanced fertilization
The survey results of South Kalimantan and West Sulawesi showed that the quality of citrus fruits produced in tidal land was very diverse and dry fruits with very low content of juice, pale colour, and tasteless are often found. In addition to the influence of genetic and environmental factors, fruit quality is also related to soil chemical fertility. The production and quality of citrus fruits are only produced by citrus trees which are fulfilled by their nutritional needs. Therefore, tidal land which naturally is infertile needs to be supplied in a balanced manner to meet the needs of plants.

Fertilizers needed by citrus plants can be approached through soil and leaf analysis [41] and fertilization test results in the field. The approach of soil and leaf analysis is relatively less affordable for citrus farmers in tidal land so that ICSFRI developed fertilizer recommendations that are simple, practical, and effective, which is based on yields [42,43].

5.6. High-density planting system for citrus
The population of citrus in the intercropping system of citrus-rice is around 200 trees/ha, equivalent to the number of half-hectares of citrus plants in monoculture systems on dry land. citrus production in the intercropping system with rice on tidal land is 10 tons/ha [9], while monoculture citrus production on dry and wet land reaches 20-40 tons/ha. The right strategy to increase the productivity of citrus in intercropping with rice in tidal land is to increase the citrus population without reducing the land area for rice, known as the cultivation of high density planting systems (HDP).

The HDP citrus cultivation technology has been developed by ICSFRI since 2017 in the wetlands of Banyuwangi District [44,45]. The population of citrus developed in HDP system can reach four times the normal population with good fruit quality. This technology is suitable to be developed in tidal land because the shallow water table on this land causes natural dwarf plants as desired in the application of HDP system. High-yielding citrus cultivation has been applied in several citrus producing countries in the world such as United States of America, Pakistan, and Spain [46–49].
Table 2. Technology package for citrus and rice intercropping system in swampland

| No. | Strategy                              | Recommendation for integrated citrus-rice management |
|-----|---------------------------------------|------------------------------------------------------|
| 1.  | Land suitability                      | 1) Potential tidal land; 2) Acid sulphate land with proper land management; 3) Shallow peat land |
| 2.  | Land and water management             | Land: using raised bed and sunken bed (sorjan system), where citrus is planted in the raised bed and rice is planted in the sunken bed, also adding soil ameliorant to neutralize soil acidity. Water: combination of the one-way flow system and the conservation system |
| 3.  | Use of adaptive variety and disease-free seeds | Citrus Rootstock: Troyer, Carrizo, and Poncirus trifoliata varieties. Upper stem: Siam citrus (Citrus nobilis), Terigas mandarin (Citrus reticulata). Rice Superior and local variety that is adaptive to swampland. |
| 4.  | Control of Diplodia and Phytophthora disease | Utilization of rootstock that is resistant to Phytophthora disease: Jansche Citroen, Rough Lemon, Cleopatra mandarin, or Poncirus trifoliata. Disease control using vegetable agents is also recommended. |
| 5.  | Balanced fertilization                | Fertilizer requirements is approached through soil and leaf analysis, and based on yield in the previous year. |
| 6.  | High-density planting system for citrus | Adjustment of spacing and plant geometry to increase the number of citrus plants per unit area. |

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