Climate change mitigation through superior varieties use to increase rice production in tidal swamp land

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Abstract. The tidal swamp is sub-optimal land that can be utilized for agricultural development. The potential tidal swamp land as agricultural land reaches 3,445,184 ha, in which 2,802,169 ha is used for rice fields. The constraints faced in tidal swamp land development for agriculture are low soil fertility including high soil acidity, pyrite content, and high iron and aluminum solubility. It is also exacerbated by climate change that has affected the season which affects water conditions in the field. To overcome these problems, proper technology should be applied with adaptive superior varieties as one of the technology components to increase rice production. This paper aims to determine the superior varieties contribution in increasing rice production in tidal swamp land. The study used the review article method which original research and relevant experimental studies, as well as review articles, were critically read and analyzed for inclusion in this paper. The superior varieties have contributed to rice production increase due to their ability to adapt to climate change. Stress-tolerant and adaptive superior varieties may cope with high iron solubility and acidity of tidal swamp land. Moreover, it also has a shorter crop duration, resistance to certain pests and diseases, biotic and abiotic stress resistance, with higher and more stable production. Some of the superior varieties that adapted well in tidal swamp land are Mekongga, Ciherang, Inpari 10, 13, 22, 31, 32, 33 dan 42, Inpara 1, 3, 5, 7, and 9.

1. Introduction
Rice consumption will continue increase along with increase in population. Rice is the main staple food for most of Asian including Indonesian. In Asia, nearly 75% of the rice supply is derived from irrigated land [1]. The Indonesia population growth is predicted to be increased by 24% from 255.5 million in 2015 to 318.9 million in 2045, yet the population growth rate tends to decline from 1.07% (2015-2020) to 0.41% (2040-2045) [2]. This urged the government to import rice from other rice-producing countries to meet food needs. In 2019 itself, as much as 444,508.8 tons of rice has been imported whether to fulfilling rice demand or keeping the buffer stock [3]. Still, the government is targeting Indonesia as the world food barn by 2045, meaning to lessen rice imports and reach food sovereignty [4]. On the other hand, there were many challenges to achieve the target, such as decreasing productive agricultural land due to rapid conversion of land function [5] and climate change. Climate change is greatly affects crop production in tidal swamp land. During a long dry season, the groundwater level falls causes pyrite layer to undergo oxidation which makes Fe becomes soluble and poisoning the plant as well as turns soil into acidic soil. Several efforts are being done to increase rice production and climate change mitigation in order to fulfill rice demand through farm intensification and extensification. Farm extensification is being done through expansion of agricultural land for the farming area while intensification is being done through improvement of soil quality/fertility through fertilization and application of ameliorant, as
well as using stress-tolerant rice varieties. Various researches and studies have proved that the use of adaptive varieties may increase rice production in tidal swamp land [6].

Since most rice farming is conducted in irrigation land, land extensification is done through the utilization of potential sub-optimal land such as tidal swamp land. The tidal swamp land in Indonesia reaches 8.92 million hectares [7]. However, many constraints are faced in tidal swamp land development as agricultural land which are low soil fertility, the high solubility of iron and aluminum, high soil acidity, and pyrite content [8], [9]. The presence of the pyrite layer in tidal swamp land is crucially considered since improper land management will lead to fatal consequences. In very dry condition, pyrite will oxidize and dissolve iron which turns soil to very acidic. Thus, unlike any other land, iron poisoning is happening more in tidal swamp land than aluminum poisoning. High iron solubility will disrupt plant root growth and decrease plant production even causes plant dead in a very high iron solubility condition. This iron poisoning is worsened in poor nutrients soil. To overcome this problem, soil fertility improvement and use of iron-stress adaptive varieties are some of the efforts to be taken.

The iron solubility tolerant varieties have root ability to release OH ions which increase soil pH then Fe absorption can be minimized [10]. Hence, the extensification effort in sub-optimal land cannot stand alone. It only works by applying land intensification using proper technology too. The optimization of land resource management to increase production can be done by implementing Integrated Crop Management (ICM) including the application of balanced nutrient management, integrated pest management, water management, and organic fertilizer, as well as using new adaptive superior varieties as mentioned [11], [12].

The current swamp land contribution to national rice stock is around 4-5 million tons/year of unhulled rice, in which most of the swamp land applies a one-time cropping index (IP 100) with low production. The swamp land rice production will be improved by applying suitable technology. Several studies and research projects had been carried out in tidal swamp land such as P4S (Tidal Swamp Land Rice Field Development Project) in 1969-1980, LREP-I (Land Resource Evaluation and Planning Project) in 1986-1990, Nedeco/Euroconsult-Biec in 1982-1984, Swamps II in 1985-1994, ISOP (Integrated Swamp Development Project) in 1994-2000 and PSLPSS project (Development of Tidal Swamp Land Farming System in South Sumatra) in 1997-2000 [13], as well as many other studies and researches by universities. However, with climate change happening over time, the technology applied should also be developed. One of the recommended technology that should be developed is the use of superior varieties. Thus, this paper aims to provide an overview of the superior variety roles in increasing rice production in tidal swamp land particularly related to climate change mitigation. This paper will discuss the tidal swamp land potential and constraints, the factors affecting rice production, and the role of superior variety in increasing rice production. This paper used the review article method in which original research and relevant experimental studies as well as review articles, electronic databases, technical reports, and other relevant literature were critically read and analyzed for inclusion in this paper.

2. The potency, size and distribution of tidal swamp land

The tidal swamp land is characterized by its water system that is influenced by river tide. The tidal swamp land is divided into mineral land and peatland. From the total of 8.9 million hectares of tidal swamp land, 7.5 million hectares is dominated by mineral land while the rest of 1.4 million hectares is peatland (Table 1). The swamp land in Indonesia can be found in all of the six biggest islands. The largest tidal swamp land is located in Sumatra (3,019,354 ha) followed by Kalimantan (2,986,438 ha) and Papua (2,426,376 ha). Considering its high potency, the tidal swamp land utilization to increase national production is high too [13] since it spreads in most of all islands in Indonesia [14].

Furthermore, Ritung et al [15] stated that from the total 3,445,184 hectares of tidal swamp land that usable for agricultural land, 2,802,169 hectares are used for rice fields; 518,827 hectares for horticulture crops; and 124,188 hectares for plantations (Table 2). Most of the tidal swamp land is utilized for rice farming with Sumatra as the largest area (1,829,044 ha). However, only Sumatra, Kalimantan, and Papua Island can be utilized both for rice farming and other commodities (horticulture and/or annual crops). Considering its large area, many projects have been conducted there thus those three islands are indeed
more developed for swamp land optimization compare to any other islands so that Java, Sulawesi, Maluku Island is limited for rice farming only.

**Table 1.** Tidal swamp land size based on topographic position, climate and acidity.

| Island    | Mineral Land | Peatland | Total |
|-----------|--------------|----------|-------|
|           | WC DC Min.   | WC DC Min. |       |
|           | A NA A NA    | A NA A NA |       |
| Sumatra   | 2,495,471 6,417 - | 2,501,888 517,466 - | 517,466 3,019,354 |
| Java      | 13,835 80,921 - | 94,756 - - | - 94,756 |
| Kalimantan| 2,301,410 - - | 685,028 - - | 685,028 2,986,438 |
| Sulawesi  | 256,232 59,083 2,715 | 318,030 - - | - 318,030 |
| Maluku    | 33,155 41,240 - | 74,395 - - | - 74,395 |
| Papua     | 2,077,316 27,687 157,399 | 2,262,402 163,974 - | 163,974 2,426,376 |
| Indonesia | 7,177,419 215,348 160,114 | 7,552,881 1,366,468 - | 1,366,468 8,919,349 |

Description: WC= Wet climate, DC = Dry climate, A= Acid, NA = Non Acid. Source: [11].

**Table 2.** The potency of tidal swamp land (hectares) for food crops, horticulture, and annual crops.

| Island   | Mineral Rice | Peatland Rice | Total of Rice | Horticulture Peatland | Annual crops Peatland | Total |
|----------|--------------|---------------|--------------|-----------------------|-----------------------|-------|
| Sumatra  | 1,655,593 173,451 | 1,829,044 284,092 | 7,491 2,120,627 |
| Java     | 94,756 - | 94,756 - | - 94,756 |
| Kalimantan | 566,994 - | 566,994 234,735 | 99,808 901,537 |
| Sulawesi | 10,380 - | 10,380 - | - 705,340 |
| Maluku   | 11,552 - | 11,552 - | - 100,336 |
| Papua    | 286,277 3,166 | 289,443 - | 16,889 306,332 |
| Indonesia | 2,625,552 176,617 | 2,802,169 518,827 | 124,188 3,445,184 |

Source: [11].

Despite its large potency, several obstacles in utilizing tidal swamp land for agricultural land are still found including low soil fertility, presence of pyrite layers, variability threats and climate change, salinity, pests, and weeds [16], [17]. To overcome these problems, proper and efficient technology is needed. Assessment studies and researches carried out by the Indonesian Agency for Agricultural Research and Development, Universities, and any other stakeholders have developed many adaptive technologies to increase land productivity. The main keys to the success of tidal swamp land management are water management and the use of adaptive varieties [18], [19]. Tidal swamp land is suitable to be developed for agricultural land is accordance with the study by Riduan et al [20], the tidal swamp land reclamation unit in Berambai South Kalimantan shows that the level of land suitability in this site for rice is in S1 and S2 criteria. This land suitability is very much determined by the soil typology and overflow water typology.

3. **Factors affecting rice production**

Rice production is strongly affected by plant genetics, environment/climate, fertilizers and plant care. The highest production plant may achieve is only 80% of its potential production. This is due to climate influence since it is unmanipulated such as rainfall, humidity, and temperature [21]; and rainfall is the climate factor that affected production more than humidity and temperature [22]. A good environment may increase rice production. In unfavorable environmental condition, farmers tend to increase more farm production input to maintain their expected rice production. This indeed is undesirable for the farming system.

Soil nutrients are also essential to achieve high production and fertilization is an effort to increase plants’ nutrient needs. The use of superior varieties will obtain a high yield if followed by good
fertilization [23]. Tidal swamp land is known for its low soil fertility, thus fertilization is one of the keys to increasing production, aside from ameliorant application. Tidal swamp land farming has obstacles of soil acidity, as well as high iron and aluminum. Hence ameliorant application will be able to improve soil quality, reduce soil acidity, and reduce iron and aluminum solubility [24], [25]. However, the unbalanced nutrient application will decrease 40% of the plants’ potential yield [26]. The study of Masganti et al. [27] P fertilizer application combined with 60 kg P2O5 and 2 tons of organic fertilizer was able to yield 5.73 tons/ha rice which is 27% higher than the application of 30 kg P2O5 and 1 ton organic fertilizer. Another study by Ar-Riza and Saragih [28] also shown that application of N, P, K fertilizer in potential soil (90 kg N + 22.5 kg P2O5 + 25 kg K2O) and acid sulfate soil (135 kg N + 45 kg P2O5 + 37.5-50 kg K2O) combined with 2 tons of lime may increase rice yield by 42%. N fertilization was able to increase rice production from 37.3% to 63.2% [29]. Furthermore, a research study in two different tidal swamp land locations (South Sumatra and South Kalimantan) for 5 planting seasons shown superior varieties use was able to increase rice production up to 42% when compared to local varieties [30].

Plant maintenance is also important to increase rice production. Low plant maintenance is effects in high weed population, high plant pests and diseases attack. The high weed population causes nutrient competition between plants and weeds, as well as a favorable place for plant diseases hosting and pests nesting. The losses of bad plant maintenance including bad fertilization will lower rice production to 50% from the highest potential yield [26].

4. The role of superior varieties in increasing rice production

Superior variety is an important factor that affects production. Its role in increasing production is very significant [31]. The advantages of using superior varieties are shorter crop duration, certain pests and diseases resistance, biotic and abiotic stresses resistance, higher and more stable production [32]. Nationally, the use of superior varieties was able to increase rice productivity by 56% [33]. During the 2000-2020 period, the IAARD had released 117 high-yielding rice varieties, consisting of 68 lowland rice varieties, 11 swamp rice varieties, 15 upland rice varieties, and 21 hybrid rice varieties [34]. In tidal swamp land with high iron and aluminum solubility and high acidity, the adaptive superior varieties of immersion stress, iron solubility, and other environmental stress can be used. Moreover, the pyrite layer content in tidal swamp land is strongly affected by climate variability. A long period of dry season will not only cause drought but also a more complex problem since groundwater levels will be stored far from the pyrite layer surface. This condition will conduce iron bond release to a dissolved iron.

Moreover, the water overflow type and land typology must be considered in selecting rice varieties in order to reduce plants’ stress levels. The Inpari 32, 33, and 42 rice varieties yielded more than 6 tons/ha unhulled rice in various types of overflow [35], while Inpari 10 and 13 planted using broadcast seeding system in the type A overflow yielded 8.35 tons/ha and 8.19 tons/ha respectively [36]. In a high-stress condition, some of the local rice varieties may have a higher yield than superior varieties using traditional cultivation; however, it also has disadvantages of longer crop duration compare to superior varieties. Research study by Dirgasari et al [37] shows several varieties resistant to Fe2+ stress were IR 64, Inpara 3, Awan Kuning Mekongga, Ciherang, Inpara 9, Cilamaya Muncul, Mashuri, Tuwoti and Siam Unus. Inpara 1 and 7, Pokalili and Siak Raya were categorized as moderate resistance to Fe2+ stress. The selection of varieties to cope with environmental stress is crucial, yet the effort of soil improvements such as fertilizer and ameliorant application should also be maintained [38]. Moreover, aside from increasing soil fertility, fertilizer may also boost plant resistance to pests and diseases [39]. The Inpara 5 planted in high acidity tidal swamp land was able to produce 5 tons/ha with ameliorant (lime) and P fertilizer application [40].

The rice varieties that resistant to certain pests and diseases are as follow: Inpara 3, Mekongga, and Ciherang are resistant to blight disease [41]; Inpara 30 and Cibogo are mild resistant to leaf blight [42]; Inpari 13, 31, and 33 are resistant to brown planthopper [43]; and Inpari 22 resistant to blast disease [44]. Integrated pest management, planting time schedule, and plant spacing also need to be done to
decrease pests and diseases. However, one continuous planted variety use is not suggested since several pests and diseases may have adaptation ability and form biotypes/strains [43], [45]. The superior variety have been proven to increase production, yet its development is still limited.

Some of the obstacles in superior variety development are the seed availability in the right number and timely manner, the level of grain loss, price competition by traders, need of farmers’ adoption level improvement, rice taste, and grain form. To make end meets of superior varieties seeds, it is necessary to grow and strengthen the breeder institution at the regional level. Moreover, socialization and assistance regarding the superiority of particular varieties are needed to be done to increase the adoption level.

5. Conclusion
Rice demand is continually increasing while productive agricultural land is decreasing thus land extensification to sub-optimal land such as tidal swamp become an option. However, many constraints are faced in tidal swamp land including low soil fertility, high solubility of iron and aluminum, high soil acidity, and pyrite content. Not to mention climate change happening has been increased environmental stress condition in tidal swamp land. Aside from soil and water management, superior varieties use has significant contribution in dealing with those condition. Stress-tolerant and adaptive superior varieties may cope with high iron solubility and acidity of tidal swamp land. Moreover it also has shorter crop duration, resistance to certain pests and diseases, biotic and abiotic stresses resistant, higher and more stable production thus gives more opportunities to increase rice production in tidal swamp land. Still, soil characteristics, tidal swamp land type and condition as well as pests and diseases resistance due to climate variability should also be considered in selecting superior varieties used.

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