Water management on peatland for food crop and horticulture production: research review in Kalimantan

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Abstract. Water management is the most important component in developing peatlands for agriculture. Utilization of peatlands for food crops and research on its physical, chemical and biological characteristics have been carried out previously since a long time. However, the implementation of peatland management technology is not much well known. Peatland agricultural commodities are developing. In 1970-1990, mostly for food crops and horticulture. Since 2000 plantation crops had been developed rapidly. About 0.5-0.8 million ha of peatlands are planted by food crops, including horticulture and 2.5-3.0 million ha for oil palm. The use of peatlands is still being debated along with threats to the environment, especially greenhouse gas (CO₂) emissions. The use of peatlands for agriculture by local communities aimed at sustaining life and has an interesting long history. Farmers who live in peatlands have special abilities and expertise in peatland management. Based on this experience and local wisdom, the government then planned to open peatlands, especially in supporting transmigration programs from Java, Nusa Tenggara, and Bali. However, the use of peatlands for agriculture has changed the fertility of peatlands and reported to be a trigger for land degradation so that improvement efforts are needed. The government has also issued several policies in improving the management and conservation of peatlands. This paper is a review of the results of research and experience on water management on peatlands for food crop and horticulture production.

Keywords: Water management, technology, food crops and horticulture, peatlands

1. Introduction

Peatlands have long been used for various agricultural activities including food crops, horticulture, and plantations. The results of the analysis of the potential of peatlands for agriculture showed that 9-10 million ha of a total area of 14.95 million ha were categorized as suitable for agricultural development. However, only about 2.5-3.0 million ha have been used or planted [1, 2]. Since 1970-1990 peatlands were developed for food crops and horticulture [3, 4]. It was estimated that about 511 thousand ha are intensively cultivated for food crops, 355 thousand ha in the form of rice fields [5]. However, since 2000 its use has been widely developed for plantation crops with commercial or agribusiness purposes, such as oil palm and rubber [6]. About 1.91 million ha of peatlands were used for plantations including 0.41 million ha for rubber, and 1.50 million ha for oil palm [7, 8].
The use of peatlands has been debated along with the threat of environmental impacts, including increasing greenhouse gas (CO₂) emissions and peatland degradation. About 4-6 million ha of peatlands have been declared degraded [9]. It is feared that this degradation of peatlands will increase in the future due to the emergence of symptoms of "land hunger" due to the increasing of population and the need for food production and other agricultural products.

In the future agricultural development plans, Indonesia has set the nine priority programs (Nawacita) to become the World Food Barn in 2045 [10, 11]. With the decreasing availability of fertile land, peatlands will become one of the prospective alternatives in supporting Nawacita by utilizing modern technological innovations from the results of research and development.

Utilization of peatlands for agriculture by local communities has been done since a long time and proven the potential and opportunities of peatlands as potential production land. The capacity and ability of farmers in dealing with peatland constraints is an interesting experience, especially in the cultivation of food crops (rice, soybeans, corn) and horticulture. Based on experience, local wisdom and the success of this community, the government cleared up peatlands for wider agricultural development for the community, including transmigrants from Java, Nusa Tenggara, and Bali. From the introduction of technology for the cultivation of food crops, horticulture, and plantations by the transmigration community, the development of horticultural crops was developing rapidly in peatlands such as celery, mustard greens, chives; tuber vegetables like uwi (Dioscorea alata), taro, sweet potato; to vegetable grains such as string beans, chili peppers, and fruit such as tomatoes, eggplant, and cucumbers.

However, the use of peatlands for food agriculture has greatly influenced and changed its soil fertility. It was reported that most of the peatlands that have been used for agriculture have experienced land degradation, so improvements are needed, among others, by applying ameliorant material, organic fertilizer, and bio-fertilizer to return to productive land that produces profits for farmers [12]. The government has also issued several policies in improving the management and conservation of peatlands including Government Regulation (Peraturan Pemerintah (PP)) Number 71/2014 junto PP No. 57/20016 concerning Management and Protection of Peat Ecosystems; Presidential Instruction (Inpres) Number 8/2015 revised by Inpres Number 11/2017 concerning the postpone of granting new permits and improving governance of primary natural forests and peatlands; and Regulation of The Minister of Agriculture (Permentan) Number 14/2019 concerning the cultivation of oil palm heads on peatlands for oil palm plantations. However, these policies are still being debated in general public and academics [12].

Apart from these policies, water management as one of the key successes in producing agricultural products as well as peatland conservation efforts will be described in this paper. The following description also states the potential and distribution area of peatlands in Kalimantan; use and opportunities for the introduction of water management technology in increasing crop production, including horticulture on peatlands.

2. Distribution of peatland in Kalimantan

According to the survey and mapping results of Indonesian Center for Agricultural Land Resources Research and Development (ICALRRD), the area of peatlands in Kalimantan (part of Indonesia) covers 4.78 million ha. While the area of Kalimantan (the part of Indonesia) is 540,000 km² (54,000,000 ha) so that which includes peatland, areas reaches 16% [1, 13]. Outside Indonesia, on the island of Kalimantan, namely the Sarawak region, Malaysia, and Brunei Darussalam, peatlands were also found, each 1.66 million ha and 1.65 million ha [14, 15]. Peatlands in Kalimantan are spread along the south and west coast. From the 1980s survey, the area of peatlands in Kalimantan was estimated to be 9.3 million ha [16] continued to decline and there were 4.78 million ha remaining [13].

In Kalimantan (the Indonesian part), peatlands are most widely distributed in Central Kalimantan following West Kalimantan, South Kalimantan, and East Kalimantan, each with an area of 2.66 million ha; 1.68 million ha; 106 thousand ha; and 332 thousand ha (note: North Kalimantan is still in the region of Central and East Kalimantan). Based on its thickness, peatlands in Indonesian part of
Kalimantan consist of shallow peat covering 1.05 million ha, medium peat 1.39 million ha, deep peat within 1.07 million ha and very deep peat 1.27 million ha [13].

Within ten years the subsidence of peatlands in Kalimantan reached almost 50% from 9.30 million ha in 1980 to 5.77 million ha in 1990 and continues to subside to 17.17% compared to 2011 which was 4.78 million ha (Table 1). In the last two decades (1990-2011) the largest subsidence occurred in peatlands in South Kalimantan by 68% followed by East Kalimantan 52% (Table 1). Some of the peatlands above degraded covering 2.77 million ha (Table 2).

| Province          | Peatlands 1980-2011 (ha) | 1980   | 1990   | 2011   | Subsidence 1990 - 2011 (ha) | (%)    |
|-------------------|--------------------------|--------|--------|--------|------------------------------|--------|
| West Kalimantan   | 4,610,000                | 1,729,980 | 1,680,135 | 49,845 | 2.88                         |
| Central Kalimantan| 2,162,000                | 3,010,040 | 2,659,234 | 350,806 | 11.65                        |
| South Kalimantan  | 1,484,000                | 331,629  | 106,271 | 225,358 | 67.95                        |
| East Kalimantan   | 1,053,000                | 696,997  | 332,365 | 364,632 | 52.31                        |
| Total             | 9,309,000                | 5,768,646 | 4,778,004 | 990,642 | 17.17                        |

Source: [9, 13, 16].

Table 1: Distribution of peatlands on Kalimantan in 1980-2011

Figure 1: Distribution of peatlands on the island of Kalimantan.
y season is saturated or sometimes flooded. It was influenced by many factors including water conditions, soil physical and chemical characteristics, rice varieties, and crop cultivation systems, including pest control and plant diseases. Potential land showed slight

### Table 2: Distribution and utilization of degraded peatlands

| Classification of degradation      | Kalimantan | Sumatera | Papua | Total   |
|-----------------------------------|------------|----------|-------|---------|
| Forest (not degraded):            | 2,780,694  | 2,283,657| 3,611,150| 8,675,501|
| Degraded peatlands               |            |          |       |         |
| 1. Plantation                     | 288,042    | 1,252,565| 3,823  | 1,544,430|
| 2. Food crops                     | 257,121    | 427,998  | 23,636 | 708,755  |
| 3. Shrubs                         |            |          |       |         |
| a. Peat thickness >3 m            | 667,934    | 364,871  | 0     | 1,032,805|
| b. Peat thickness 2-3 m           | 279,966    | 434,697  | 309,818| 1,024,481|
| c. Peat thickness <2 m            | 362,922    | 1,230,924| 86,894 | 1,680,740|
| 4. Post-mining                    | 153,344    | 491,825  | 12,820 | 657,989  |
| Total                             | 4,790,024  | 6,486,537| 4,048,138| 15,324,701|

Source: [7, 8].

### 3. Utilization of peatland for food crop and horticulture

The first planned utilization of peatlands for agriculture was carried out in concurrently with the Tidal Swamp Reclaiming Project in 1969-1985 by the Indonesian government with the main objective of increasing the production of food crops, especially rice.

Until the 1970s Indonesia was still known as a major rice importer on the international market. In 1977 Indonesia imported rice up to 2 million tons or one third of the rice offered on the world market [18]. Efforts to increase production especially rice reached a peak with the achievement of food self-sufficiency in 1986 where President Soeharto was invited to receive it at Rome by the FAO. But after entering 1990 Indonesia returned to be a rice importer country again. Thereafter, the government expanded the utilization of peatlands through the Mega Rice Project in Central Kalimantan in the 1995-1999.

#### 3.1. Utilization of peatlands for food crops

Generally utilization of peatlands by farmers for rice cultivation are on type B, *i.e.* peat tidal swampland that is flooded with spring tide or type C, *i.e.* land that is not affected by tides, but it has shallow ground water level (<50 cm), when the rainy season is saturated or sometimes flooded. It is very rare that peatland is on type A. In managing water to enter water from rivers or secondary canal during high tide, a small canal perpendicular to the river is made (locally called *handil*) which is commonly called a tertiary canal. This canal also acts as a drainage canal at low tide to remove water from the plot or tertiary into the river/secondary canal. This water management system called a two-ways flow system.

According to [14] who cited Andriese (1988), [19, 20, 21] showed that characteristics of peatlands which suitable for food crops include (1) having thickness <1 m, (2) depth of pyrite layer >100 cm without substratum quartz sand layer, (3) hemic to sapric decomposition level, (4) moderate to high nutrient status, (5) moderate to low acidity potential and low Al toxicity and (6) smooth water circulation resulting in routine dilution and flushing. From the research results of [22] in the Sakalagun peatland, South Kalimantan; [3] on the Karang Agung peatland, South Sumatra, and [23] in the thick peatland of Kiambang Bay, Riau with the optimum fertilizer and amelioration technology package, yield of rice was 4.05-4.50 t ha\(^{-1}\); 4.50-4.80 t ha\(^{-1}\); and 4.8-5.5 t ha\(^{-1}\), respectively [18].

Lower rice yield (3.53 t ha\(^{-1}\)) reported by [24] from peatlands in Kanamit Jaya Village, Pangkoh, Pulang Pisau Regency, Central Kalimantan, which had been reclaimed since the 1980s by applying 100 kg of urea, 75 kg SP36 and 100 kg KCl. Rice yields on tidal swamps are influenced by many factors including water conditions, soil physical and chemical characteristics, rice varieties, and crop cultivation systems, including pest control and plant diseases. Potential land showed slight
constraints and higher yields of 4.0-5.0 t ha\(^{-1}\) compared to peatlands and acid sulphate (without acidity improvement) with yields of 1.0 to 3.0 t ha\(^{-1}\) [25].

Whereas from several varieties such as Inpara (\textit{Inbrida padi rawa}) 2, 3, and 4 which are widely planted by swamps farmers in Kalimantan have a potential yield of 5.6-7.6 t ha\(^{-1}\) [26]. In other words, increasing rice yields on peatlands has the opportunity through the selection of adaptive and high yield varieties, improving cultivation technology and appropriate land management, including water management.

![Figure 2: Rice performance on peatland at experimental site of Pangkoh, Pulang Pisau Regency, Central Kalimantan, August 2010 (Photos by M Noor and A Hairani/Balittra).](image)

On peatland, farmer income is inadequate if it only relies on rice commodity due to low yield of rice farming. It could be increased through rice diversification with secondary crops and/or horticulture (table 3) or by fisheries or livestock businesses such as poultry.

| Commodity                  | Cost (Rp ha\(^{-1}\)) | Revenue (Rp ha\(^{-1}\)) | Profit (Rp ha\(^{-1}\)) | R/C ratio |
|---------------------------|-----------------------|--------------------------|-------------------------|-----------|
| Local rice                | 856,000               | 2,910,000                | 2,054,000               | 3.40      |
| Orange fruit (sunken-bed) | 1,162,000             | 10,070,000               | 8,908,000               | 8.67      |
| Chili (sunken-bed)        | 810,000               | 1,500,000                | 690,000                 | 1.85      |
| Total                     | 2,828,000             | 14,480,000               | 11,652,000              | 4.93      |
| High-yield rice (twice)   | 3,794,000             | 6,984,000                | 3,190,000               | 1.84      |
| Orange fruit (sunken-bed) | 1,162,000             | 10,070,000               | 8,908,000               | 8.67      |
| Chili (sunken-bed)        | 810,000               | 1,500,000                | 690,000                 | 1.85      |
| Total                     | 5,766,000             | 18,554,000               | 12,788,000              | 3.21      |

Note: Currency exchange rates 1 US$ = Rp 8.573. Source: [27].

Table 3: Cost analysis of diversifying rice farming with orange fruit and chili on tidal swampland, Barito Kuala, South Kalimantan, 2003

### 3.2. Utilization of peatlands for horticulture crops

The utilization of peatlands for horticulture crops arises from the side business of farmers using the yard so as its cultivation area is limited (<0.25 ha). However, some farmers specifically apply horticulture cultivation on their farm or paddy fields (1-2 ha). Farming on peatlands can be classified based on typology of peatlands, namely shallow peat (peat thickness <1 m), medium peat (1-2 m peat thickness), and deep peat (peat thickness >2 m). Furthermore, it is also be distinguished between cropping patterns on the yard and cropping patterns on farming system [28, 29]. The cropping patterns on the farming system on peatlands is also be categorized based on other typology of swamps such as on tidal swampland or freshwater swampland (Tables 4 and 5).
Table 4: Cropping patterns and various commodities in farming system on peatlands, including non-peat swamps

Vegetable commodities that develop on peatlands generally include long beans, mustard greens, eggplants, cucumbers, chilies, shallots, turnips, and sweet potatoes. Celery, chives, and aloe vera were also planted in small amounts area. On shallow peat, more planting patterns and commodities that can be planted include rice, secondary crops (maize and soybeans), sago and industrial crops, whereas for medium peat, planting patterns and commodities are more limited, and deep peat (>3 m) is used for conservation or preservation areas (table 4).

Horticultural cultivation technology on peatlands is divided according to horticultural commodity. In general, the technology components of horticultural cultivation on degraded peatlands carried out by farmers include (1) water management, (2) land management, (3) planting, (4) fertilizing, (5) pest and disease control, and (6) harvesting. On tidal swampland type B or medium freshwater swampland are needed land arrangement called raised-bed system (surjan) so that the horticultural crops are not affected by the tide. The height of the surjan is adjusted to the height of the tide.

Table 4: Cropping patterns and commodities

| No | Land typology   | Cropping patterns and commodities                                      |
|----|----------------|------------------------------------------------------------------------|
| I  | Acid sulphate land | Oranges, coconut, local rice, vegetables (cucumber)                    |
|    | - Type A        | Oranges, rice, pineapple, tomatoes, chili, long beans                  |
|    | - Type B        | Rice, peanuts, soybeans                                                |
| II | Freshwater swampland | Rice, secondary crops, chili                                           |
|    | - Shallow       | Rice, secondary crops, watermelons, vegetables (long beans, pumpkin, eggplant, chili, cucumber and luffa) |
|    | - Medium        | Rice, fish, swamp buffalo (B. bubalis carabaeusis)                     |
| III | Peatland        | Rice, secondary crops, sago, vegetables, plantation crops, industrial crops |
|    | - Shallow (< 1 m) | Vegetables, secondary crops, plantation crops, industrial crops     |
|    | - Medium (1-2 m) | Vegetables, secondary crops, plantation crops, industrial crops      |
|    | - Deep (> 2 m)  | Vegetables, plantation crops, industrial crops                         |

Source: [28, 29, 30].

A raised-bed system needs 500 working days for one ha. In the first step farmers form it gradually by making gradual surjan (locally called tukungan), then after crops have been grown it to be widened and connected among them to form a raised-bed.

In slightly dry swampland such as type C or D, it is necessary to have ridges/beds and shallow drainage canals to prevent crops from getting wet when it rains. This system is also called shallow drainage system or wet culture technology. Since peatlands have high ability to absorb and store water so that the shallow drainage has function to increase soil aeration therefor crops grow...
optimal[14]. Raised-bed dimension for horticulture crops on peatlands is 6-12 m in length, 2-3 in widths with height 20-25 cm [33].

| Land typology               | Cropping pattern                                                                 |
|-----------------------------|----------------------------------------------------------------------------------|
| Acid sulphate land          |                                                                                  |
| - Type A                    | Rice + orange, coconut                                                          |
|                             | Rice + orange + vegetables + banana                                             |
|                             | Orange                                                                          |
| - Type B                    | Rice + orange + vegetables                                                      |
|                             | Rice + orange + banana + vegetables                                            |
|                             | Orange                                                                          |
| - Type C                    | Orange + other fruits                                                          |
|                             | Rice, peanut, soybeans                                                         |
| Freshwater swampland        |                                                                                  |
| - Shallow                   | Livestock + fruits                                                             |
| - Medium                    | Livestock + fruits                                                             |
| - Deep                      | -                                                                               |
| Peatland                    |                                                                                  |
| - Shallow (< 1 m)           | Livestock, vegetables                                                           |
| - Medium (1-2 m)            | Secondary crops- vegetables                                                    |
| - Deep (> 2 m)              | -                                                                               |

Table 5: Food crop and horticultural crop in the farming patterns on peatlands and non-peat swamps (mineral tidal swampland) in South and West Kalimantan

Figure 3. Raised-bed system for growing eggplant (left) and tomatoes (right) on peaty swampland at Jambi province, January 2003 (Photos by M Noor/Balittra)

Mulching is a prerequisite for successful cultivation. Mulching with either straw or plastic on horticultural crops on peatlands could increase soil water content by 30-60% and crop yields by up to 33% [34]. Application of plastic mulch gave the result of Hot Chili variety as 7.5 t ha⁻¹ which was the same as rice straw mulch as much as 6 t ha⁻¹. Application of 6 t ha⁻¹ litter as mulch and minimum soil tillage yielded 22.43 t ha⁻¹ of Permata tomatoes variety.

Mulch provides additional effects including (1) reducing evaporation as of the soil is always moist, (2) suppressing weed growth, and (3) suppressing runoff, leaching and soil erosion. Straw
mulch can be obtained from rice yields whereas plastic mulch can be used up to three times planting (Figure 4).

Horticultural commodities especially vegetables produced with varied results on peatlands. Table 6 showed production and cost analysis of vegetable farming on peatlands.

| Land/commodities   | Production (kg) | Revenue (Rp) | Cost (Rp) | Profit (Rp) | R/C |
|--------------------|-----------------|--------------|-----------|-------------|-----|
| A Farmer level     |                 |              |           |             |     |
| Eggplant           | 631             | 631,009      | 441,707   | 189,303     | 1.43|
| Pumpkin            | 750             | 750,000      | 429,000   | 321,000     | 1.75|
| Long beans         | 928             | 1,392,713    | 793,044   | 599,669     | 1.76|
| Cayenne pepper     | 200             | 2,000,000    | 1,243,000 | 757,000     | 1.61|
| Bitter melon       | 375             | 1,125,000    | 495,000   | 630,000     | 2.27|
| Cabbage            | 600             | 1,349,175    | 775,599   | 573,576     | 1.74|
| Mustard            | 660             | 2,444,775    | 1,070,180 | 1,374,595   | 2.28|
| Spinach            | 8,333           | 12,499,500   | 6,250,000 | 6,249,500   | 2.00|
| Chives             | 3,333           | 9,999,000    | 6,107,139 | 3,891,861   | 1.64|
| Celery             | 2,775           | 22,200,000   | 7,829,440 | 14,370,560  | 2.83|
| Spring onion       | 2,775           | 24,975,000   | 7,427,065 | 17,547,935  | 3.36|
| Aloe vera          | 5,138           | 4,624,200    | 2,882,600 | 1,741,600   | 1.60|
| B Result of research |               |              |           |             |     |
| Tomato             | 3,598           | 8,995,000    | 2,675,050 | 6,319,950   | 3.36|
| Chili              | 1,197           | 5,985,000    | 2,532,286 | 3,452,714   | 2.36|
| Cucumber           | 3,132           | 7,830,000    | 2,034,943 | 5,795,057   | 3.84|
| Eggplant           | 2,583           | 5,166,000    | 1,881,393 | 3,284,607   | 2.74|

Source: [35].

Table 6: Production and cost analysis of vegetable farming on peaty lands and peatlands in Central and West Kalimantan (0.1 ha).

4. Implementation of water management technology
Water management is one of the key successes in managing peatlands for sustainable agriculture. In the era of 1970-1995 water management in swamplands including peatlands was emphasized on drainage aspects therefore in the development of swamplands there was a principle of "how to drain the swamp" due to peatlands were generally wet and some were permanently inundated. After
understanding that peatlands are easily subsidized, irreversible, easily degraded, and prone to burning, the principle of drainage changed to "how to irrigate and conserve".

The paradigm shift above gave rise to the view that peat must be managed in an integrated system. Peatlands need to be view as part of a peat ecosystem unity in a single peat hydrological unit. Therefore, the partial approach as known as Transmigration Settlement Unit or Swamp Irrigation Area that divided swamplands based on reclamation management schemes (5,000-20,000 hectares) changed into the Peat Hydrology Unit approach. Macro and micro water management for food crops and horticulture on peatlands will further describe as well as infrastructure support.

4.1. Macro and micro water management system.
Water management on peatlands consists of macro and micro water management units. The macro water management unit includes water management from primary, secondary to tertiary canals, whereas from tertiary canals to rice fields or agricultural plots called micro water management unit. Poor macro water management will cause problems in managing water on micro unit. Integration, synergy, and synchronization are needed in water management. Macro water management is under the authority of the Ministry of Public of Works and Housing under the Directorate Irrigation and Lowland, while micro water management is under the authority of the Ministry of Agriculture under the Infrastructure and Facilities Directorate General of Agricultural.

There are differences in macro water management in Central and South Kalimantan with West Kalimantan. In South and Central Kalimantan using the fork or herringbone with a reservoir at the upstream end of the main canals, which can flush the canal system meanwhile in West Kalimantan is called the comb system, a rectangular grid without a reservoir [14].

Related to the relationship between macro and micro water management, improvement of water management system requires a design that is in line with the following rules: (1) Micro water management system must be follow in a one-way flow, both its surface and ground water; (2) The water level in the tertiary canal (drainage) must be designed lower than the lowest tide level; (3) The water level in the tertiary canal (irrigation) must be designed higher than the water level at the highest tide; (4) if the water system in tertiary canal is designed with gate control, then the effective volume of drainage canal must be sufficient to accommodate excess water due to rainfall estimates (based minimum data series for 5 years); (5) if the control location is in the tertiary canal, the tertiary gate must be operated automatically; and (6) by placing the water control at the tertiary level, the secondary and primary network system can be integrated with the river so that the river water transport and canal network become in one unit [36, 37].

Hereinafter, it will be described a micro water management system that is applied in swamps for agricultural development in Kalimantan such as a two-way flow system, one-way flow system, dam overflow system, raised-bed system, and shallow drainage system.

4.1.1. Two-way flow system.
Two-way flow system is a water system commonly used by local farmers of Banjarese in regulating water for their rice fields. Farmers make small canal perpendicular to the river (locally called handil) along about 2-3 km, canal width 2-3 m, and depth of 0.5-1.0 m. Sometimes handil is extended up to 5 km in order to irrigate 20-60 hectares of rice fields. The inter-handil distance is 200-300 m [14]. The weakness of this system is the shortage of washing and refreshing of incoming tide. Replacement of good quality water only occurs in estuary areas close to rivers/secondary [38].

4.1.2. One-way flow system.
A one-way flow system is a water flow regulation that applies water flow in one direction. If the handil system is bi-directional, that is, entering and removing water in the same canal, then in this one-way flow system the flow of water enters through the inlet and comes out through another different canal (outlet). In each canal a semi-automatic flap gate is installed to close (at the outlet) and the opening (at the inlet) is assisted by a push or tide movement (Figure 5). This one-way flow system is be proven to not only increase rice yield but also improve chemical properties and fertility
of swamplands. The water gates in the inlet canal are designed to be open as soon as the tide comes up so that semi-automatic of tidal water enters, while the outlet gate which are in the outlet canal will be closed because of the push of the tide. Conversely, at low tide the inlet gate closes due to a push of water down, while the outlet gate at the outlet canal opens.

The results of [38] on acid sulfate soils type B at experimental unit of Tatas, Kapuas Murung District, Kapuas Regency, Central Kalimantan showed an increased yield of 60% in the dry season and 150% in the rainy season until up to 4 t ha\(^{-1}\)season\(^{-1}\). In Delta Air Saleh, South Sumatra reported that a one-way flow system increased rice yield from 2.39 to 5.59 t ha\(^{-1}\)season\(^{-1}\) and improved soil acidity from pH 4.33 to pH 5.59 [40]. Optimization of land and water management in the tidal swampland in Terusan Mulia Village, Selat Regency, Kapuas Regency, Central Kalimantan produced 7.5 t ha\(^{-1}\) [41].

4.1.3. **Dam overflow system.**

Dam overflow (locally called *tabat*) is used to dam up water. The term *tabat* is taken from the Banjarese language in South Kalimantan. The installation of the dam overflow in freshwater and tidal swampland is aimed in conserving water in the dry season, releasing water as needed during the rainy
season, and directing the flow of water toward the land to be irrigated. It is made from simple materials such as earth mounds, plant litter, sacks containing sand, wooden boards to plastic or metal slabs. At the dam overflow, water flows from the top of the bulkhead, not from the bottom. The shape of it has progressed to become made of concrete equipped with elbow called Tasel (Figure 6). The implementation of this dam allows farmers to plant twice (IP 200) from initially once a year (IP 100).

![Figure 6. Dam overflow made of earth mounds (a), Meranti (Shore sp.) wood (b), Ulin (Eusideroxylon zwageri Teijsm and Binn) wood (c) and concrete + elbow (d) for water management in peatlands and tidal swamplands in Rasau, Kubu Raya Regency, West Kalimantan, March 2014, Tumbang Nusa, Pulang Pisau Regency, Central Kalimantan, July 2013 and Tamban Catur, Kapuas Regency, Central Kalimantan, January 2019 (Photos by M Noor/Balittra)](image)

4.1.4. Raised-bed (surjan) system.

Raised-bed (surjan) system is intended to cope with the inundation by raising the soil surface by digging the soil on the right and left side to be buried in the elevated part. The elevated part is called a raised-bed (surjan) that is planted with secondary crops or horticulture, while the digging part is called sunken-bed (tabukan) which planted with rice [31]. The distance between raised-bed system should be at least 14 meters to facilitate tractor operational for soil tillage, but there are other opinions of 8.5-9.0 m. Surjan can also be a land ownership boundary so that it is made at 200 m. The width of the upper raised-bed is 3-5 m, the bottom width is 3.5-5.5 m and the height is 60-90 cm depending on the height of the water surface during a tidal overflow, whereas the length between 25-50 m depending on ownership [32]. The raised-bed system has several advantages i.e. increase land utilization, diversify crop production, minimizes the risk of total failure, and increase farmer’s income.

4.1.5. Shallow drainage system.

Shallow drainage system is applied to prevent the reduction of surface inundation by making shallow canals so that the land is dry and safe for crops/horticulture. The canal is made with a width of 30-40 cm and in 40-50 cm depending on the typology of tidal land. The results of research in type B with thin peat in the Tatas experimental unit, Central Kalimantan can maintain a 40-50 cm high soil
surface with a yield of 0.58 t dry corn ha\(^{-1}\), 1.38 t dried soybean ha\(^{-1}\), and 1.52 t peanut seeds ha\(^{-1}\) in the rainy season. For the dry season, each produces 4.32 t ha\(^{-1}\) of corn, 1.99 kg of soybeans ha\(^{-1}\) and 2.70 t of peanuts ha\(^{-1}\) [39]. In the type C, the potential acid sulphate field in Barambai, South Kalimantan obtained 3.81 t corn ha\(^{-1}\), soybean 1.79 t ha\(^{-1}\) and peanuts 1.79 t ha\(^{-1}\) [31].

4.2. Water management infrastructure support

Water management systems on peatlands for food crops and horticulture require adequate water availability especially during the dry season, hence infrastructure support in water management such as canal, water gate, dam overflow, embankment, water pump and pump housing for water level regulation and operational and maintenance systems are very important.

The network of canals and water gates on peatlands is far from adequate. In the field, water gates were not be built as needed, some of have been damaged and some have not been built since the land was reclaimed and occupied. Inadequacy of water management infrastructure and lacking attention and initiative of farmers in water management so that during the dry season most of the peatlands used for agriculture have drought with water levels falling below >1 m beneath surface therefor the top layer of peat is dry and prone to burning. Fire on peatlands is a serious problem since impact of land fires and haze are very detrimental to society and the country [42].

4.2.1. Soil and water aspects.

Soil and water aspects are key in the management of swamps for agriculture. Swampland is categorized as a recent soil. With conditions that are always flooded so that it is generally still unripe. This condition is not favorable for plant growth and operational agricultural machinery that often collapsing. Water management in this case through drainage, provides an opportunity for the process of soil ripeness thereby increasing the carrying capacity. One of the objectives of water management in swamps is to accelerate the ripeness of soil.

4.2.2. Design aspects of water gate.

There are various design models of water gate used in the implementation of water management including screw, flap gate, and dam overflow. Likewise, materials used such as soil, wood, stone, concrete, fiber, iron or steel. Each model and material have each weaknesses and strengths. In the implementation of a one-way flow system, a semi-automatic flap gate at the inlet opened, the water gate opens due to a tidal push so that water can enter as irrigation. On the other hand, at the outlet, the flap gate closes when high tide, but opens when low tide. Whereas type C or D, which is an area that is not directly affected by both spring and neap tide, it is necessary to installed dam overflow to conserve water.

4.2.3. Operational aspects of water management

All this time, water management operations have relied more on tidal capacity so that areas far from estuary and/or secondary canal receive less water supply. In the swamp reclamation project known as Tidal Rice Development Project (P4S, Proyek Pengembangan Pesawahan Pasang Surut) through the construction of primary and secondary canal that jutting into the inland between 5-7 km made the distant areas get a tidal overflow. Implementation of micro-water management at the farm requires water gates installed in the estuary of tertiary canals to divide and maintain surface water and ground water so that it is sufficiently available for crop cultivation. The main features of micro water management include (1) water supply (irrigation) and drainage if it is excessive according to the needs of crops; (2) flushing out of toxic compounds such as Al, Fe, Mn, H\(_2\)S; (3) maintaining the
reduction conditions for preventing pyrite oxidized, and avoiding rapid subsidence, particularly in peat soil; (4) preventing the occurrence of salt accumulation in the rooting area or poor water intrusion from galam (*Melaleuca cajuputi*) forests, and (5) prevent the growth of weeds and *orong-orong* (*Gryllotalpidae*) pest that attack rice [18].

The problem in water management operations is the dependence on human labor in opening and closing water gates. Most gate operations still use human power, although tidal power can be used to move flap gate to open and close. Though the occurrence of tides is not always during the day, but also at midnight when farmers sleep so that water management becomes ineffective. To improve the water management system, research is now being conducted on the implementation of the industrial revolution 4.0 in agriculture including the internet base (internet of things) in the form of gate operational design using sensors based on water level and water quality (pH).

5. Conclusion
Peatlands are important land resources and economic. Clearing and utilizing peatlands requires appropriate and environmentally friendly technological interventions. Peatlands that are ideal for agriculture must have a thickness of <3 m, hemic to sapric ripeness, depth of pyrite layer> 100 cm from the surface, moderate to high fertility status and moderate to high soil acidity.

Utilization and management of peatlands requires scientific and technological innovations related to the nature of peat which, among other things, have a great ability to store water and irreversible drying. Peatlands easily dry out, making them vulnerable to land degradation and also prone to fire. Water management is an important component in developing peatlands for agriculture, especially food crops and horticulture due to the ease of water release and the ability to store water. Water management can also be an effort to conserve peat, so it is not easily damaged and prevent peatland fires.

Water management requires integrated planning between the peat hydrology unit, the macro water management unit, and the micro water management development unit. Micro water management requires tertiary canals for irrigation (inlet), tertiary for drainage (outlets), embankment, water gates, dam overflow, water pumps and pump housings for the purpose of adjusting the water level as needed. The support of water management infrastructure is very important and is the key to the success of water management for the development of agricultural food crops and horticulture on peatlands.

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