Overcoming constraint of tidal swampland with water management with one-way flow system to increase of rice growth

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Abstract. The paper addresses the issue whether water management is the key and the only practical way to reclaim and ameliorate a large area of tidal swampland. It reviews recent developments in water management practices with special emphasis on leaching acid sulphate soils are found throughout the length and breadth of the earth. Success in water management is the key for the reconciliation between agricultural yields and environmental sustainability. Water management of tidal swampland, which is dominated by acid sulphate soils, is a serious problem and challenges to reconcile agricultural practices and sustainable quality of ecosystem. Mismanagement of water dynamics may bring about catastrophic consequences instead of friendly environment. The local knowledge/wisdom in managing water supply and drainage to sustain rice yields with a two-way flow system of channels that allows a supply of fresh water during spring tide and drainage during tide has been introduced. The traditional system for reclaiming the tidal swampland by digging a drainage channel called *handil*. The experiment was carried out to investigate the effects of water management on soil chemistry of tidal swampland. Water management with a one-way flow system reduced of soil acidity, toxic elements and increased rice growth in tidal swampland.

1. Introduction

Lowland areas, especially swampland, have a high potential to be used as a strategic choice for development of agricultural production area to cope with food security [1]. Acid sulphate soil is one type of soil found in tidal swampland area and classified as marginal land because the soil has unprofitable properties with a low fertility rate. The presence of sulfidic material which contains a lot of pyrite is the specific characteristic of acid sulphate soil. This pyrite has unique properties and depends on the state of the water. Pyrite in acid sulphate land has become a serious obstacle in the development of tidal swampland for rice cultivation. The pyrite formed is stable under such reduction condition unless to oxidized was produced of sulphuric acid [2-4]. The oxidation of the pyrite occurs in tidal swampland as a result of artificial drainage or natural phenomena such as falling water levels, e.g. droughts [5]. Water management is the key to success in the development of tidal swampland to provide water supply as well as maintain reductive conditions. Lack of water or excess of water will create a disaster. Crops that experience water deficit will result in a decrease of product quality and quantity. Excessive water will create the decrease of harvesting yield and diseases outbreak. Extreme condition of excessive water will results in soil leaching, erosion and flood [6].
The concept of water management is based on hydrology in tidal swampland i.e the amplitude of inundation (Type A, B, C dan D). The water management system applied by farmers (at tertiary and quarter level) on tidal swampland is generally two-way flow. Wignyosukarto [7] reports that a two-way flow system that allows the supply of fresh water during high tide to overcome the process of washing land in the tidal swamp and is called a tabat system that can control the water level in the field, based on local knowledge. The one-way flow system of water management in swampland, which supplies water from the secondary system to the field (tertiary system). This system is mainly designed to leach out the acid accumulating in the water.

The local farmers have developed the traditional technology system for reclaiming the tidal swampland by digging a drainage channel called a handil. The word handil comes from the Dutch word ‘aandeel’, meaning a share or part of the work and have several functions: (1) Draining excess water and acidic water from agricultural land, (2) Providing fresh irrigation water during tidal waves. This irrigation is limited to the topography and distance of the river to the land, (3) Communication channel for transportation of people and goods [8]. The water management in tidal swampland should meet at least two objectives i.e: (1) to supplying enough water for leaching out pyrite oxidation products and diluting acid water, (2) to drainage of excess water and to keeping the potential acid sulphate soil under reduced conditions in order to avoid excessive oxidation. The experiment was carried out to investigate the effects of water management on soil chemistry of tidal swampland.

2. Materials and methods
The research was carried out in the Indonesian Swampland Agricultural Research Institute greenhouse by mimicking field conditions using a completely randomized factorial design. The treatment consisted of two factors, namely: the first factor of the washing system includes: (1) one-way flow system (water was not returned), (2) two-way flow system (water was returned). The second factor was amelioration, namely: (1) without ameliorant, (2) ameliorant with dolomit, (3) ameliorant with calcite. NPK fertilizer was given at 100% of the recommended dosage determined based on the results of soil testing using DSS software for rice in swamps. Fertilizer N (Urea) was given at the age of 7 days after planting (HST) 1/3 part, then 2/3 part based on BWD (Leaf Color Chart). Whereas P (SP 36) and K (KCl) fertilizers were given at the beginning of planting. The rice variety used was the Inpara 2 rice variety. The nursery was carried out outside the plantation business area to save time and seedlings aged between 20-25 days in the nursery.

Observation of water and soil quality which was carried out periodically includes: Water pH and electrical conductivity (EC) were conducted at 2 mst, 4 mst, 6 mst and 8 mst. As for growth, plant height was also observed. Experimental data analysis was performed using analysis of variance to determine the average treatment. If the effect was significantly different (F count> F table), then proceed with Duncan's multiple range test (DMRT) to find out which treatment was significantly different. This analysis used SAS 9.10 software for Windows.

3. Results and discussion
3.1. Dynamic of water acidity (pH)
The increase in soil pH is due to the liberation of OH- and H+ consumption followed by a decrease in the activity of H+ ions [9]. In addition, the increase in soil pH is determined by the ratio of H+ consumption / electron consumption. In figure 1, it can be seen that at the beginning of inundation the soil pH continued to increase until it reached the peak (observation 6 mst) and again decreased at 8 mst observation. The lowest acidity (the high of pH value) at 8 wap was shown in one-way flow system with ameliorant dolomit reached 5.28. The decrease in pH after reaching the peak at 8 mst observation was due to precipitation of Fe3+ with carbonates and sulfides which would contribute to H+ ions so that soil pH decreased. The decrease in pH at 2 WAP was due to dissociation of HCO3- ions to ion H+ and ion HCO3- at a pH ranging from 4.5 that would emit H+ ions [10]. Ion H+ would increase the concentration of H+ ions in soil solution, so that the pH decreased.
3.2. Dynamics of salinity (EC)

The result showed that water management with one-way flow system gave lower water salinity compared to water management with two-way flow system (figure 2). Inundation of paddy soil initially would reduce the soil DHL to a stable value. It is seen in the figure 2 that DHL land continued to decline until the 8 WAP observation period. The decline in the value of DHL was due to the precipitation of Fe$^{3+}$ as Fe$_3$(OH)$_8$ and FeS as well as loss of CO$_2$ and conversion of RCOO$^{-}$ to CH$_4$. This high salinity resulted in inhibition of absorption of water and nutrients by plants. This is also a result of the inundation process. Rice was tolerant to salinity with values ranging from 4 - 10 dSm$^{-1}$ [11], but for flooded soils the highest DHL values were between 2 - 4 dS m$^{-1}$ [12]. The high salinity caused plant poisoning mainly by Na$^+$ and Cl$^-$ ions.

3.3. Water potential redox

Water potential redox for the two water management treatments and the three ameliorant systems was shown in figure 3. Redox potential value determines the soil conditions. At a redox potential value $>$ 300 mV soils under oxidative conditions, then the value of Eh 100 - 300 mV soils in slightly reduced conditions, whereas the reduction soil conditions range from 100 - (-100) mV, and potential values $>$ -100 mV indicate soils in very conditions reduced. Oxidants (electron acceptors) and reductants (donor electrons) limit the oxidation reduction process in stagnant soils. If the acceptor electrons are more than the reductant, the redox potential tends to increase (positive), but if the reductant (donor electron) is more than the oxidant, the redox potential tends to decrease (negative) [9]. The highest redox potential value was shown in one-way water treatment and lime ameliorant treatment which reached +315.15 mV which showed oxidative conditions.

![Figure 1. Dynamic of water acidity for the two water management treatments and the three ameliorant systems.](image-url)
Note: L0=one way flow system; L1=two way flow system; Ao=without ameliorant; A1=ameliorant with dolomite; A2=ameliorant with calcite

**Figure 2.** Dynamics salinity for the two water management treatments and the three ameliorant systems.

Note: L0=one way flow system; L1=two way flow system; Ao=without ameliorant; A1=ameliorant with dolomite; A2=ameliorant with calcite

**Figure 3.** Water potential redox for the two water management treatments and the three ameliorant systems.
Figure 4. Plant height of rice for the two water management treatments and the three ameliorant systems.

Figure 5. Soil acidity for the two water management treatments and the three ameliorant systems in the 8 WAP.
3.4. **Plant height of rice**

The result showed that effect of water management treatments with two-way flow system with ameliorant dolomitic gave higher plant height of rice compared to other treatment (figure 4). And the lowest plant height was shown in the water management with one-way flow system without ameliorant reached 72.33 cm. This is related to the increase in soil pH value reached 4.18 (figure 5). Calcification applications using agricultural lime in acid soils can neutralize soil pH, increase the concentration of alkalinity and total hardness, increase the availability of carbon for photosynthesis, and create a pH buffer system for waters [13].

4. **Conclusion**

The success of the use of tidal swamps to become agricultural land is determined by the appropriate water management system. Water management treatments with one-way flow system without ameliorant gave higher plant height of rice reached 90.50 cm. The highest plant height in tidal swampland was shown in water management with one-way flow system with ameliorant dolomite.

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