Effects of the Purun Tikus (Eleocharis dulcis (Burm. F.) Trin. ex Hensch) Planted in the Horizontal Subsurface Flow-Constructed Wetlands (HSSFCW) on Iron (Fe) Concentration of the Acid Mine Drainage

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Effects of the Purun Tikus (*Eleocharis dulcis* (Burm. F.) Trin. ex Hensch) Planted in the Horizontal Subsurface Flow-Constructed Wetlands (HSSF-CW) on Iron (Fe) Concentration of the Acid Mine Drainage

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ABSTRACT

Purun Tikus (*Eleocharis dulcis* L.) is a plant in the natural aquatic ecosystems of acid sulfate swamp; it has potential as a bio filtered metal pollutant. This plant can grow and adapt well to the flooded acid soils. In this study, Purun Tikus was planted in the Horizontal Subsurface Flow Constructed Wetland (HSSF-CW) system. This HSSF-CW system was designed using subsurface flow and take advantages of the natural processes that occur therein. The process in this wastewater system treatment is involving wetland vegetation, soil growing medium, and wetland microbial communities. The HSSF-CW with Purun Tikus was known able to decrease concentration of Fe in the AMD of coal. However, populations of plants and its seedlings in accordance with the HSSF-CW system is unknown. Therefore, this study was conducted to determine the space-planting and Purun Tikus seedlings in the HSSF-CW system which is able to decrease concentration of Fe in the coal AMD. This study used a model (reactor) of HSSF-CW with dimensions of 100 cm x 30 cm x 35 cm. Purun Tikus were planted with a spacing of 5 cm, 10 cm, 15 cm; and the seedlings are tiller, young plant, and old plant. Results showed that a space-planting and seedlings are significantly influencing the decrease of Fe concentration in the AMD coal. Decreased of Fe concentration was higher in the treatment of 15 cm planting space and the seedling is "tiller".

KEYWORDS: Purun-tikus, Horizontal Subsurface Flow Constructed Wetland (HSSF-CW), iron, acid mine drainage.

INTRODUCTION

Purun Tikus (*Eleocharis dulcis* (Burm. F.) Trin. ex Hensch) is one of the aquatic plants that are found in acid sulfate soils or peat soils [1]. In general, these soils experiencing acute acidification [2]. This plant belongs to the family of Cyperaceae or Cyperus group. The stem is cylindrical and the diameter of 2-3 mm, height of 150 cm, stems without branch and green, so it can photosynthesize. The flowers are located at the end of the stem [3]. Purun Tikus suggests the potential bio-filter because it can grow well in environments with low pH [1, 2]. Research conducted by Krisdianto, Purnomo, and Mikrianto (2006) showed that the Purun Tikus decreased content of dissolved Fe in rice lands irrigated by the coal wastewater. Fe uptake by an average of 1.1766 mg.L-1 and Total Dissolved Solid (TDS) by an average of 0.4505mg.L^{-1}. Purun Tikus suggests the wide spectrum of habitat, and it is a relatively fast growing plant [4].

Purun Tikus can be used in the Horizontal Subsurface Flow Constructed Wetland (HSSF-CW) system. This HSSF-CW system is designed with subsurface flow and take advantage any natural processes that occur therein. These natural processes are involving wetland vegetation's, growing medium of soil, and wetland microbial communities, for wastewater treatment. Compared with other types of constructed wetlands, the HSSF-CW is a concept that can be applied broadly. Wastewater treatment with the HSSF-CW system is performed by a wide variety of biological processes, physical, chemical and microbiological processes; includes sedimentation, filtration, precipitation, absorption (sorption), uptake of nutrient by plants, microbial decomposition and transformation of nitrogen [5].

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Figure 1. Purun-Tikus (*Eleocharis dulcis*).

The HSSF-CW system with Purun Tikus can decrease concentration of Fe in the coal AMD [6, 7]. This AMD contain a large amount of Fe-soluble, it is very acid, it can cause corrosion and dissolve other heavy metals, so the AMD contaminated water is toxic to the aquatic organisms. Therefore, we need an effective method of AMD treatment, easier and cheaper. The CW technologies are widely used in treating acid mine drainage [8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. The main component of the CW is the aquatic plant, so the selection of these plants is very important [18]. The CW usually involves aquatic plant species that are tolerant and capable of absorbing a large amount of pollutants.

Plant growth is influenced by the availability of essential nutrients. Proper spacing reduces the level of competition in nutrient absorption, so the plants do not impair metabolism due to nutrient deficiency [19, 20]. These metabolic disturbances may ultimately affect the ability of plants in absorbing and accumulating pollutants. In addition to plant spacing, seedling age also affect nutrient uptake, including iron [21, 22].

The HSSF-CW system with Purun Tikus is able to decrease concentration of Fe-soluble in the coal AMD. However, plant spacing and seedlings suitable for planting in this HSSF-CW are unknown. Therefore, this study aimed to determine whether the planting space and seedling age determine the ability of the HSSF-CW in lowering the concentration of soluble-Fe. In addition, we want to evaluate the planting space and seedlings which are the most suitable to the HSSF-CW model.

RESEARCH METHOD

Constructed Wetlands (CW) used in this research is the Horizontal subsurface flow type (HSSF). It is operated continuously with a flow rate of wastewater (result of calculation of 5 L/day) within a specified period of time for 4 days.

The reactor was made of wood covered with plastic; its size is 100 cm x 30 cm x 35 cm. Growing media used are acid sulfate soils derived from Puntik Village Central, South Kalimantan. This location is the natural habitat for Purun Tikus. The growth media thickness in the reactor is about 30 cm. Influent is the acid mine drainage from the coal mining area in South Kalimantan.

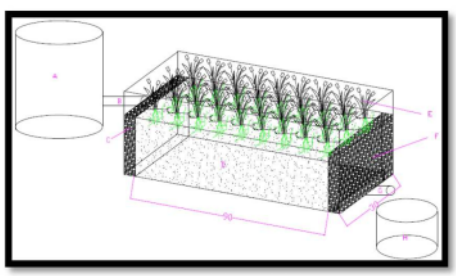


Figure 2. Reactor Design of the HSSF-CW system.

Notes :

A = reservoir of influent	E= Aquatic plant of Purun-tikus
B= inlet pipe	F= gravel
C= gravel	G= outlet pipe
D= planting media	H= reservoir of *effluents*

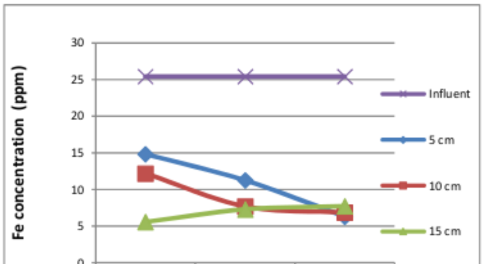
The aquatic plants used in this study were Purun Tikus taken from the Central-Puntik Village, South Kalimantan. This plant is chosen because it is one of the abundant natural vegetation in acid sulfate swamp ecosystems, in South Kalimantan. These plants can grow and adapt well to the flooded acid soil. Variations of planting distance are 5 cm, 10 cm, and 15 cm; while the plant seedlings are the tiller, young plants, and mature plant.

Parameter measured in this study is pH of AMD and concentration of soluble-Fe in AMD. The concentration of soluble Fe was measured by the method of atomic absorption spectrophotometry (AAS).

Data were analyzed using the two-way variance analysis to determine effect of plant spacing and seedling age on the concentration of soluble Fe in AMD. If a significant effects of treatment, then followed by DMRT analysis at the 95% confidence level (p = 0.05). Purpose of this analysis is to determine where the most effective treatment in lowering the soluble Fe [23].

RESULTS AND DISCUSSION

Concentration of the soluble Fe in the AMD is presented in Figure 3.



	tiller	young	mature
Influent	25.44	25.44	25.44
5 cm	14.84	11.25	6.32
10 cm	12.20	7.70	6.86
15 cm	5.59	7.30	7.73

seedling age of Purun Tikus

Figure 3. Concentration of Fe in AMD (Acid Mine Drainage).

Results of measurement of concentration of the soluble-Fe in sample of AMD influent are 25.44 ppm Fe. This figure exceeds the wastewater standard, the concentration of soluble Fe in AMD a maximum of 7 ppm Fe [24]. Average soluble Fe concentration in the effluent of HSSF-CW ranged from 5.59 to 14.84 ppm Fe (Figure 3). Another type of CW with organic matter on media can reduce Fe average 54% from 3.00 ppm to 1.38 ppm[7]. In this study, the HSSF-CW model that produce effluent with soluble Fe concentrations below the standards, namely: The HSSF-CW with tiller seedling and plant spacing of 15 cm; The HSSF-CW with mature plants and planting space of 5 cm and 10 cm. Decrease of soluble Fe concentrations in effluents compared to influents are occurred on all of the HSSF-CW with Purun tikus plants. This is due to the physico-chemical and biological processes occurring in the HSSF-CW. These processes is involving wetlands vegetation, growing medium and communities of microorganisms that exist in the CW [15, 17, 25, 26]. Purun Tikus supply oxygen that necessary for Fe precipitation processes, and this plant absorbed soluble Fe for its metabolism [27], so that the soluble Fe concentrations in effluents are lower than the concentration of Fe in wastewater influents.

Process of heavy metals removal from the wastewater are affected by the type of treatment method and its system, the vegetation, the ionic form of metal, substrate conditions, and retention time [28]. In the process of phytoremediation, roots, stems and the media are served as a substrate for bacteria, these bacteria promote the immobilization of heavy metals and plant uptake of these heavy metals. In general the function of plant on the CW in relation to wastewater treatment is the biophysical effects. This plant provides a large surface for the attachment and growth of microbes [3]. Interactions between plants and these microorganisms are considered to be the main process of metal removal from wastewater [29].

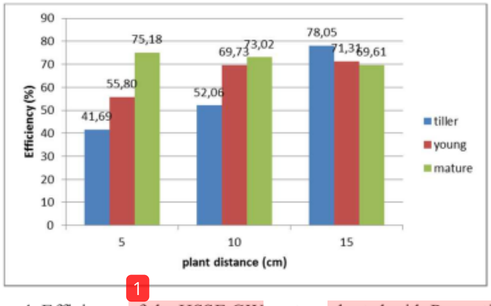


Figure 4. Efficiency of the HSSF-CW system planted with Purun tikus.

Removal efficiency reflects a decrease in concentration of soluble Fe as well as showing the performance of the HSSF-CW system. The highest efficiency occurs in the HSSF-CW system with the planting space of 15 cm and the tiller seedlings; it is equal to 78.05% (Figure 4).

Statistical analysis showed that interaction of planting space and seedling age very significantly affects concentration of soluble Fe in the AMD (p <0:01). The lowest concentration of soluble Fe was founded in in the combination of planting space of 15 cm and the tiller seedlings. This suggests that Purun tikus tiller seedlings with the planting space of 15 cm in the HSSF-CW system is the most effective in removing soluble Fe from the coal AMD.

Chemical and physical characteristics of soil are an important factor that affects efficiency of the wastewater treatment systems [27]. Soil media are served as a filter and promote filtration process when the soil colloidal particles bind metal cations dissolved in the AMD. Purun tikus plant root system to form a filter that can trap soluble Fe contained in the AMD. The growth of plant roots affecting the physical quality of soil and also affect the rate of flow of wastewater in the CW system and ultimately affect the removal of contaminants [27].

pH affects processes of Fe removal from the coal AMD. Measurements suggest the pH of influents about 3.0, while the pH of effluents in the range of 4.80 – 5.55. The HSSF-CW treatment system can raise the pH value of 1.00 – 2.55. Increase in the effluent pH value is greatest in the HSSF-CW system with the seedlings planted under a distance of 15 cm (Figure 5). The result study of Herniwanti *et al.* (2014) show same phenomena, Purun Tikus can increase pH of AMD from 2.54 - 3.88 (design 1, Purun Tikus planted without organic matter on media) and 2.54 - 2.63 (design 2, Purun Tikus planted with organic matter in the media)[7]. Effluent pH value is inversely proportional to soluble Fe, and pH is directly proportional to the bacterial population. Increasing the pH value causes a decrease in Fe solubility and lead to an increase in bacterial populations [30]. The lower pH value in the AMD is caused by the iron oxide sulfate [31]. Reducing sulfate bacteria decrease sulfate concentrations and increase pH of the AMD. These bacteria can use organic compounds or hydrogen in reducing sulfate to sulfide. Sulfate reduction resulted in a decrease in the amount of sulfate and increase bisulfide and HCO_3^-. Hydrogen sulfide gas can be formed from bisulfide and hydrogen ions. The loss of H_2S to the atmosphere and production of HCO_3^- result in the lower acidity and increase pH value of the AMD [29]. The increase in pH encourages ferrous ions (Fe^{2+}) undergo oxidation into ferric (Fe^{3+}) and bind hydroxide anion to form a $Fe(OH)_3$ that is insoluble and settles on a substrate with a reddish color [32].

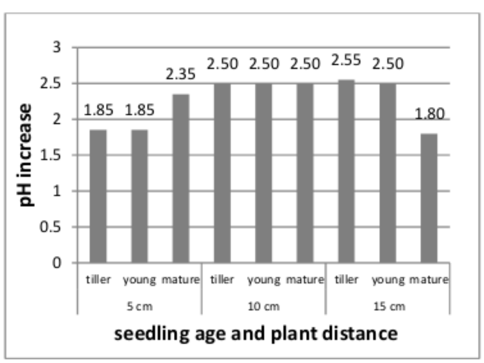


Figure 5. pH increase of the HSSF-CW effluents.

The HSSF-CW planted with tiller-seedlings in 15 cm spaced, showed the highest growth of Purun Tikus (Figure 6). This suggests that water-chestnut can grow well on that planting space condition. Spacing arrangement is one way to keep any plant needs to be available equally to every individual plant and to optimize the use of available resources in their growth environment. The irregular distance between individuals plants results in the highly variation of plant growth. The denser plants are usually grown smaller and the wider plants grow larger, according to the availability of space and nutrients in their growth environment. The dense planting led to the narrowness of the distance between the clumps. This leads to greater competition in the use of environmental resources [20], thus affecting plant growth. Spacing affects the amount of nutrients and solar energy available to plants. The sufficient supply of nutrients and solar energy, can improve absorption of carbon dioxide and the process of photosynthesis, which is impacted in improvement of plant growth. The rate of plant growth promotes the uptake of nutrients and heavy metals from their growth medium [13].

The age of plant determines the amount of nutrients needs to support their growth rate. Usually the nutrient needs decrease with increasing age of plants. During their growth, uptake of nutrients and heavy metals proceeds continuously [33]. The Purun tikus requires Fe as a constituent element of chlorophyll, proteins, enzymes, and play a role in the development of chloroplasts. The new roots and root hairs absorb Fe and other nutrients. *Phragmites communis, the* other species of aquatic plants suggests the high concentrations of Fe in their roots [34].

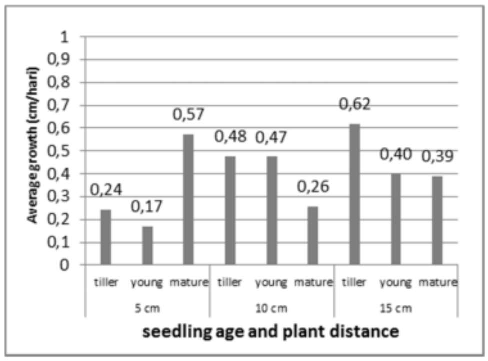


Figure 6. Average growth of Purun-tikus in the HSSF-CW

Mechanism of Fe uptake by Purun Tikus plant is not known in more detail. As a species of monocotyledon, this plant may use the chelation-based strategy in absorbing Fe from its substrate. This strategy uses the release chelate called phytosiderophores into the rhizosphere to bind Fe^{3+} and absorp it into the plant. Phytosiderophores is synthesized from methionine and usually refers to a family mugenic acid [35, 36]. Together with Zn, Fe absorbed by plant roots in the form of phytosideraphore-chelate [35, 36] by the YSL transporters that are located in the epidermal cells. This metal is moving through the vasculature symplastic pathway through the Casparian ring in the endodermic cells. Citrate fluxer FRDL1 is very important in transporting Fe into the shoot tips of plants through the transpiration streams. Fe can also be transported from the phloem tissue leading to the shoot tips and young tissues in the plant [36, 37, 38, 39, 40, 41, 42, 43].

Metals are accumulated in plant tissues after forming complex substances with other elements or organic compounds, one of which is phytochelatin composed of amino acids of cysteine and glysine. Phytochelatine is served in forming the complex substances with heavy metals in plants tissues, and detoxification of heavy metal in plant tissues. If plants cannot synthesize phytochelatine sufficiently, usually they suggest the stunted growth and eventually die. Usually the high levels of phytochelatine is found in plants that are tolerant to heavy metals [44, 45, 46, 47, 48, 49, 50].

Conclusion

The Horizontal Subsurface Flow Constructed Wetlands (HSSF-CW) Model capable of removing soluble Fe from the coal AMD with the percentage decrease of 41.69% - 78.05%. An interaction between plant spacing and tiller seedlings is very significantly affects the concentration of soluble Fe in the coal AMD. The lowest concentration of the soluble Fe, is found in the HSSF-CW model using tiller seedlings planted at the space of 15 cm. This combination is the most appropriate to the Horizontal Subsurface Flow Constructed Wetlands (HSSF-CW) model in removing soluble Fe from the coal AMD.

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