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Enhanced Soil Chemical Properties and Rice Yield in Acid Sulphate Soil by Application of Rice Straw

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ABSTRACT

Swampland development such as acid sulphate soil for agricultural cultivation has various problem, including high soil acidity, fluctuated and unpredictable water flooding and the presence of toxic elements such as Fe which resulting in low crop yields. The research was conducted at the experimental station Belandean, Barito Kuala regency in dry season 2007. The objective of research was to study the effect of rice straw on the dynamic of soil pH, the concentration of iron and sulphate and yield on tidal land acid sulphate soil at two different water inlet channel. This research was designed in RCBD (Randomized Completely Block Design) with five treatments (0, 2.5, 5.0, 7.5 and 10 Mg ha^{-1}) and four replications. Dolomite as much as 1 Mg ha^{-1} was also applied. This research was divided into two sub-units experiment *i.e.* two conditions of different water inlet channel. The first water channels were placed with limestone and the second inlet was planted with *Eleocharis dulcis.* The results showed that (i) rice straw application did not affect the dynamic of soil pH, concentration of iron and sulphate, and (ii) the highest yield was obtained with 7.5 Mg ha^{-1} of rice straw.

Keywords: Acid sulphate soil, rice straw, rice yield, soil chemical properties

INTRODUCTION

Swampland has an important role in agriculture development. The development of acid sulphate soils have several constraints including high soil acidity. Oxidation of phyrite compound increases soil acidity and the solubility of Fe^{2+}. Fluctuated and unpredictable water flooding causes low water quality. Improving the water quality can be carried by flowing water through the biofilter of *Eleocharis dulcis* and it could increase the pH from 0.14 to 0.25 units and decrease concentration of Fe (6-27 mg kg^{-1}) and SO_4 (30-75 mg kg^{-1}) (Jumberi *et al*. 2003). *E. dulcis* can be applied on both in tertiary channel and quaternary channels.

Soil acidity can be reduced by applying ameliorant such as organic matter and lime. Organic mater is a source of nutrient that have ability to chelate heavy metals that poisoned plants. Rice straw contains several nutrients such as N, P, K, and S (Makarim *et al*. 2007). Dobermann and Fairhurst (2000) stated that every 1,000 kg of rice straw that returning contained approximately 5-8 kg N ha^{-1}, 0.7-1.2 kg P ha^{-1} and 12-17 kg K ha^{-1}.

Limestone also reduces the concentration of toxic ions such as H^+, Al^{3+}, Fe^{2+} and SO_4^{2-}.
Ca element contained in the lime plays a key role as an essential nutrient in plant and participates in root and stem elongation (White and Broadley 2003). It is related to its role as a regulator of growth and development (Hepler 2005). Lime has the ability to neutralize soil acidity so that the macro and micro nutrient availability will be increase. Therefore nutrient availability in acidic sulfate soil is low to very low, knowledge of nutrient deficiency is important factor when the reclamation and management practices are performed in acid sulphate soil (Jintaridth *et al*. 2006).

Result of research showed that 1.5 Mg ha^{-1} $CaCO_3$ increased rice yield 30% on acid sulphate soils type B Unit Tatas, Central Kalimantan. However, application of 2.0 Mg ha^{-1} $CaCO_3$, increased rice yield by 20% on acid sulphate soils type C Barambai, South Kalimantan (Noor 2004). Combination of rice straw (5.0 Mg ha^{-1}) with lime (3.5 Mg ha^{-1}) increased soil pH from 4.32 to 4.50, decrease the concentration of Fe^{2+} and SO_4^{2-}, as to 22.9% and 11.7%, and increase the yield of paddy (variety Margasari) 59.96% compared with controls (Hairani *et al*. 2006). Results of these studies indicated that proper management of land (utilization of materials such as rice straw ameliorant and lime and water management, combined with the use of biofilter) could increase productivity of soil and plant.

The objctive of the present study was to study the effect of rice straw on the dynamic of soil pH, the concentration of iron and sulphate and the rice yield on tidal land acid sulphate soil at two different water inlet channel.

MATERIALS AND METHODS

Study Site

This research was conducted on acid sulphate soils type B in the dry season in 2007. This research was a long-term experiment that began in dry season 2003 in experimental station Belandean, Barito Kuala, South Kalimantan.

Exprimental Set up

The plot experiment was a 6 × 6 m. Ameliorant that used was rice straw with five dosages: 0, 2.5, 5, 7.5; 10 (Mg ha^{-1}). Treatments were arranged in RCBD with four replications so all treatments were 20 units. Lime, 1 Mg ha^{-1} was also applied. Irrigation system on experimental plots set up by the system of water flow in one direction by using automatic door. Water from the tertiary channel came through the door into the water inlet, and then flowed into the plot of paddy field. The experiment was divided into two sub-units of the experiment, two conditions of water inlet channel with channel dimensions (50 m length, 1 m width and 0.8 m depth). The first water channels was placed with limestone given as much as 300 kg of lime (6 sacks), and placed separately (3 parts), respectively - each was 2 sack which equals to 100 kg. The second water channels was planted as much as 2% of land area and planted simultaneously with rice seedlings.

Land Preparation and Plantation

Land was prepared by cutting the weed and cultivating with trowel (traditional tool). The spread straw and lime were spread on land that has been prepared, before scattered, straw should be mashed with chopped, then according to the dosage, each straw was spread into the plot before planting. Rice was planted when seedlings were 25 days old with a distance of a 20 × 20 cm (Batanghari varieties). Urea fertilizer was applied twice that were at one-week-old and one-month old plants with total 100 kg ha^{-1} while KCl fertilizer dosage of 100 kg ha^{-1} and SP-36 fertilizer with a dosage of 200 kg ha^{-1} given during one-week-old plants. Observation of plant performance was iron scoring (IRRI 1996) at rice severed from environmental stress and the grain weight.

Soil Sampling and Analysis

Soil samplings were conducted twice, depend on certain condition of soil chemical properties that have known based on previous research. Soil parameters that observed were pH (H_2O extract of 1: 2.5 - Electrodes Glass), Fe^{2+} (extract NH_4OAc 1 N pH 4.8 - AAS) and SO_4^{2-}(H_2O extract - Spectrophotometer) (Balai Penelitian Tanah 2005).

Statistical Analysis

All data were analysed by standard error and drawn with Sigma Plot program by Systat Software Inc.

RESULTS AND DISCUSSION

Dynamic of Soil pH, Fe^{2+} and SO_4^{2-}

Dynamic of soil pH

Rice straw treatment did not show the differences among the treatments both on observation 5 and 10 WAP both in two different water inlet channel (Figure 1). Organic acids that produced from rice straw decomposition process is dominated by acetic acid that buffer the process of soil pH. Acetic acid is the dominant organic acids formed in the early stages of rice straw decomposition in flooded soil and have an influence on soil acidity (Tadano and Yoshida 1978). According to Huang and Violante (1986) the concentration of acetic acid in the soil solution could reach 265-570 × 10^5 M. The occurrence buffer during the changing process of soil pH because of the release of H^+ ions from soil solvent due process of dissociation of acetic acid carboxyl group. Carboxyl group dissociation that can occur at pH 3-9 (Tan 1986), so that although straw can cause reductive condition but remains statistically not different on pH values among treatments.Figure 1 shows a higher pH value at 10 WAP observation. It was the reaction of dolomite which was slower in release (Kuswandi 1993), Ca and Mg ions were produced from the hydrolysis process of lime sufficient to neutralize soil acidity so that the soil pH increased. According to Kovaèeviæ and Rastija (2010)_dolomite and calcite are plenty of used to neutralize soil acidity.

Although there was no difference between treatments, but the water inlet with lime treatment, visible increased in soil pH with increasing doses of

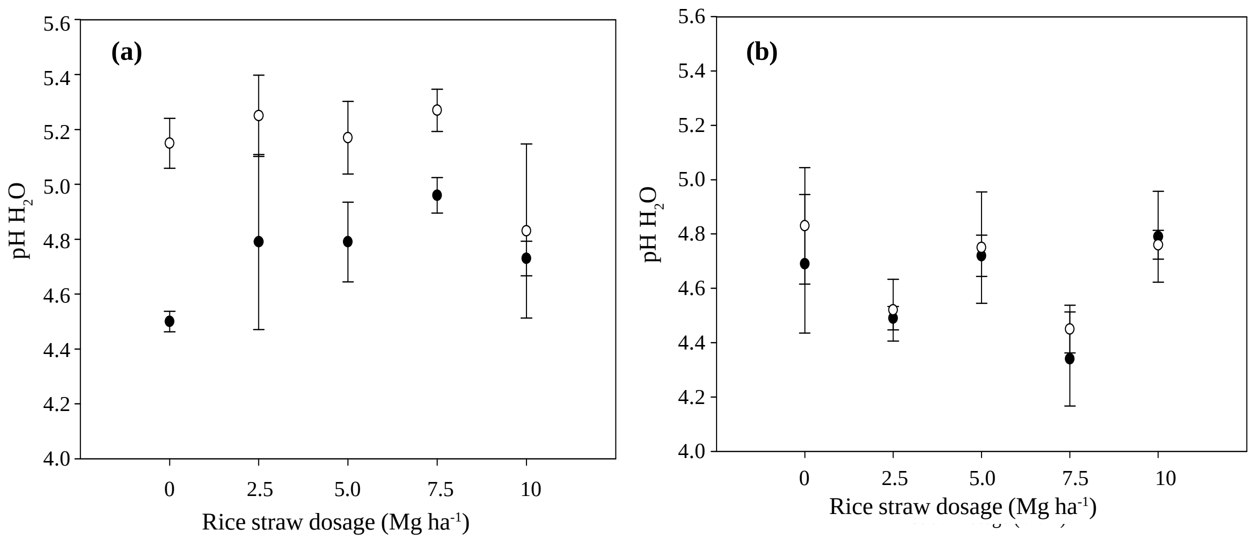

Figure 1. Dynamic of soil pH as affected by applicaion of ameliorant rice straw on the water inlet with lime treatment (a) and water inlet that planted with *E dulcis* (b). ● = 5 WAP and ○ = 10 WAP.

straw given (0 to 7.5 Mg ha^{-1}), this was due to reduction of Fe^{3+} to Fe^{2+} by the organic materials that could increase soil pH and increased the concentration of Fe^{2+} (Figure 2a) (Konsten *et al.* 1990), whereas at straw doses of 10 Mg ha^{-1} decreasing soil pH was related with organic acid produced from the decomposition process. Kongchum (2005) reported that rice straw paddy decreased soil pH. Soil pH values on the water inlet that planted with *E. dulcis* were fluctuated and was in the ranged of 4.3 to 4.8. Unlike to water inlet with lime treatment, soil pH increased to 5.3. This was related to lime which was technically better than other ameliorant materials in improving the soil pH.

Dynamic of Fe^{2+} Concentration

Application of straw with different dosages were not affected the measured concentration of Fe^{2+} on both inlet water channel (Figure 2). Nevertheless, Straw application tended to increase the concentration of iron because the organic material is an electron donor which causes more reductive atmosphere, resulting in increase concentration of Fe^{3+} to Fe^{2+}. However treatment of 10 Mg ha^{-1} (10 WAP) straw showed more lower value in Fe^{2+} concentration. It shows that if organic material completely decomposed, it will produce humic substances that have a role in lowering the concentration of Fe^{2+} through chelation (Stevenson 1994). Figure 2 also shows that the concentration of Fe^{2+} was higher on 5 WAP at both inlet water channel. This is apparently related to soil redox condition. Inundation that supported with availability of organic material will trigger a reduction of Fe^{2+}, increases solubility with the following equation: $Fe(OH)_3 + \frac{1}{4} CH_2O + 2H \; Fe^{2+} + \frac{1}{4} CO_2 + 1\frac{1}{4} H_2O$ (Groenenberg 1990).

Increasing the concentration of Fe^{2+} in the acid sulphate soil due to inundation will also be balanced by the increasing concentration of humic in soil solution, so naturally between Fe^{2+} and material Humic will always balanced, the process will depend on the amount or quality of organic matter (Tan 2003). The solubility of Fe^{2+} increased in conditions of reductive (5 WAP) but it was not followed by an increase in soil pH (Figure 1) which was caused by process soil buffers, although there was consumption of H^+ ions from soil solution, soil pH did not increase because it simultaneously released H^+ ions from soil solution which caused dissociation of carboxyl groups. At 10 WAP drained land (before harvest), dry land conditions made oxygen entry easily and caused the oxidation of Fe^{2+} which resulting in decreasing the concentration of Fe^{2+}. In addition, on treatment of 0 Mg ha^{-1}, Fe^{2+} reduction was still occurred, it shows that the influence of inundation was greater than the effect of straw in the process of reduction of Fe^{2+}.

Dynamic of SO_4^{2-} Concentration

Both in water inlet channel, there was no different in SO_4^{2-} concentration (Figure 3). On observation of 10 WAP, SO_4^{2-} concentration increased. This is related to soil redox conditions during the cultivation where the concentration of SO_4^{2-} increaseing with plant age was related to dry

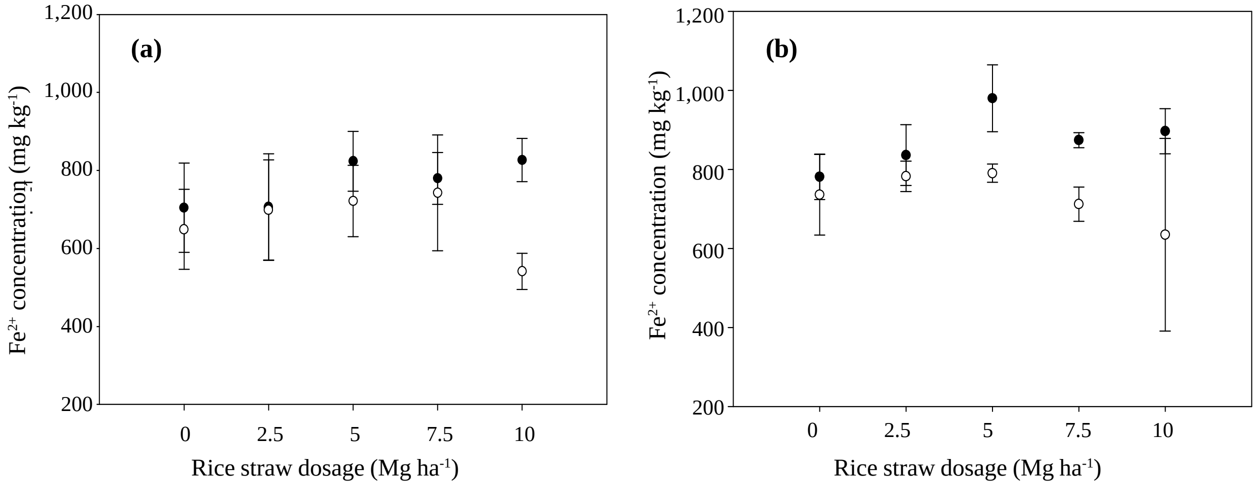

Figure 2. Dynamic of Fe^{2+} concentration as affected by application of ameliorant rice straw on the water inlet with lime treatment (a) and water inlet that planted with *E. dulcis* (b). ● = 5 WAP and ○ = 10 WAP.

conditions (oxidative) to support the ripening fruit. While the observation at 5 WAP, oxygen availability and sulfate reducing activity of microorganisms was limited so that the SO_4^{2-} concentration decreased. The reduced concentration of SO_4^{2-} also caused by microorganisms that caused metals such as SO_4^{2-} precipitated (Gazsó 2001). The mechanism of micro-organisms to influence toxic elements include the mobilization and immobilization (Gazsó 2001). Immobilization of heavy metals are shown by the formation of precipitation, biosorption and bioaccumulation. One was influencing the pH of biosorption and bioaccumulation.

Figure 3 also shows the SO_4^{2-} concentration at 10 WAP which was more lower on dosage of 0, 2.5 and 5.0 Mg ha^{-1} at channel that placed with limestone. It is caused by Ca^{2+} ions from lime neutralize the ion SO_4^{2-} that forming $CaSO_4$ (gypsum), thereby reduce the activity of sulfate ions. This condition was also supported by the pH values above 5 (Figure 1) that consequently inhibited the activity of oxidizing bacteria, due to the increased population of other bacteria that could compete in making the various needs of life such as oxygen and others. According to Mills (2002) bacterial substitution occurs with changes in soil pH.

The ability to absorb or neutralize the element of S caused SO_4^{2-}concentrations were lower in the water inlet channel which was planted *by E. dulcis* (Figure 3b). Mulyanto *et al.* (1998) cited by Jumberi *et al.* (2003), reported that *E. dulcis* were able to absorb S element as 4,500 mg kg^{-1}

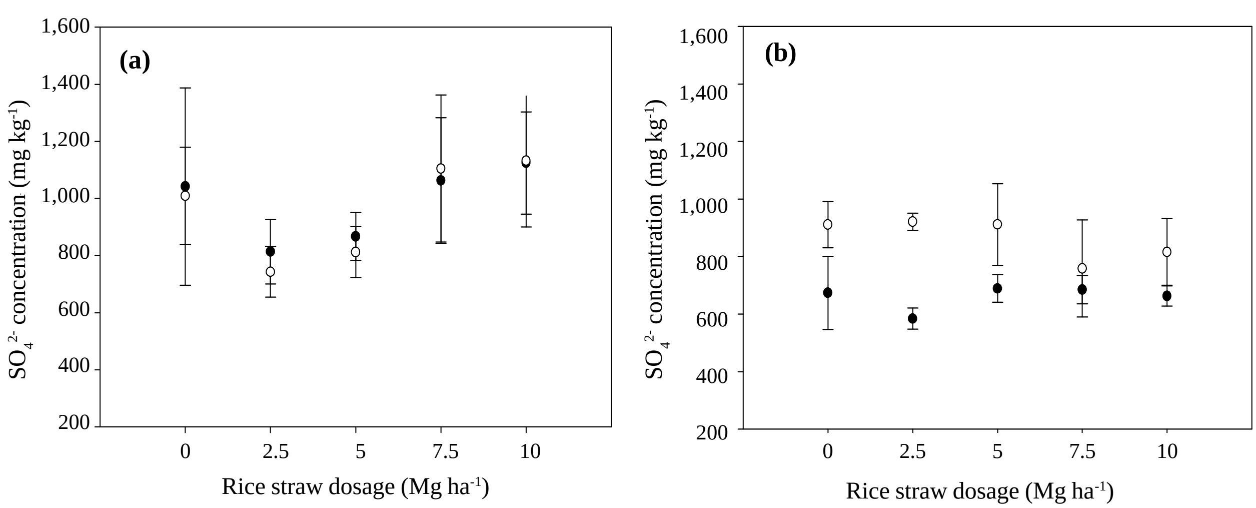

Figure 3. Dynamic of SO_4^{2-} concentration as affected by application of ameliorant rice straw on the water inlet with lime treatment (a) and water inlet that planted with *E. dulcis* (b). ● = 5 WAP and ○ = 10 WAP.

Table 1. Score of Fe^{2+} toxicity based on IRRI (1996).

Rice straw Dosage (Mg ha^{-1})	Water inlet with lime		Water inlet that planted with *E. dulcis*	
	5 WAP	10 WAP	5 WAP	10 WAP
0	5	4 – 5	4 – 5	4 – 5
2.5	4	4	4	3 – 4
5.0	4	4	3 – 4	3
7.5	3 – 4	3	2 – 3	3
10	3 – 4	3	2	2 – 3

Fe-toxicity : 2 = growth and tiller formation is almost normal, reddish brown spots at the end of the old leaf, 3 = growth and tiller formation is almost normal, older leaves reddish brown or yellow orange, 5 = growth is slightly inhibited the formation of tillers, leaves many change in color, and 7 = growth and seedling establishment are largely halted.

Iron Toxicity Score and Grain Yield

Rice plants on the water inlet channel which was planted *by E. dulcis* showed better performance than treatment of incoming water channels which were given lime (Table 1). This was related to *E. dulcis* that had the ability to absorb and neutralize the element of Fe^{2+} and SO_4^{2-} and might be due to its rooting had rhizosfer microbes, as reported by Suriawira (2003) that plants generally have functioning as a biofilter microbial rhizosfer. This microbes are able to release organic and inorganic materials so it has capability to improve the water quality of from metal pollution like Fe^{2+} and SO_4^{2-}, this had resulted in hazardous metals were not active and was not toxic to plants and finally it increased crop yields (Figure 4).

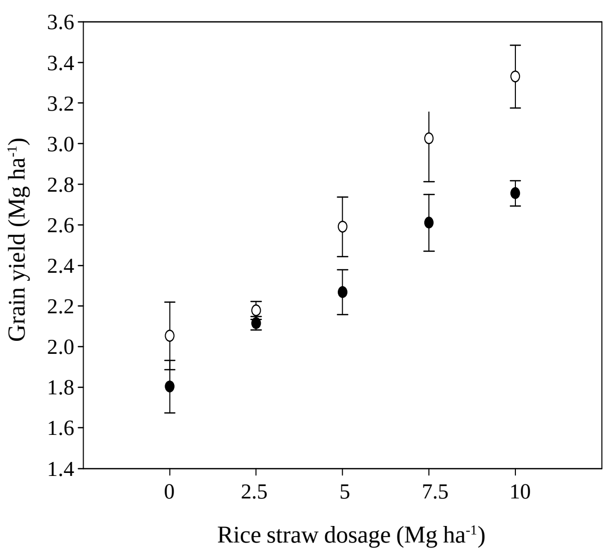

Figure 4. Grain yield as affected by application of rice traw on the two water inlet channels. ● = water inlet with lime and ○ = water inlet that planted with *E. dulcis*.

Grain yield increased with increasing dosage of straw (Figure 4). Straw is the major organic material for rice that N was released during decomposition and its return is slowly (Cho and Kobata 2002). Water inlet channel which was planted by *E. dulcis* had higher yield. Based on statistical analysis, 7.5 Mg ha^{-1} and 10 Mg ha^{-1} did not give different yield both in two water inlet channel and increased yield was 45% (water inlet with lime) and 47.3% (water inlet that planted with *E. dulcis*). Application of straw compost improved the availability of nutrients so that the paddy yield also increased (Indriyati and Jumberi 2001; Luu *et al*. 2001). The addition of organic matter will increase the negative charge that can increase soil cation exchange capacity, there is a correlation between soil organic matter with the CEC (Stevenson 1994). The role of organic matter on nutrient availability in soil can not be separated by the process of mineralization which is the final stage of the decomposition process and in the process of organic matter will be released minerals plant nutrients such as N, P, K, Ca, Mg, S, and micro nutrients as well as reduce the solubility of elements in soil solution poisoned by reaction chelation and fixation that can increase nutrient availability and finally increase crop yields.

CONCLUSIONS

Rice straw application at various dosage levels did not affect the dynamic of soil pH, concentration of iron and sulphate at two different water inlet channel. Dynamic of soil pH was more influenced by the lime while the concentration of iron and sulphate were more influenced by soil redox conditions. Rice straw with a dosage 7.5 Mg ha^{-1} gave an optimum grain yield with the increase in grain yield in the amount of 45% to water inlet with lime treatment and 47.3% to water inlet that planted with *E. dulcis.*

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