Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2014.19.2.77

Influence of Height Waterlogging on Soil Physical Properties of Potential and Actual Acid Sulphate Soils

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Received 31 March 2014 / accepted 2 May 2014

ABSTRACT

Water management is main factor that determines the successful of rice cultivation in acid sulphate soil. Soil waterlogging determines the direction and rate of chemical, geochemical and biological reaction in the soil, indirectly these reactions may influence to the changes of soil psycal properties during soil waterlogging process. The experiment was aimed to study the changes of two type of acid sulphate soils physical properties during rice straw decomposition processes. The research was conducted in the greenhouse consisting of the three treatment factors using the completely randomized design with three replications. The first factor was soil type: potential acid sulphate soil (PASS) and actual acid sulphate soil (AASS). The second factor was height of water waterlogging: 0.5-1.0 cm (muddy water–level condition) and 4.0 cm from above the soil surface (waterlogged). The third factor was organic matter type: rice straw (RS), purun tikus (*Eleocharis dulcis*) (PT) and mixed of RS and PT (MX). Soil physical properties such as aggregate stability, total soil porosity, soil permeability, soil particle density and bulk density were observed at the end of experiment (vegetative maximum stage). The results showed that acid sulphate soil type had large effect on soil physicl properties, soil waterlogging decreased aggregate stability, soil particle density and bulk density both of soil type.

Keywords: Acid sulphate soils, soil physical properties, and waterlogging

INTRODUCTION

Originally, acid sulphate soils is unfertile soil for rice cultivation. Low soil pH, low phosphorus availability and high iron concentration are the dominant characteristics of acid sulphate soils. In Addition, acid sulphate soils have high clay content, this condition lead low soil permeability and poor drainage. Rice cultivation on acid sulphate soil in tidal swampland usually is carried out under waterlogged or muddy water–level condition, esspecially during land preparation and vegetative stage of rice growth. In wetlands, soil waterlogging and incorporating of rice straw that conducted by farmers to improve soil properties and increased rice yield (Kongchum *et al.* 2006; Sukristiyonubowo *et al.* 2013).

Organic matter application influences soil physical properties such as soil structure, bulk density and soil porosity (Shaver 2010; Lucas *et al.* 2014). Application of organic residues often exhibit different physico–chemical properties and impact on soil ecosystem in different ways. However, water management plays key role in agricultural practice on tidal sampland. Rice field is generally subjected to many cycles of alternative waterlogging and drying during rice growing. Soil waterlogging enhances chemical properties of acid sulphate soil (Fahmi *et al.* 2012). In addition, soil waterlogging influences soil physical properties such as; lead swelling of colloids, reduce aggregate stability, and reduces permeability of soil (Ponnamperuma 1984), and according to Reddy and DeLaune (2008) soil bulk density usually decreases due to the destruction of soil aggregates and the high water-absorption capacity of organic matter.

The term of acid sulphate soil is related with the presence of sulphidic material (pyrite) in the soil, if it is oxidized it may produce sulfuric acid and lead soil pH become very acid (Dent 1986). Based on the presence of pyrite layer and soil acidity, acid sulphate soil is divided in two order; (1) potential acid sulphate soil (PASS) *i.e.* if pyrite layer on > 50 cm from soil surface, (2) actual acid sulphate soil (AASS), *i.e.* if pyrite layer on < 50 cm from soil surface. Soil survey staff (2010) classifies acid sulphate soil in two great group, *i.e. sulfaquent* (entisol) and *sulfaqeft* (inceptisol). Potential acid sulphate soil including in great group *sulfaquent* with characteristics are greyish colored and unripe (n < 0,7), whereas AASS including in great group of *sulfaqeft* with characteristics are brownish colored, ripe (n = 0,7) and very acid (pH < 3,5) (Breemen and Pons 1978).

Water availability is main factor that determine the successful of rice cultivation in acid sulphate soil. Soil waterlogging governs the direction and rates of chemical, geochemical and biological reaction in the soil, indirectly these reactions may influence to the changes of soil physical properties during soil waterlogging process. The magnitude of changes are greatly influenced by many factors, such as duration of waterlogging, soil type, soil texture, and soil organic matter (Cosentino *et al.* 2006; Li and Shao 2006; Shaver 2010; Bandyopadhyay *et al.* 2010). According to Zhang *et al.* (2013) the temporal changes of soil physical properties in paddy soils depend not only on intrinsic soil properties but also on external hydrological condition, Goebel *et al.* (2005) stated that soil wettability influences soil physical property such as agregate stability. Previously, Hairani and Susilawati (2013) concluded that soil type determines the pattern of changes in soil chemical properties rice straw decomposition processes. Based on those facts, the present work was aimed to study the changes of soil physical properties during rice straw decomposition processes on the two type of acid sulphate soils under waterlogged and muddy water–level condition.

MATERIALS AND METHODS

The research was conducted in the greenhouse consisting of three treatment factors using a completely randomized design with three replications. The first factor was soil type: potential acid sulphate soil (PASS) and actual acid sulphate soil (AASS). The second factor was height of water waterlogging: 0.5-1.0 cm (muddy water–level condition) and 4.0 cm from above the soil surface (waterlogged). The third factor was organic matter type: rice straw (RS), purun tikus (*Eleocharis dulcis*) (PT) and mixed of RS and PT (MX). The soil used in the experiments was taken at depth of 0–20 cm from potential and actual acid sulphate soils which are located Belandean research station, Barito Kuala District, South Kalimantan, Indonesia, with 6 m elevation and geografic positions at South : 3°10'14.32" and East : 114°36'30.87". The soils were air dried and sieved (< 2 mm) and rice straw was cutted into small pieces (about 5 cm in size) to homogenize their particle size before application. Twenty four kg of air dried soil and 60 gr of rice straw (equally with 5 t ha^{-1}) were placed into plastic pot (60 cm and 30 cm for diameter and height of pot respectively). Sufficient amount of rain water was added into each pot such that the water level was 3 cm above the soil surface. Two weeks later, water was drained to leach soil acidity and toxic elements due to pyrite oxidation during air dried soil.

Rice seedlings (aged 21 days) were planted in the pot, sufficient amount of water was added into the pots in accordance with treatments such that the water level were 1 cm and 4 cm above the soil surface. During the experiment, aquadest was regularly added into each pot in order to maintain the water level. Three days after planting, 2.36 g SP–36, 1.18 g each of urea and KCl were applied as basal fertilizers to the soil in the pot (equally with 100 kg urea ha^{-1}, 200 kg SP–36 ha^{-1} and 100 kg KCl ha^{-1}). Soil physical properties that observed were aggregate stability which expressed as mean weight diameter (MWD), total soil porosity, soil permeability, soil particle density (PD) and bulk density (BD)which were conducted at the end of experiment (maximum vegetative stage of rice plant).

The size distribution of the dry-stable aggregates was determined using single sieving method (Rachman and Abdurachman 2006), soil permeability was determined using falling head soil core method (Reynold and Elrick 2002), soil PD was determined using immersion method with a volumetric flask (Agus and Marwanto 2006). The soil BD was determined using the core method (Agus *et al.* 2006), soil porosity was calculated using data BD and PD according to the following equation:

$$\text{Porosity}\ (100\%) = 1 - \frac{\text{BD}}{\text{PD}} \times 100$$

Data collection and analysis

Only soil type and height of waterlogging factor on the observed parameters were statistically significant. Therefore, they were analyzed by the Analysis of Variance (ANOVA) method and presented in a scatter form. Since there were no significant effects of height waterlogging treatments,

Tabel 1. Soil properties of PASS and AASS that were used in the experiment.

Soil properties	**PASS**	**AASS**
C organic (%)	9,75	7,30
Texture		
Clay (%)	36	56
Silt (%)	61	43
Sand (%)	3	1

therefore to explore the information, results and discussion of parameters were more focused on the main effect of soil type.

RESULTS AND DISCUSSION

Soil Aggregate

Aggregate stability is a relative term used to describe the resistance of a soil's structure to destructive forces such as dispersion, raindrop impact and slaking (Six *et al.* 2000). Bronick and Lal (2005) stated that aggregates are formed through the combination of mineral particles with organic and inorganic substances**.** Application of OM influences soil physical properties (Ruehlmann and Korschens 2009; Bandyopadhyay *et al.* 2010). Contrary, Eluozo (2013) reported that addition of OM to a soil was typically low percentage, so it did not significantly influence soil bulk density. The recent study showed that OM type did not affect significantly to the changes of soil physical properties such as PD, BD and soil porosity (data not shown). For this reason, we only discuss about influence of soil type treatment on soil physical properties. There were no effect of OM type on soil physical properties likely related with OM quality (C/N ratio). Carbon and Nitrogen ratio of RS, PT and MX were 38.8: 42.5, and 40.6 respectively. In the previuos study, Fonte *et al.* (2009) concluded quality of organic matter that was applied did not influence the aggregate formation and aggregate stability. Aggregate formation and aggregate stability were influenced by soil organic carbon content, Abiven *et al.* (2007) stated that soil aggregate stability did not only influenced by the quantity but also by the quality of OM. Mineralization of OM contributed to soil structure degradation (Obalum and Obi 2010), and according to Le-Guillou *et al.* (2012) late stage of decomposition played a greater role than during the initial stages on soil aggregate stability.

Cosentino *et al.* (2006) concluded that variability in soil water content had less impact on aggregate stability than the addition of straw, whereas the recent experiment showed that soil waterlogging decreased aggregate stability both of soil type (Figure 1). This difference may be related to soil type that was used in the experiment, in which Cosentino *et al.* (2006) had used soil with low clay content whereas this experiment had used soil with large clay content (Table 1). Soil texture mainly clay fraction is the one of the important factor that influence on aggregate stability (Shaver 2010).

Aggregate stability of both soil type decreased due to soil waterlogging (Figure 1). Soil waterlogging decreased soil aggregate stability throught swelling of colloids, De–Campos *et al.* (2009) was also reported that soil waterlogging decreased soil aggregate stability and increased dissolution of cementing agents such as iron oxide. Furthermore soil waterlogging decreased oxygen availability, subsequently restricted the activity of microorganisms decomposer, in which microorganisms activity in soil promotes soil aggregate formation (Tang *et al.* 2011). Li and Shao (2006) revealed that aggregate stability were affected by soil texture, predominant type of clay, extractable iron, and extractable cations.

In addition, these fact may be corelated with increasing iron concentration due to reduction proceses of iron (hydr)oxides under waterlogged

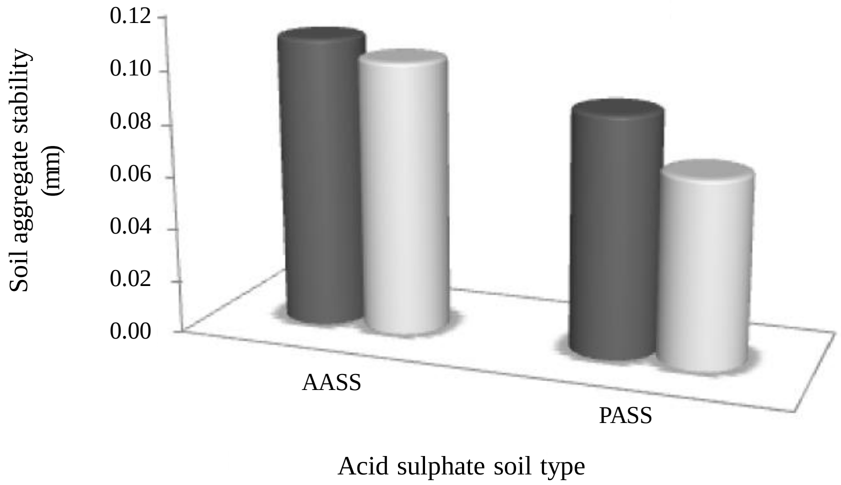

Figure 1. Soil aggregate stability of actual acid sulphate soil (AASS) and potential acid sulphate soil (PASS) under waterlogged and muddy water–level condition. ■ : Muddy water-level, □ : Flooded.

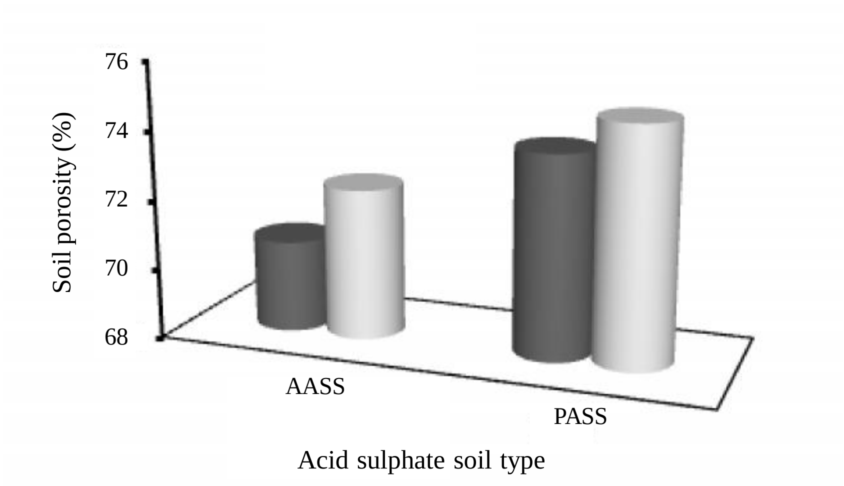

Figure 2. Soil porosity value (%) of actual acid sulphate soil (AASS) and potential acid sulphate soil (PASS) under waterlogged and muddy water–level condition. ■ : Muddy water-level, □ : Flooded.

condition as reported by Hairani and Susilawati (2013) (Table 2). Soil waterlogging increased Fe^{2+} concentration in soil solution, iron (hydr)oxides have been reported to be important aggregators (Rhoton *et al.* 2003). De–Campos *et al.* (2009) and Sung (2012) stated that increase in Fe^{2+} concentration in soil solution was well correlated with the decrease in the aggregates stability. Additionally based on soil type under waterlogged condition, lower aggregate stability value was observed in PASS than in AASS (Figure 1), and this fact confirm that Fe^{2+} concentration in soil has an important role in aggregate stability. Furthermore, Duicker *et al.* (2003) stated that poorly crystalline Fe component appears more important than organic carbon in terms of agregate stability for soils with relatively low soil OM contents.

In Addition, lower aggregate stability due to soil waterlogging may explain with increasing water content in clay structure, this condition leads aggregate in unstable condition. Ponnamperuma (1984) stated that soil waterlogging destroys aggregate, this condition caused by aggregates are saturated with water. Sudjianto *et al.* (2011) concluded that swelling of clay linearly increases with the increasing of water content.

Total soil porosity, soil permeability, bulk density and particle density

Total soil porosity of PASS and AASS were very high (Figure 2), this condition may be related to soil preparation before the experiment was conducted, in which both of soils that used in this experiment were air dried and sieved to homogenize their particle size. This condition may lead soil more porous even though they have high clay content.

Total soil porosity of PASS and AASS under waterlogging condition were higher than soil under muddy water–level condition (Figure 2). This condition was related to BD of both soil types, in which soil waterlogging decreased soil BD (Figure 4). Furthermore BD is an important soil property that affects soil porosity (Shaver 2010). The porosity of a soil is inversely related to the soil BD, Li and Shao (2006) stated that soil BD was negatively corelated with total porosity, similiar corelation of total soil porosity and BD have been showed in this result, BD values of AASS and PASS increased (Figure 4) with decreasing their total soil porosity (Figure 2). Increase of soil BD will decrease soil pore spaces that are occupied by air and water. Soil waterlogging leads swelling of soil colloids especially for soils that contain expanding clay type such as smectitite and vermiculite. Alwi (2011) found that soil clay mineralogy in Belandean research station that used in this experiment contained mixed of smectite, kaolinite and vermiculite.

Total soil porosity of AASS was lower than PASS in both soil conditions (Figure 2), this fact may related to soil ripeness and clay content. Soil ripeness (n) is drawing for sum of water (gram)

Table 2. Iron concentration in actual acid sulphate soil (AASS) and potential acid sulphate soil (PASS) for 8 weeks observation after RS application.

Soil type	Iron concentration (mg kg^{-1})			
	2 WAP	**4 WAP**	**6 WAP**	**8 WAP**
PASS	654	653	700	920
AASS	201	279	251	434

WAP : weeks after planting

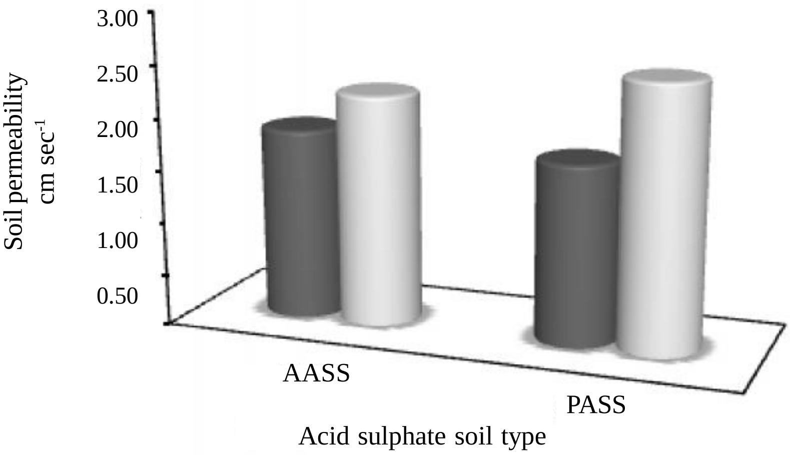

Figure 3. Soil permeability value of actual acid sulphate soil (AASS) and potential acid sulphate soil (PASS) under waterlogged and muddy water–level condition. ■ : Muddy water-level, ▫ : Flooded.

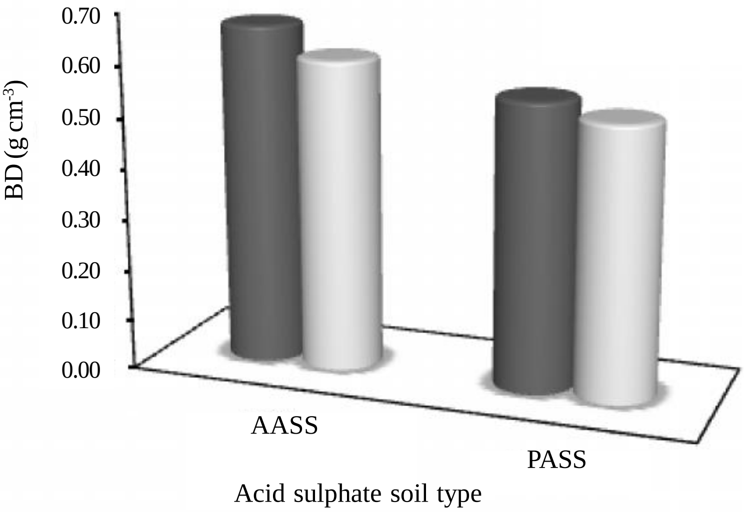

Figure 4. Soil BD value of actual acid sulphate soil (AASS) and potential acid sulphate soil (PASS) under waterlogged and muddy water–level condition. ■ : Muddy water-level, ▫ : Flooded.

that adsorbed in 1.0 g of soil clay. Based on soil classification that proposed by Soil Survey Staff (2010), PASS includes in entisol whereas AASS includes in inceptisol order, and based on soil taxonomy, clasification for AASS is sulfaquept if n value < 0.7 whereas PASS is sulfaquent if n value > 0.7. This mean that clay content in AASS were higher than PASS, such as demonstrated in Table 1.

Soil permeability is intimately related to soil porosity, increasing pore within soil particle increases soil permeability. Soil waterlogging increased porosity of both soil type (Figure 3). As stated previously, soil waterlogging increased soil porosity (Figure 2), thereby increasing soil pore volume can lead water move easily within the soil matrix. In addition, soil permeability of AASS was lower than PASS under waterlogged condition (Figure 3), this condition was related to soil ripeness and clay content of both soil that infleunced to soil porosity, in which total soil porosity of AASS was lower than PASS (Figure 2).

Soil BD is defined as a ratio of dry mass to the total volume of soil (solids added pore space occupied by air and water). Soil BD is intimately related to soil porosity, which is the volume of space within a soil filled with air and water. Chaudhari *et al.* (2013) found negative correlation between porosity and soil BD. Soil waterlogging decreased soil BD of both soil type (Figure 4). Soil waterlogging lead swelling of soil colloids, increased water content in clay stucture, further more lead increasing water percentage compared to solid component in certain volume of soil.

Figure 4 shows that soil BD of PASS was lower than AASS, this condition was related to clay content of both soil type. As stated previously that clay content of AASS was higher than PASS. The role

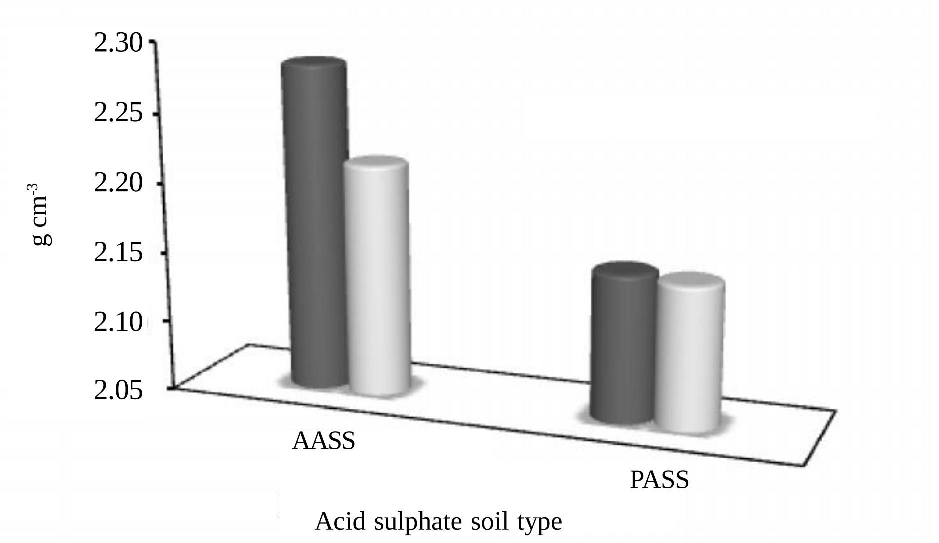

Figure 5. Soil PD value of actual acid sulphate soil (AASS) and potential acid sulphate soil (PASS) under waterlogged and muddy water–level condition. ■ : Muddy water-level, □ : Flooded.

of clay content on soil BD is related to water content, the higher clay content the greater swelling of clay, this condition lead lower soil pores that occupied by air and water. According to Heuscher *et al.* (2005) clay content and water content have significant effect on soil BD.

Particle density is the density of the solid particles that collectively make up a soil sample, PD of a soil sample is actually a weighted mean value for the various kinds of minerals and soil OM. Soil PD describes the soil weight ratio compared to its volume (Lal and Shukla 2004). Figure 5 shows that soil PD of PASS was lower than AASS. Large effect of soil waterlogging on PD of AASS compared to PASS indicated that PD might influenced by soil ripeness, soil development and soil redox condition. Higher clay content of AASS compared to PASS as indication that AASS more ripe than PASS lead PD of AASS is higher than PASS. Soil PD is correlated to clay content, the higher clay content the greater water retention. As a result, this condition causes decreasing proportion of solid particles in certain volume of soil.

CONCLUSIONS

Acid sulphate soil type has large effect on soil physical properties, mainly its clay content. Higher clay content in AASS lead soil more expand, and this condition decreased soil aggregate stability compared to PASS. In addition, the changes of soil physicl properties were influenced by iron concentrations in soil solution. Soil waterlogging decreased aggregate stability, PD and BD through dissolution of cementing agents. Further more, soil waterlogging lead soil more porous as a result increased soil permeability.

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