

Physical Properties of Soils from Several Land Uses in a Tidal Swampland Area Applied with a Fork Irrigation System

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ABSTRACT

In Indonesia, tidal swampland is potential to be developed into agricultural land uses. Water management is the key success of farming on the tidal swampland. In the tidal swampland of Kalimantan, Indonesia, a fork irrigation system is widely applied in the water channels to supply irrigation water to the land. Besides irrigation, soil physical characteristics play an important role in controlling water availability for crops. The ability of soil to store water will determine the amount of available water that can be taken up by plants. This research aimed to determine the soil physical properties that are related to water availability in the soils from different land uses in a tidal swamp land area applied with a fork irrigation system. The experiment was conducted in dry season 2012, in Belawang, Barito Kuala district, South Kalimantan province. The soil samples were taken from four land uses, namely rice field, rubber plantation, mixed cropping, and unmanaged land. The soil physical properties, namely soil bulk density, particle density, porosity, texture, pF 1, pF 2, pF 2.54, pF 4, water content, total pore space, rapid drainage pores, slow drainage pores, available water, groundwater level were measured. In addition, the mineralogical properties of the soils were measured as well. The results showed that the physical properties of the soils taken from different land use varied, however, the change of the land use did not cause changes in the soil mineralogical properties. The mineralogy of the soils from different land uses are relatively the same, namely: quartz, illite, and chlorite.

Keywords: Soil physical properties, land use, fork irrigation system, tidal swampland

ABSTRAK

Lahan rawa pasang surut merupakan lahan yang cukup potensial untuk dikembangkan menjadi lahan pertanian di Indonesia. Pengelolaan air menjadi kunci keberhasilan usahatani di lahan tersebut. Lahan rawa pasang surut Kalimantan menerapkan sistem garpu dalam desain saluran air yang mensuplai air ke lahan. Selain air irigasi, tanah juga berperan penting terhadap ketersediaan air bagi tanaman. Kemampuan tanah menyimpan air akan menentukan jumlah air yang dapat digunakan oleh tanaman. Penelitian ini bertujuan untuk mengetahui sifat-sifat fisika tanah yang terkait dengan ketersediaan air pada berbagai jenis penggunaan lahan di sistem garpu kawasan rawa pasang surut. Penelitian dilaksanakan pada musim kemarau 2012 di Belawang, Kabupaten Barito Kuala, Propinsi Kalimantan Selatan. Contoh tanah diambil dari empat jenis penggunaan lahan, yaitu sawah, kebun karet, kebun campuran, dan lahan yang tidak digunakan. Parameter sifat fisika tanah yang diamati adalah berat volume (BV), kerapatan partikel (BJ), porositas, tekstur, permeabilitas, pF 1, pF 2, pF 2,54, pF 4, kadar air, ruang pori total, pori drainase cepat, pori drainase lambat, air tersedia, dan tinggi muka air tanah. Selain itu, analisis sifat mineralogi tanah juga dilakukan. Hasil penelitian menunjukkan bahwa sifat-sifat fisika tanah berbeda pada berbagai jenis penggunaan lahan. Perubahan penggunaan lahan tidak menyebabkan perubahan mineralogi tanah yang ditunjukkan oleh hasil analisis mineralogi tanah di lokasi penelitian yang relatif sama, yaitu: kuarsa, *chlorite* dan *illite*.

Kata Kunci: Sifat-sifat fisika tanah, penggunaan lahan, sistem irigasi garpu, lahan rawa pasang surut

INTRODUCTION

Tidal swampland is the land that is affected by sea tide. In Indonesia, the tidal swampland spreads out in Sumatera, Kalimantan, Sulawesi, and Papua islands with the total area of 20.13 million ha (Subagyo 2006; Nugroho and Suriadikarta 2010), and about 9.53 million ha out of 20.13 million ha is suitable for agricultural land. The area of tidal swampland that has been opened or reclaimed by the Indonesian government is about 2.27 million ha, while that that has not been reclaimed is approximately 7.26 million ha. The area of tidal swampland that has been used for agricultural land is approximately 1.43 million ha or 53% of the total area of tidal swampland that has been opened by the government. In addition, the area of tidal swampland that is opened independently by local communities is around 3.0 million ha (Haryono *et al.* 2013). Other data show that the total area of tidal swampland that spreads out in 30 provinces in Indonesia is around 11.03 million ha, of which 9.32 million ha is potentially or suitable for agricultural land (Mulyani and Sarwani 2013).

Water management is the key success of farming in the wetlands. Without good water management, the plants at any time may be inundated, especially during the rainy season due to high rainfall, while during the dry season the plants can experience drought stress. In addition to supply the sufficient amount of water, water management is also aimed to keep the layer of pyrite (FeS_2) to be wetted or flooded.

To facilitate the water management in the tidal swampland, then the tidal swampland is divided into 4 types based on the types of flooding, *i.e.* overflow type A, B, C, and D (Widjaja-Adhi 1986; Kselik 1990). The tidal swampland with the overflow type A always experiences an overflowing tide, both in the rainy season and dry season, while the tidal swampland with the overflow type B only experiences an overflowing tide during the rainy season. Further, the tidal swampland with the overflow type C experiences an overflowing tide with the groundwater level of <50 cm, while the tidal swampland with the overflow type D is similar to that of C-type, but the depth of the groundwater is >50 cm.

In the development of tidal swampland, a macro water management system that covers about 5,000 up to 20,000 ha can consist of (1) "anjir" system, (2) fork system, and (3) comb system. In the tidal swampland in Kalimantan, the fork system is widely applied for the water supply network to the land.

The need for land resources due to the increase of human population has resulted in its own pattern

of land uses in a certain area. The impact of this phenomenon is the change on land uses, such as the change of forest into agricultural land or other land uses, which further can disrupt the hydrology and soil stability (Asdak 2003).

Land use strongly influences runoff, erosion, and sedimentation, especially in terms of land capability that plays a role as a buffer against inputs on land, so that rainfall will not cause runoff, soil erosion and flooding. The ability of soil to absorb water is determined by the nature of the soil and land conditions, especially the land use (Haan *et al.* 1982). So far, the studies on soil properties at various land uses of the tidal swampland are still limited.

The study was conducted to determine the physical properties of soils from different land uses located in the tidal swampland area applied with a fork channel system. The results of this study can be used as a reference to understand the soil characteristics and water management in the tidal swampland areas as part of sustainable agricultural management.

MATERIALS AND METHODS

Study Site

The experiment was conducted in 2012 at various land uses of the tidal swampland applied with a fork irrigation system in Wanaraya village, Belawang subdistrict, Barito Kuala district, South Kalimantan. The Wanaraya village is geographically located at $114^{\circ}35'616''$ East longitude and $3^{\circ}01'481''$ South latitude. The type of overflow in this tidal swampland is type B (overflow when high tide) with the slopes of 0% - 2% (level) and altitude of 1-3 m above sea level. The land uses existed in the study area are rice field, rubber plantation, mixed cropping, and forest/unmanaged land.

Soil Sampling and Analysis

Soil samples were collected from the rice fields, rubber plantations, mixed cropping land and unmanaged land, and the physical properties and mineralogy of the soils were analyzed. In each land use, soil samples were taken from 9 sampling points using soil sample rings (diameter 5 cm, height 5.3 cm) with a depth of 0-30 cm. The soil physical properties including bulk density (clod method), particle density (pycnometer method), porosity (calculated from the values of bulk density and particle density), texture (pipette method), pF1, pF2, pF2.54, pF4 (hanging water column technique), water content (volumetric method), total pore space,

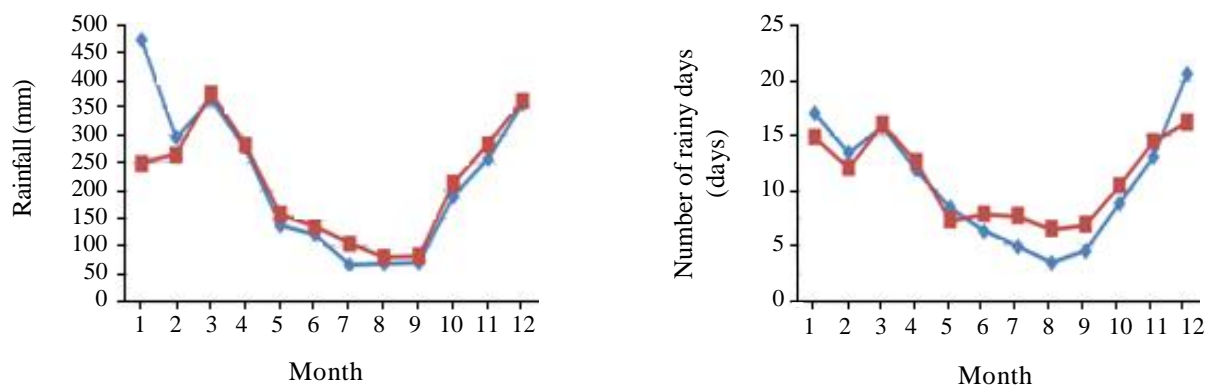


Figure 1. Rainfall and number of rainy days during the last 10 years in Wanaraya village, Barito Kuala District. —◆—: R1 = Year 2002-2006, —■—: R2= Year 2007-2011.

fast drainage pores, slow drainage pores, available water (pF curve), groundwater level in the soil (piezometer method) were measured. In addition, the soil mineralogical properties (X-ray method) was measured as well. The climatic data were collected from the Meteorological, Climatological, and Geophysical Agency of Banjarbaru, South Kalimantan.

RESULTS AND DISCUSSION

General Condition of the Research Area

The patterns of rainfall and number of rainy days during the last 10 years occurred in the study site is presented in Figure 1. The rainfall during the last 10 years showed a similar pattern, except those in January 2002 until 2006 in which the rainfalls were higher than in January 2007-2011. The numbers of rainy days in the last 5 years during the dry season

were higher than in the previous 5 years, while during the rainy season the numbers of rainy days in the last 5 years were lower than in the previous 5 years.

The patterns of temperature during the last 10 years was the same, in which the lowest temperature and the highest temperature occurred in the same months, although the values of the temperature were different. The highest temperature occurred in 2002-2006, while the lowest temperature occurred in 2007-2011.

Physical Properties of the Soils

Table 1 shows that in general the physical properties of the soils from different land uses (rice field, rubber plantation, mixed cropping and unmanaged land) are different. The lowest bulk density, particle density, moisture content, and permanent wilting point were measured in the soil samples taken from unmanaged land, but this soil has the highest soil porosity. This result is in line with the study of Sharma and Aggarwal (1984), which indicated that the soil physical properties may change due to various management practices.

The lowest bulk density and particle density (0.68 g cm^{-3} and 1.95 g cm^{-3} , respectively) were measured in the soil samples taken from unmanaged land. It is believed that this phenomenon is related to the number of vegetation growing on this land, which are dominated by ferns (*kelakai*) and *Galam* trees, so that the entire surface of the land is fully covered by the vegetation. The dense canopy is able to reduce the kinetic energy from the raindrops on the soil surface. In addition, the plant canopy can absorb the rainwater and let the water falls gently to the soil surface without breaking the soil aggregates. In addition, the protection from the plant canopy can result in smaller size of raindrops that fall directly to the soil surface. This condition

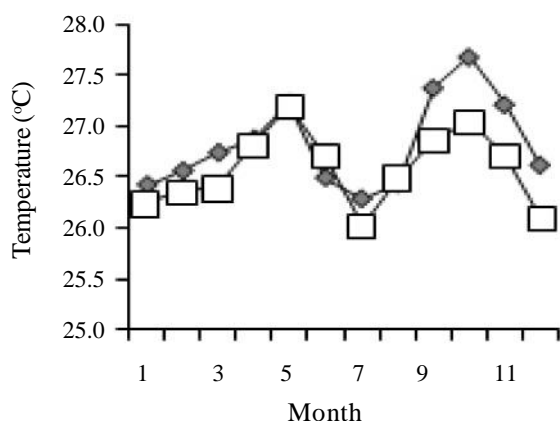


Figure 2. Temperature over the last 10 years in Wanaraya village, Barito Kuala district, South Kalimantan. —◆—: R1 = Year 2002-2006, —□—: R2= Year 2007-2011.

Table 1. Soil physical properties at different land uses of fork irrigation system, at Wanaraya village, Barito Kuala district, South Kalimantan.

Parameter	Land use			
	Rice	Rubber	Mixed	Unmanaged
BD (g.cm ⁻³)	0.74 ± 0.03	0.73 ± 0.02	0.74 ± 0.01	0.68 ± 0.06
PD (g.cm ⁻³)	2.09 ± 0.12	1.99 ± 0.21	1.98 ± 0.09	1.95 ± 0.22
Porosity (%)	64.58 ± 1.24	64.77 ± 0.12	64.41 ± 0.47	69.09 ± 2.13
Texture				
- Sand (%)	31.75 ± 1.71	13.52 ± 0.07	13.08 ± 0.94	41.55 ± 2.58
- Silt (%)	45.48 ± 3.37	42.25 ± 1.14	40.31 ± 0.65	31.28 ± 0.91
- Clay (%)	22.76 ± 1.88	47.28 ± 1.22	46.60 ± 5.83	27.16 ± 4.92
Permeability (cm.h ⁻¹)	9.21 ± 0.01	47.52 ± 3.83	72.73 ± 3.42	4.84 ± 4.80
Water content (% v)	61.9 ± 1.41	57.1 ± 0.70	55.1 ± 0.84	56.05 ± 0.07

provides an opportunity for raindrops to be infiltrated into the soil pores, thus reducing soil compaction triggered by raindrops. Moreover, no soil tillage was conducted on the unmanaged land such as that conducted on other land uses (rice field, rubber plantation and mixed cropping). The results of current study is similar to that in the study of Marieta (2011), which indicated that the high soil bulk density was observed at the less covered soil surface, because during the rain the soil particles will be dispersed and the soil particles can further fill the soil pores, causing soil compaction. The study of Raja (2009) showed that the high soil bulk density may also be affected by the intensive tillage practices. In addition, the mechanical stress on the soil can be indicated by the soil bulk density (Pabin *et al.* 1998).

The higher amount of plant litter in the unmanaged land than that in other land uses (rice field, rubber plantation and mixed cropping) cause more organic matter content in the soil from the unmanaged land than that in other land uses. Soil organic matter content is very influential on the soil bulk density. The study of Buckman and Brady (1982) showed that the soil organic matter content can lower the soil bulk density since the density of organic matter is smaller than the density of soil mineral particles. The study of Handayanto and Hairiah (2007) also indicated that organic matter does not only decrease the soil bulk density, but also binds the soil particles.

The highest soil porosity was measured on the soil samples taken from the unmanaged land, *i.e.* 69.09%. This is presumably due to the lack of soil tillage applied on this land. Soil compaction is the result of continuous tillage, resulting in reduced total porosity of the soil and increased soil bulk density. The compressive force created by the soil moving equipments has reduced the size of soil pores. Therefore, the total soil porosity in rice field, rubber

plantation and mixed cropping land that receive intensive soil tillage is lower than that in the unmanaged land. The relatively broad canopy covering the unmanaged land would protect the soil surface and create good microclimatic conditions, such as the soil surface becomes more moist and the temperature and sunlight intensity becomes lower. Good microclimatic conditions thus support the proliferation and activity of soil organisms. The activities and development of soil organisms can be accelerated due to the availability of organic matter in the soil surface as their energy source. The activities of soil organisms will affect the formation of soil pores, causing the total amount of soil porosity increases. The study of Sutanto *in* Idris (2010) shows that the difference in the soil porosity is influenced by soil organic matter content.

Table 1 shows that the textures of the soils taken from rice field, rubber plantation, mixed cropping land, and unmanaged land are sandy clay loam, silty clay, silty clay and clay loam, respectively, although each soil contains different amounts of sand, silt, and clay. The soils with clay texture have a greater surface area, so the ability of the soils to hold water is high. Fine-textured soils (clay, silty clay and sandy clay) have a larger surface area, so they have high total capacity to hold water, while Hakim *et al.* (1986) suggested that in fact the highest available amount of water is provided by moderate-textured soils (loam, sandy clay loam, and silty clay). This phenomenon occurs due to water molecules are adsorbed more strongly by the fine-textured soils, suggesting that despite the ability of soil to hold water is high, it is not necessarily that the availability of water for plants is high as well.

The water content in the soil from mixed cropping land is lower (*i.e.* 55.1% v/v) than that in other land uses (rice field, rubber plantation and unmanaged land). This is because the process of augmentation of water into the soil that is determined

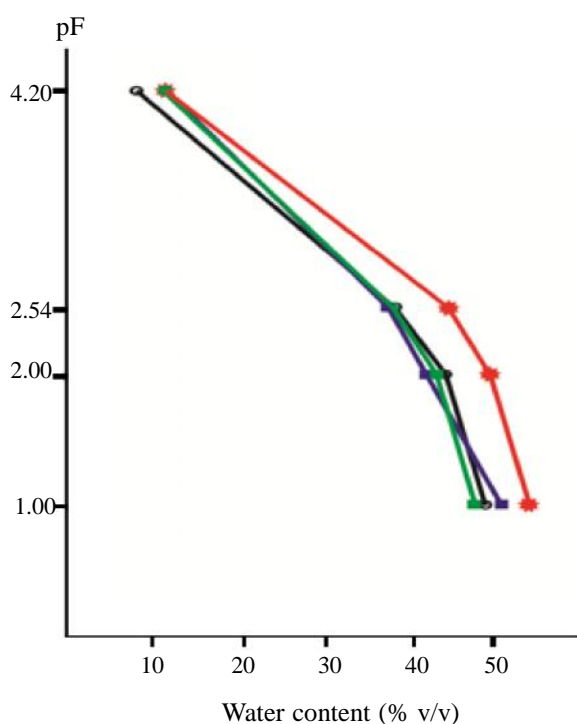


Figure 3. pF curves of the soils from different land uses applied with a fork irrigation system.
 —●— : unmanaged land, —■— : rubber plantation, —■— : mixed cropping, —★— : rice field.

by the soil physical properties regarding its ability to transport and store water. In addition, the porosity of the soil in the mixed cropping land is lower than that in other land uses. Porosity of the soil is an important parameter to predict the soil water-holding capacity. The porosity of the soil will determine the infiltration capacity, water storage and water flow.

The higher the soil porosity, the higher the water infiltration is (Rahim 2003).

Water movement in the soil cross-section is a dynamic process. The pF curve or commonly referred to soil moisture retention curve describes the characteristics of the soil matrix that are related to water retention, the ability of the soil to provide water to plants, and soil pore distribution patterns. The pF curves of the soils from various land uses are presented in Figure 3.

Figure 3 shows that the permanent wilting point of the soil from unmanaged land is lower than that in other land uses. In contrast, the soil from rice field has higher field capacity and permanent wilting point than the soils from other land uses. The available water capacity of soil is characterized by a state of water held between field capacity and permanent wilting point, in which plants can absorb water easily. The study of Soepardi (1983) suggested that the amount of available water that can be absorbed and utilized by plants should be more than the water content in the permanent wilting point. Therefore, knowing the field capacity and permanent wilting point of soil is very beneficial to farmers in determining the timing of irrigation to meet the water needs for plants. The pF curve can also indicate the distribution of soil pores. Plants need oxygen and good soil aeration for their growth, so that rapid drainage pores and slow drainage pores should not be too long filled with water. This condition highly depends on soil texture and structure, the number of mesopores and micropores of the soil, soil drainage, and climate in particular temperature and rainfall. The study of Clair (1998) suggested that balanced precipitation and evaporation is an

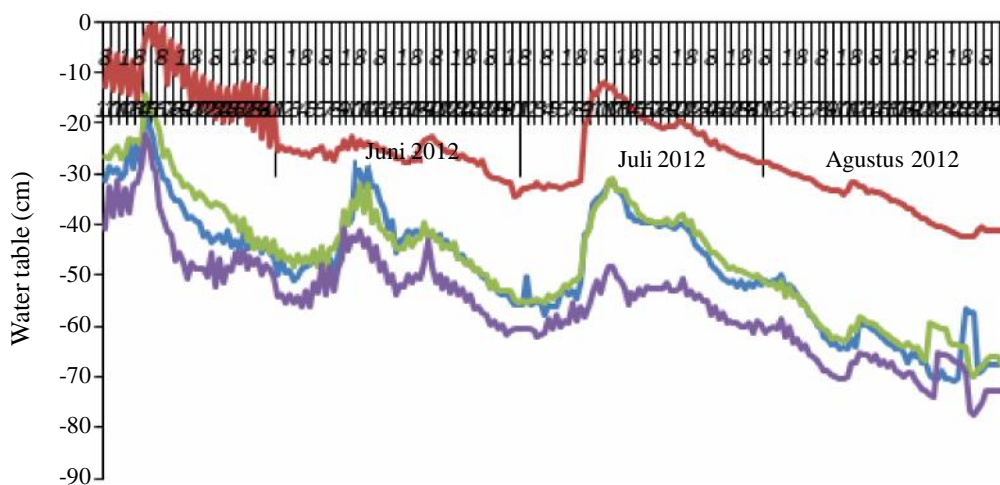


Figure 4. Fluxtuation of groundwater level during dry season (May-August 2012) in different land uses applied with a fork irrigation system, at Wanaraya village, Barito Kuala district, South Kalimantan.
 —■— : rubber plantation, —■— : rice field, —■— : unmanaged land, —■— : mixed cropping.

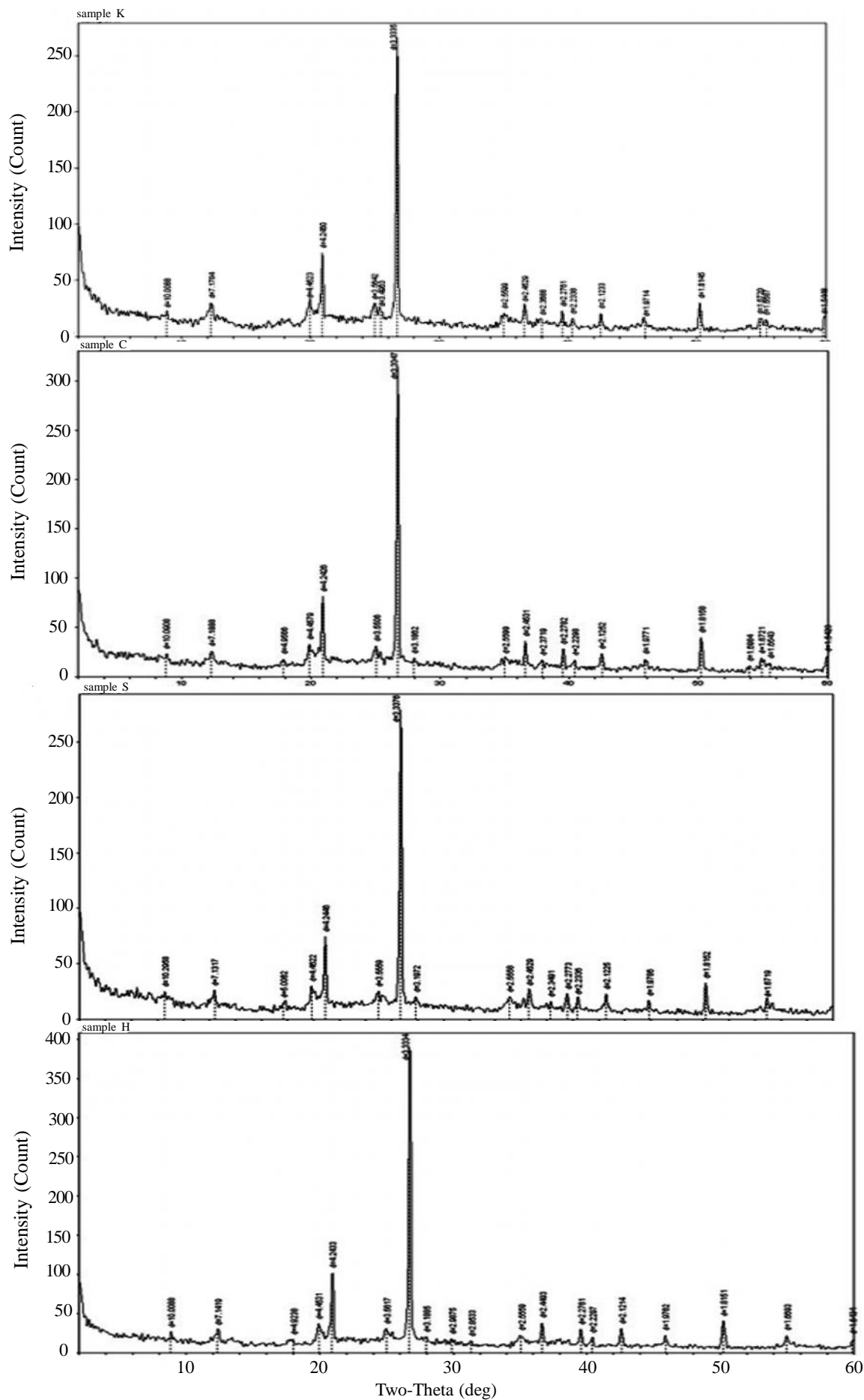


Figure 5. Mineralogy of the soils from different land uses applied with a fork irrigation system, at Wanaraya village, Barito Kuala district, South Kalimantan.

important factor in the wetland management. Drought can affect water tables and runoff (Clair and Ehrman 1998).

Groundwater is the water that is belowground level located in the saturated region in which all the pores and spaces between soils particles are filled with water, in which the top part is called the water table and the bottom part is called groundwater (Asdak 2004). In the hydrological cycle, groundwater is one component that can be renewable. Replenishment (recharge) of groundwater on a land that uses a fork management system is derived from aboveground water such as rain water, river water that percolates further into the ground vertically and reaches water table and eventually the groundwater.

The groundwater level in the rice field during the dry season (May until August 2012) was shallower than that in other land uses. This is presumably due to the pattern of rice cultivation by farmers, such as siltation, *etc.* This condition is in accordance with the fact that rice plants require more water for their growth. Shallow groundwater contributes to the significant amount of water needed by plants. Pratharpar and Qureshi (1998) reported that the land with a shallow water table is able to reduce the amount of irrigation water up to 80% of the total water irrigation requirement without reducing the crop yields. The high water table can increase the water flux into the root zone (Liu *et al.* 2006).

The groundwater level in the rubber plantation, mixed cropping land or unmanaged land showed a similar pattern, in which in August the water table was very deep. This condition can be due to the adaptation of woody plants growing on the three land uses, such as root activities to absorb deeper water and an increased plant respiration. The results of current study is similar to that in the study of Waddington and Roulet (1996), which indicates that the low water table will lead to an increased plant respiration.

Mineralogical Properties of the Soils

The soil mineral content can be used to determine the physical and chemical properties of soil, so the identification of type of clay minerals in soil is important. The results of analysis of mineralogical properties of the soils taken from each land use are presented in Figure 5.

The results showed that the type of minerals found in the soil samples taken from different land uses is the same, namely quartz, illite and chlorite (Figure 5), in which the proportion of the quartz in the soils is the highest among other minerals. On the other hand, the proportions of mineral illite and chlorite

in the soils are almost similar. The same types of minerals observed in the soils taken from different land uses are thought to be caused by the same parent material of the soils in the study site. The study of Prasetyo (2004) suggested that the soils from dryland and wetland (such as rice fields) contain the same primary mineral composition when the soils have the same parent materials. On the other hand, other studies indicated that the primary mineral compositions in soil from rice field can be different from that from non rice field (Winoto 1985; Munir 1987; and Rayes 2000). The high quartz content in the soils observed in the current study can indicate: (1) the soils have experienced a further level of development; (2) the soils have low nutrient sources; and (3) the parent material of the soils is acidic. Generally, the soils that are dominated by quartz mineral have low CEC values.

CONCLUSIONS

The physical properties of soils in different land uses varied, however, the change of land use did not cause changes in soil mineralogical properties. The mineralogy of the soils from different land uses is relatively the same, namely quartz, illite, and chlorite.

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