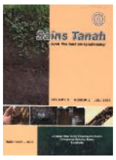
SAINS TANAH – Journal of Soil Science and Agroclimatology

Journal homepage: http://jurnal.uns.ac.id/tanah



Characterization of physical, chemical and microstructure properties in the soft clay soil of the paddy field area

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ARTICLE INFO

Keywords:
Paddy soil
Kaolinite
Organic matter
Soft clay
Soil structure

Article history
Submitted: 2021-04-20
Accepted: 2021-06-02
Available online: 2021-06-25
Published regularly: June 2021

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ABSTRACT

The soft clay soil has been categorized as infertile soil. The occurrence of soft clay soil in paddy field areas can decline soil quality and rice production. Therefore, to find the best technique for amending this soil, this study aimed to analyze the physical, chemical, and microstructure properties of the soft clay soil in the paddy field area. The soft clay soil samples were collected from two paddy blocks in Kedah, Malaysia. The physical and chemical properties of the soil were determined using the standard method in the laboratory. The microstructure properties were analyzed using Zeiss SUPRA 55VP microscopes. The results found that the soft clay soil was composed of silt – clay (> 90%) with the texture of silty clay. The soft clay soil was characterized by low values of organic matter (2.63-3.42%), pH (3.32-3.69), cation exchange capacity (6.89-8.72 $cmol_c\ kg^{-1}$), available P (0.14-0.41 mg kg^{-1}), aggregate stability (16.53-17.78%), and hydraulic conductivity (0.17 cm hr^{-1}). In contrast, it indicated high values of soil water content (42.24-43.21%), and exchangeable Na^+ ions (2.48-2.50 $cmol_c\ kg^{-1}$). In addition, the analysis of heavy metals content revealed that their concentrations were below the critical level in the soil. The soft clay soil was largely governed by kaolinite minerals, and it had less compact structures with many large voids among soil aggregates. In conclusion, the quality of soft clay soil in the study area was poor with low physical and chemical parameters. The quality of the soil could be improved by the addition of soil amendments such as zeolite, cement, and other additive materials to absorb the excess water in the soil and increase the soil strength.

How to Cite: Rendana, M., Idris, W.M.R., Rahim S.A., Rahman Z.A., Lihan T. (2021). Characterization of physical, chemical and microstructure properties in the soft clay soil of the paddy field area [Research]. Sains Tanah Journal of Soil Science and Agroclimatology, 18(1): 81-88. https://dx.doi.org/10.20961/stjssa.v18i1.50489

1. Introduction

Rice is the main source of food for Asian countries, including Malaysia. The Asian countries have provided around 90% of total world production. The highest rice producer countries in the world are China (28.1%), and followed by India (21.22%), Vietnam (6.07%), Thailand (4.4%), Pakistan (5.13%), and the United States (1.35%), with Malaysia contributing as low as 0.36% (Shamshiri et al., 2018). Recently, Malaysia has around 75% rice self-sufficiency level (SSL) (Rahim & Abidin, 2018). The authority has planned to achieve a value of 100% rice SSL in production to fulfill the demand of the population in the future. The low rice yield in Malaysia can be due to soil quality issues (Sahibin et al., 2016). In general, this region has tropical soil that is marked as problematic soil, such as sandy soil, peat soil, acid sulfate soil (Paramananthan, 2013), and soft clay soil that currently requires a specific amendment technique to improve the soil quality for rice production. For instance, in Kedah of Malaysia, around 8,107 hectares of paddy fields have encountered the soft clay soil issue, and the authority has spent about 15 billion U.S. dollars to mitigate it, but the problem persists (Nordin et al., 2014). Typically, the soft clay soil was not appropriate for crop production (Rendana et al., 2020). The soil was characterized by low compressive strength which could be resulted to decline in rice production (Rendana et al., 2018). Previous studies have investigated soft clay soil issues in agricultural areas. For instance, Hore et al. (2020) has successfully created a model for zonation of soft clay soil. Nasir et al. (2019) has reported the rubber wheel tractors and half-track tractors can devastate the soil hardpan layer and may cause soft soil spots around the paddy fields. Nordin et al. (2014) has recommended the soil replacement technique to improve the soil hardpan layer in the soft clay soil areas. Based on those studies, the understanding of the physical, chemical, and microstructure properties of the soft clay soil in the paddy fields has not studied yet. Hence, this current study will focus on analyzing all of the soft clay soil parameters starting from physical (organic matter, aggregate stability, hydraulic conductivity, texture, soil density), chemical (pH, exchangeable cations, cation exchange capacity, available nutrients, and heavy metals content), and microstructure (voids of clay particles and minerals content). This analysis will elaborate more comprehensive results regarding how the characteristics of the soft clay soil in a specific location (agricultural area) which will obviously different properties from other soft clay soils in most construction sites (Li et al., 2017; Low et al., 2018). Therefore, in this study, we also take soil samples from two different locations of soft clay soil areas to minimize bias. Furthermore, the result of this study is expected to provide new baseline data in the field of soil science. To assist the authority increase rice production, a study regarding the characterization of soft clay soil properties is prominent. Then, the amending techniques can be proposed to mitigate the main soil parameters which contribute to the soft clay soil incidence. Therefore, the aim of this study is to investigate the physical, chemical, and microstructure properties of the soft clay soil in the paddy field area, Kedah, Malaysia. The output of this study can be the scientific basis or baseline data to plan amending techniques for soft clay soil issues in the paddy field area.

2. Materials and Methods

2.1. The Study Area and Soil Sampling

The study area was divided into two blocks of paddy cultivation area, namely; (i) Alor Senibong block, and (ii) Alor Pudak block, as shown in Figure 1. The total area was about ±1 hectare for each block, and paddy plots within the blocks were separated by small trenches. Both paddy blocks have been experienced with low rice yield due to soft clay soil problems (Nordin et al., 2014). The occurrence of soft clay soil in the study area caused the agricultural machines could not be operated over the field because the soil was not able to resist the mechanical pressure (Nasir et al., 2019). In this study, we used a grid sampling method to collect soft clay soil samples in each paddy block. Thirty soil samples were obtained from the depth (0 - 45 cm) using PVC tubes for soil profile analysis. The samples were then wrapped in tight plastic and brought to the laboratory.

2.2. Analysis of Physical and Chemical Properties

The soft clay soil samples were analyzed for determining the physical, and chemical properties such as soil particle size distribution, bulk density, organic matter content, water content, hydraulic conductivity, aggregate stability, exchangeable base cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}), cation exchange capacity, pH, available nutrients (K, Mg, and P), and heavy metals (Pb, Zn, Cu, Fe, Cr, Cd, and As) in the soil. The particle size distribution was determined by the pipette method (Šinkovičová et al., 2017). The soil water content was determined using the gravimetric method (Sato et al., 2014), and the hydraulic conductivity was determined using the falling head method (Bagarello et al., 2014). The aggregate stability was determined by the wet sieving (Besalatpour et al., 2013). The bulk density was determined using the wax method (Al-Shammary et al., 2018). Furthermore, the organic matter content was obtained by loss on ignition (Sato et al., 2014).

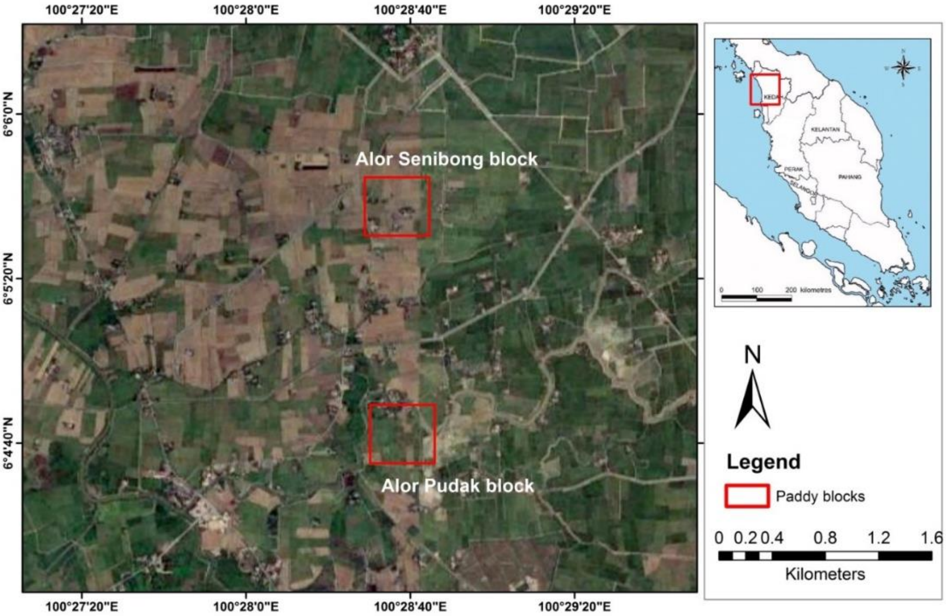

Figure 1. Location of the study area.

Table 1. Particle size distribution of the soft clay soil.

Paddy Blocks	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Alor Senibong	0-15	10±0.24	49±0.61	41±0.38	Silty Clay
	15-30	9±0.55	46±0.51	45±0.44	Silty Clay
	30-45	10±0.17	44±0.73	46±0.60	Silty Clay
	Mean	10	46	44	Silty Clay
Alor Pudak	0-15	10±0.05	33±0.63	57±0.67	Clay
	15-30	11±0.16	44±1.00	45±0.58	Silty Clay
	30-45	11±0.12	48±1.47	41±1.35	Silty Clay
	Mean	11	42	48	Silty Clay

The soil pH was measured by the meter pH Model WTW INOLAB Level 1 (Metson, 1956). The exchangeable base cations were extracted with 1.0 M ammonium acetate solution and determined using the Inductively Coupled Plasma - Mass Spectrometry (ICP-MS). The exchangeable sodium percentage was calculated using exchangeable sodium, and other exchangeable cations. Available nutrients were extracted by ammonium acetate-acetic acid extractant, for K, and Mg elements were determined using the Inductively Coupled Plasma - Mass Spectrometry (ICP-MS). While, the available P was extracted using the molybdate-blue colorimetric method, and determined by using the Spectrophotometer Ultraviolet Model Vis UV 1201 (Adesanwo et al., 2013). The heavy metals content was determined by the double acid digestion with a mixture of HNO_3-H_2O_2 (da Silva et al., 2014), and analyzed by the Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).

2.3. Analysis of Microstructure

The microstructure of the soft clay soil samples was analyzed by the scanning electron microscope using a Zeiss SUPRA 55VP microscope. Total 1 g of soil with a size of 63 µm was provided for the scanning electron microscope analysis (Lin & Cerato, 2014). The soil samples were coated with a thin layer of conductive material prior to analysis. The images were analyzed at specific magnification to obtain the best images for this study.

3. Results

3.1. Physical Properties of the Soft Clay Soil

The result of the particle size distribution of the soft clay soil samples was shown in Table 1. The result of organic matter content and bulk density of the soft clay soil samples was depicted in Table 2. It was found that the soft clay soil tended to have a low amount of organic matter. But, the content of organic matter in all paddy blocks was found an increase by increasing the depth of soil. The mean values of organic matter in soft clay soils of Alur Senibong, and Alur Pudak blocks were 2.63% and 3.42%, respectively. Moreover, there were no notable changes in bulk density value between both paddy blocks. It was ranged from 1.00 to 1.02 g cm^{-3}. The values of soil water content, hydraulic conductivity, and water-soil aggregate stability in soft clay soil samples were shown in Table 2. The mean value of soil water content was 42.24% for the Alor Senibong block, and 43.21% for the Alor Pudak block. The mean hydraulic conductivity of the soft clay soil in the study area was around 0.17 cm hr^{-1}. The lower layer indicated a slightly higher hydraulic conductivity than the upper layer of soil. The mean aggregate stability of soft clay samples was 17.78% (Alor Senibong block), and 16.53% (Alor Pudak block). The aggregate stability values were almost unchanged in each soil depth. Based on the result of the study, aggregate stability in the study area was classified as low level.

3.2. Chemical Properties of the Soft Clay Soil

The value of pH and cation exchange capacity in the soft clay soil samples was shown in Table 3. The content of available nutrients in soft clay soil samples was shown in Table 4. The mean available P in the soft clay soil samples was 0.14 mg kg^{-1} (Alor Senibong block), and 0.41 mg kg^{-1} (Alor Pudak block). Based on the mean values in both paddy blocks, we could classify the available P level as very low. The mean value of available K in soft clay soil was 143.27 mg kg^{-1} (Alor Senibong block), and 160.11 mg kg^{-1} (Alor Pudak block). The available K was slightly higher in the subsoil than topsoil. Based on our result, we found the content of available K was high and considered satisfactory for rice cultivation.

Table 2. Organic matter, bulk density, water content, hydraulic conductivity, and aggregate stability of the soft clay soil.

Paddy Blocks	Depth (cm)	OM (%)	BD (g cm^{-3})	WC (%)	HC (cm hr^{-1})	AS (%)
Alor Senibong	0-15	2.16±0.32	1.00±0.01	43.70±0.13	0.14±0.04	16.08±0.03
	15-30	2.51±0.06	1.01±0.01	43.64±0.03	0.20±0.06	15.26±1.16
	30-45	3.21±0.22	1.02±0.01	39.37±0.17	0.18±0.02	21.96±0.88
	Mean	2.63	1.01	42.24	0.17	17.78
Alor Pudak	0-15	3.23±0.12	1.00±0.01	40.48±0.72	0.13±0.06	17.29±0.10
	15-30	3.36±0.23	1.01±0.01	41.35±0.07	0.17±0.02	16.01±0.71
	30-45	3.68±0.45	1.02±0.01	48.10±0.03	0.20±0.02	16.28±1.24
	Mean	3.42	1.01	43.21	0.17	16.53

Remarks: OM: Organic matter; BD: Bulk Density; WC: Water Content; HC; Hydraulic Conductivity; AS: Aggregate Stability.

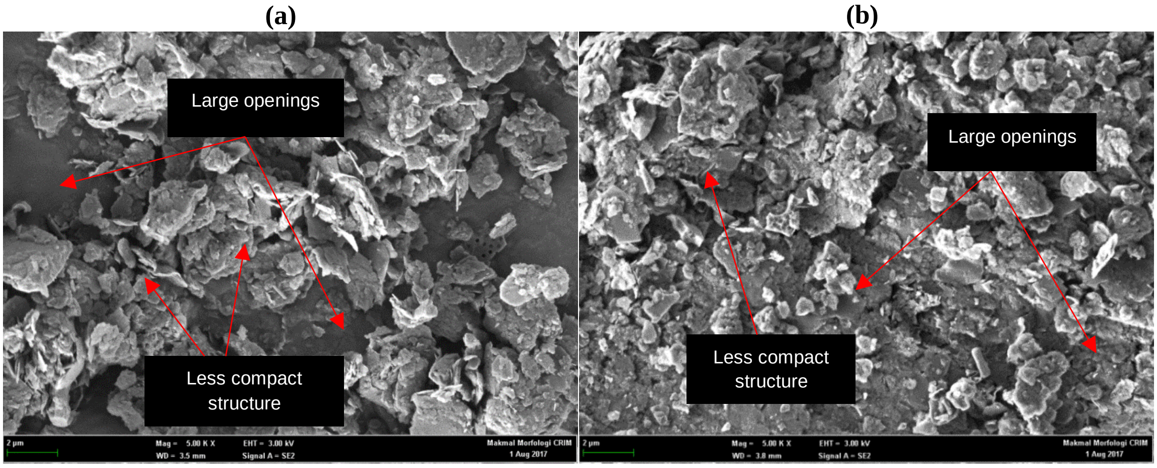

Figure 2. The scanning electron microscope images of the soft clay soil in the Alor Senibong block **(a)**, and the Alor Pudak block **(b)**.

Table 3. pH, and cation exchange capacity of the soft clay soil.

Paddy blocks	Depth (cm)	pH	Exchangeable base cation (cmol$_c$ kg^{-1})				CEC (cmol$_c$ kg^{-1})
			Mg^{2+}	Ca^{2+}	Na^{+}	K^{+}	
Alor Senibong	0-15	3.20±0.04	1.02±0.02	1.15±0.02	2.35±0.03	0.38±0.01	7.97±0.21
	15-30	3.36±0.02	1.40±0.02	1.25±0.03	2.47±0.38	0.22±0.01	8.47±0.63
	30-45	3.39±0.01	1.70±0.14	1.59±0.05	2.63±0.03	0.28±0.01	9.74±0.16
	Mean	3.32	1.37	1.33	2.48	0.29	8.72
Alor Pudak	0-15	3.66±0.01	1.27±0.08	1.57±0.25	2.26±0.03	0.74±0.03	6.57±0.25
	15-30	3.73±0.01	1.35±0.41	1.81±0.17	2.57±0.03	0.77±0.01	7.27±0.39
	30-45	3.68±0.01	1.25±0.21	1.44±0.47	2.69±0.24	0.70±0.03	6.85±0.43
	Mean	3.69	1.29	1.60	2.50	0.74	6.89

Similarly, the content of available Mg was also high in the studied soil. The mean available Mg in the soft clay soil was 70.61 mg kg^{-1} (Alor Senibong block), and 99.53 mg kg^{-1} (Alor Pudak block). The contents of heavy metals in the soft clay samples were shown in Table 5. The mean values of Fe, Pb, Cr, Zn, Cu, As, and Cd in the soft clay soil of Alor Senibong block were 3097.14 mg kg^{-1}, 24.42 mg kg^{-1}, 18.97 mg kg^{-1}, 5.57 mg kg^{-1}, 5.03 mg kg^{-1}, 1.73 mg kg^{-1}, and 0.03 mg kg^{-1}, respectively. While, for Alor Pudak block were 2188.53 mg kg^{-1}, 30.61 mg kg^{-1}, 32.69 mg kg^{-1}, 11.39 mg kg^{-1}, 7.82 mg kg^{-1}, 2.43 mg kg^{-1}, and 0.06 mg kg^{-1}, respectively. The contents of heavy metals tended to fluctuate with increasing soil depth. Based on the result, heavy metals content in the soil was sequenced as Fe > Pb > Cr > Zn > Cu > As > Cd.

3.3. Microstructure Properties of the Soft Clay Soil

According to the results of scanning electron microscopy (Figure 2), it could be found that the major clay mineral in the soft clay soil was kaolinite, and low amounts of illite, and montmorillonite. These kaolinites can be seen through scanning electron microscopy images with hexagonal shapes. The content of clay mineral type and the existence of kaolinite influenced the swelling, plasticity, and compression properties of the soil. In addition, the scanning electron microscopy images showed soil structures were less compact and had many large voids space of approximately 250 – 500 nm in between soil aggregates.

4. Discussion

The soft clay soil was a longstanding problem faced by farmers in Kedah and Perlis areas. The soft clay soil has deteriorated more than 8,000 ha of paddy fields in the areas over the last five years (Nordin et al., 2014). Because of this issue, the rice production in the areas has significantly declined because most of the paddy fields could not be cultivated. The average rice production was observed as less than 2 t ha^{-1} season^{-1} (Nordin et al., 2014; Rendana et al., 2018). Several studies have agreed that the soft clay soil had bad impacts on the rice yield, they have explained some contributors of soft clay soil incidence, such as the extensive use of heavy field machinery (Ahmad et al., 2020), the broken hardpan layer (Kim Huat, 2010), climate factor, and drainage system condition. Based on the result of the study, we found the soft clay soil in the study area was characterized by low soil quality which if it was not improved quickly, would degrade land use function for agricultural activities. The characteristics of soft clay soil have been discussed in the following explanations. The soft clay soil was distinguished by a silty clay texture (Table 1) with the percentage of clay content was around 44-48%. This result was consistent with a study by Nu et al. (2020) who obtained total clay content in the soft clay samples of the Mekong Delta Region of Vietnam was ranged from 44 to 50%. In general, the parent material could contribute to a significant impact on the soil particle composition. The clay soil could supply more nutrients than sandy soil for paddy growth. The cation exchangeable of Ca^{2+}, and Mg^{2+} increased along with increasing clay content in the soil. This was because claybound cations had negative charges around their surface (Ghorbani et al., 2019). The soft clay soil was characterized by very low organic matter (<3.5%), this value was not suitable for rice cultivation (Table 2).

Table 4. Available nutrients of the soft clay soil.

Paddy blocks	Depth (cm)	Available nutrients (mg kg^{-1})		
		P	K	Mg
Alor Senibong	0-15	0.12±0.01	141.99±24.98	75.84±1.05
	15-30	0.11±0.01	140.77±24.84	75.53±0.25
	30-45	0.18±0.01	147.06±28.13	60.47±0.62
	Mean	0.14	143.27	70.61
Alor Pudak	0-15	0.46±0.01	166.20±0.31	107.29±0.15
	15-30	0.50±0.01	167.52±0.87	107.88±0.34
	30-45	0.26±0.01	146.60±0.29	83.42±0.16
	Mean	0.41	160.11	99.53

Table 5. Heavy metals contents of the soft clay soil.

Paddy blocks	Depth (cm)	Heavy metal content (mg kg^{-1})						
		As	Cd	Cr	Pb	Zn	Cu	Fe
Alor Senibong	0-15	1.82±0.07	0.03±0.01	18.43±1.23	24.42±1.71	4.39±1.29	4.93±0.11	2263.53±95.42
	15-30	1.52±0.01	0.04±0.01	19.67±0.50	22.46±0.65	7.44±0.52	4.91±0.05	4006.46±99.22
	30-45	1.84±0.08	0.02±0.01	18.82±0.87	26.38±0.79	4.89±0.14	5.24±0.10	3021.42±79.50
	Mean	1.73	0.03	18.97	24.42	5.57	5.03	3097.14
Alor Pudak	0-15	2.42±0.11	0.06±0.01	32.66±0.78	32.82±1.14	10.69±0.65	7.95±0.08	2159.57±104.74
	15-30	2.37±0.43	0.06±0.01	32.78±0.23	28.31±1.08	12.14±0.34	7.46±0.22	841.81±101.05
	30-45	2.51±0.04	0.05±0.01	32.62±0.11	30.71±0.46	11.34±0.99	8.05±0.08	3564.22±63.58
	Mean	2.43	0.06	32.69	30.61	11.39	7.82	2188.53

Therefore, we assumed the paddy cultivation practice in the study area was less applied organic component into the paddy soil. Nu et al. (2020) was also found almost similar organic matter content in their study site that was ranged from 2.15 to 3.85%. Low organic matter in the soil could make soil structures become more susceptible to the dispersion process when it was soaked with water (Jensen et al., 2019). Then, it would accelerate the formation of soft clay soil around the paddy field area. Hence, the addition of organic amendment could be used to improve soil structure, and aggregate stability (Moreno-Barriga et al., 2017). Moreover, the contents of clay and organic matter could also affect the bulk density value of the soil (Johannes et al., 2017). Higher clay content in soil usually makes the value of bulk density was around 1 g cm^{-3}.

The soil water content in the soft clay soil was usually higher than normal paddy soils which had a value around 25 – 35% (Carrijo et al., 2018). If we compared with our current study, we found soil water content was higher than the previous study with more than 40% (Table 2). The high soil water content could be related to low hydraulic conductivity. The low hydraulic conductivity indicated water infiltration into the soft clay soil was slow. In general, the soft clay soil had more micropores than macropores thus the water was more retained in micropores. The retained water leads to high soil water content and decreased stability of soil structure. The aggregate stability of the soft clay soil was categorized as low level. The normal paddy soil generally obtained a value above 30%. The low value of aggregate stability indicated the soil structure was in an unstable condition (Shah et al., 2017). Soil with low aggregate stability tended to easily disperse and had low strength. The low soil strength then attributed to agricultural machines could not be applied over the paddy soil because the soil could not resist the load of heavy machines. Several studies assumed that low aggregate stability of soil could be caused by the intensive use of tillage, and chemical fertilizer, especially for N-fertilizer (Bottinelli et al., 2017; Zhu et al., 2018). Therefore, reducing tillage, and chemical fertilizer application resulted in an increase in soil aggregate stability.

The pH value of soft clay soil was at acidic class (<3.8), this value was still below an optimum level for paddy cultivation (pH 6.5) (Table 3). If we compared with another study, we found the pH value was significantly lower than soft clay soil in Southern Vietnam with values ranging from 4.7 to 6.8 (Nu et al., 2020). The different value of soil pH could be caused by there was acid sulfate soil in the study area. This type of soil tended to make the pH value become more acidic than its natural condition. This low pH was generally caused by the oxidation of jarosite minerals in the soil (Trueman et al., 2020). A value less than 4.0 was considered as a critical level of pH for optimum rice production. Lime application was an alternative method to improve pH value of the acidic soil (Teutscherova et al., 2017). It would precipitate Al ions as inert Al-hydroxides which then reduced the toxicity in soil. The cation exchange capacity value of the soft clay soil in the study area was lower than the normal paddy soils (>16 cmol$_c$ kg^{-1}). The value of cation exchange capacity was associated with organic matter content in the soil. The cation exchange capacity value in our study was notable lower than other soft clay soil in a study by Nu et al. (2020), they found the value varied from 21.84 cmol$_c$ kg^{-1}, and 25.86 cmol$_c$ kg^{-1}. This difference might be due to the specific mineralogical content in each site. The basic cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) in the soft clay soil were very little content, meaning that the exchange bases in the clay surface were more dominated by acidic cations such as Al^{3+}, and H^+. The optimum level of cation exchange capacity for rice cultivation was at 16 cmol$_c$ kg^{-1}. This level could not be achieved if the paddy field was still affected by the soft clay soil problem. Furthermore, the exchangeable Na^+ was significantly higher than other basic cations. It caused clay particles were more binded with Na^+ ions in cation exchange site. Several studies have explained Na^+ ions would make a weak bonding with clay particles thus the soil was easily to disperse (Farahani et al., 2018).

The available P level in the soft clay soil was very low (Table 4). This condition occasionally occurred in low pH soil such as acid sulfate soil (Jin et al., 2019). The low pH would promote higher Al ions, and inhibit available P in the soil. Phosphorus element was mostly available for plant uptake as the pH ranging from 6.0 to 6.5. Therefore, the low pH of soil would decrease the P uptake by plants. Another reason that related to low P content in the study area was that the P was immobilized by forming insoluble $AlPO_4$ or $FePO_4$ solutions when the soil was dried (Wasoontharawat, 2017). In contrast, the content of available K, and Mg was high and considered satisfactory for rice cultivation (Table 4). The high content of K and Mg in the soil could be caused by the routine of K-fertilizer, and Mg-fertilizer applications in the study area. Furthermore, the contents of heavy metals tended to fluctuate with increasing soil depth (Table 5). Qaswar et al. (2020) revealed that heavy metal content showed a significant correlation with soil pH and nutrient contents. The heavy metal pollution risk could be caused by long-term fertilization in acidic paddy soil that then resulted in infertile soil and soft clay soil problems. Our study indicated that soft clay soil problems were responsible for the elevated Fe, Pb, and Cr in surrounding paddy soil. Based on the result, heavy metals content in the soil was sequenced as Fe > Pb > Cr > Zn > Cu > As > Cd. This result was quite different from other paddy soil which had heavy metals content was sequenced as Pb > Cd > Ni > As > Zn > Cu > Cr (Li et al., 2019). The content of heavy metal was usually governed by parent material, and acidic condition factors (Yang et al., 2020). As a whole, our result found the contents of all heavy metals in soft clay soil were still below the critical limit of soil based on Kabata-Pendias (2011). According to microstructure analysis, the soft clay soil showed less compact soil structures and had many large voids space between soil aggregates (Fig. 2). We observed an abundance of kaolinite in the soil matrix. This result was consistent with another study by Nu et al. (2020) that found a higher amount of kaolinite, and illite in soft clay soil. This clay mineral would affect the swelling, plasticity, and compression properties of the soil. In the case of kaolinite, it tended to have weak bonding in soil particles as compared with montmorillonite. These factors would drive the occurrence of soft clay soil problems in the study area.

Overall, our study revealed some major soil parameters that might contribute to the soft clay soil incidence. These parameters were soil water content, organic matter, aggregate stability, hydraulic conductivity, and kaolinite content, but there was also a little effect from other parameters such as percentage of sand and silt, and exchangeable Na^+. The soft clay soil mechanism process was started from the high water content in the soil which could be resulted from a bad drainage system or natural condition of the soil. The excess water would make the soil become waterlogged and saturated which showed that the soil had a low hydraulic conductivity value. The high water content in the soil for a long period would decrease soil strength especially for the hardpan layer of soil. Soil aggregates would easily disperse as contact with water, indicating the low aggregate stability value, at this stage, the soil was considered an unstable condition or slightly soft clay soil began to develop. In addition, the low organic matter and kaolinite contents also could govern the soil aggregate stability. The soil particles tended to have weak bindings when the soil had a low organic matter and high kaolinite clay minerals, as shown by previous studies (Abdeldjouad et al., 2019; Abdi et al., 2018). Therefore, this current study has revealed significant results regarding the physical, chemical, and microstructure characteristics of soft clay soil in the paddy field area, but for future studies, it was needed to ameliorate the soil in the laboratory scale. Several soil amendments could be proposed to treat the soil such as zeolite, lime, and additive materials which used to accelerate the flocculation process among soil particles.

5. Conclusion

The soft clay soil in the paddy field area was characterized by low organic matter content, low hydraulic conductivity, and low aggregate stability values, but high soil water content. The pH, and cation exchange capacity, and available P content were at a low level. The contents of heavy metals in soft clay soil were below a critical limit tolerance of the soil thus it could not contribute to negative effects on the environment. Furthermore, the soft clay soil was dominated by kaolinite minerals, and it had less compact structures with many large voids space in between soil aggregates. Therefore, to stabilize the soft clay soil, this study suggests soil amendments such as cement, zeolite, or lime to reduce dispersion, and improve soil strength.

Acknowledgements

The authors would like to thank the Universiti Kebangsaan Malaysia (UKM) and the Faculty of Science and Technology for providing the facilities to assure the success of this study. This study was done with UKM research grant ETP-2015-003.

Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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