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# Particle size distribution and clay minerals in dryland soils of Aceh Besar, Indonesia

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**Abstract.** Soil particle size distribution is a fundamental physical property affecting other soil properties. This property also affected by mineral composition in soil. Characterizing of soil texture and clay minerals is very important in environmental and soil research. This research aims to determine the distribution of soil particles and the composition of clay minerals on each layer of the horizon in four soil profiles (P1, P2, P3, and P4) with different parent materials in the dryland of Aceh Besar district which includes Entisols Jantho, Andisols Saree, Inceptisols Cucum, and Oxisols Lembah Seulawah. Particle size distribution (or texture) and bulk density (BD) were analyzed in the laboratory. Soil structure and consistency were observed directly in the field. The type of clay minerals was identified by X-ray diffraction, while Fe, Al, and Si-oxide were extracted by dithionite-citrate solution. The results shown that the particle size distribution and the physical properties of dryland soils of Aceh Besar vary between soil orders. Andisols Saree has better physical properties than the physical properties of other soils and low of bulk density. The Al, Fe, and Si fractions and clay mineral composition in the soil profiles also vary considerably between soil orders. The Andisols are dominated by allophane minerals (amorphous fractions) while in Entisols, Inceptisols and Oxisols consist of mixed minerals of feldspar, quartz, halloysite, goethite, and other clay minerals. These soil orders have some soil physical constraints i.e. high bulk density, poor soil structures, and low water holding capacity. Improvements in the physical properties of the soil on Aceh Besar dryland are indispensable to improve the quality of the soil.

## 1. Introduction

Indonesia has an area of 182.2 million hectares and 144.5 million hectares is dryland agriculture system [1]. Based on climatic conditions, dryland in Indonesia is divided into two types, dryland with wet climate (annual rainfall more than 1500 mm/year) and dryland with a dry climate (annual rainfall less than 1500 mm/year). Dryland with wet or humid climate is the area that occupies the most extensive area compared to the dry climate. The dryland of wet climate is widespread on the islands of Sumatra, Java, Kalimantan, Sulawesi, and Papua which characterized by high or heavy rainfall (1,500-3,500 mm/year), while dryland with dry climate is spread in the East Nusa Tenggara Islands which characterized by low rainfall (<800 mm/year). Based on the data, agricultural development has the potential to be developed on dryland in wet climate. There are several obstacles facing the development of dryland farming [1]. The availability of water which is highly depended on rainfall and long dry season are among others. The potential for agricultural development in this the region is estimated more

than 60 million hectares [1] and suitable for agriculture covering an area of 99.6 million ha that has been used for existing agriculture both food crops and annual crops/plantations, as well as other activities covering an area of 74.8 million ha [2].

Aceh Province, which is located in the North of Sumatera Island (Indonesia) has dryland that is still large enough to be developed for intensive agricultural areas. The dryland contains several soil orders such as Inceptisols, Ultisols, Alfisols, Entisols, and Oxisols and a small area of Andisols [3]. The difference in the order of this soil is in addition to the difference in the shape of the region (slope) also because of the difference in soil parent material [4]. The results of research that has been conducted on dryland farming system show that soil fertility rates is generally low [5], and also has a low soil quality index [6], [7]. From the chemical aspect, these soils has a number of constraints such as low organic matter content [8], low cation exchange capacity [7] and in some soil orders such as Ultisols, Inceptisols and Oxisols are characterized by low soil pH [9]. Although less fertile, this dryland has been partially used for food farming, horticulture, plantations, and grazing land as found in Aceh Besar District [10].

Another constraint is that most of the dryland in Aceh Besar is mostly found on hilly system with steep topography and shallow solum [9], so it is very potential to degrade the land because it is easily eroded, especially on open areas without vegetation. Erosion is a very serious problem in the dryland farming system because most farmers do not apply the methods of soil conservation in land management [11]. In addition to slope and vegetation, erosion is also influenced by soil erodibility [12], [13], and it is largely determined by soil properties, such distribution of soil particle size (texture), soil structure, aggregate stability index, and soil organic matter [14], [15]. Decrease soil organic matter in addition to reducing carbon content can also stimulate erosion and loss of nutrients [16], [17]. In some studies, soil compaction and composition of soil minerals have also influence to soil erosion [18], [19]. The composition of soil minerals also affects to chemical properties, plant nutrients, and physical properties in relation of soil quality.

Therefore, it is necessary to evaluate the distribution of soil particles and mineral composition in dryland in Aceh Besar (Indonesia). The objectives of this study were to evaluate the particle size distribution on dryland soils of Aceh Besar, Indonesia.

## **2. Materials and Methods**

### *2.1. Study Area Description.*

The location of study area is the dryland of Aceh Besar District, Aceh Province, Indonesia, and geographically located between 5° 2' – 5°, 8' N latitude and 95° 80' – 95°,88' E longitude. This area belongs to the tropical climate with an average precipitation of about 1,251-1,426 mm/years and average air temperature is 23-27°C and classified as dry climate because in yearly has a dry month more of 3-4 months [20]. Based on the climate classification according to Schmidt-Ferguson, Aceh Besar District belongs to the C climate type which is rather humid, while according to Oldeman this region belongs to type E (dry climate) [21]. For wetland, farming is generally only available water for 1-2 harvests a year [22], while in dry season, the water is not sufficient for crops, especially for annual crops. The areas of study have iso-hyperthermic regime with two soil moisture regimes i.e. udic and ustic regime [9].

The study focused on dryland areas in Aceh Besar (Indonesia) district representing several soil orders including Entisols, Andisols, Inceptisols, and Oxisols and represented 4 types of parent materials each weathered bedrocks, volcanic ash, sedimentary rock, and tuff andesitic-basaltic [5]. Four pedons were selected to represent the parent materials and soil orders. To identify soil morphology used Soil Research Centre procedures [23] while to classify soil subgroup was used The USDA Soil Taxonomy [24].

### *2.2. Methods*

*2.2.1. Physical and Chemical Analysis.* Field observation and taken soil samples were carried out from May to July 2020. Before analysis, the soil samples were air-dried and sieved with a 2-mm sieve for texture analysis and 0.5 mm for soil mineral analysis. The pipette method used for particle size analysis [25]. Four soil orders from Aceh Besar dryland included in this study are Entisols (Typic Udorthents) from Jantho (05°16'58.41" N; 95°37'51.82" E), Andisols (Typic Hydrudands) from Saree (05°27'15.6" N; 95°44'09,1" E), Inceptisols (Oxic Dystrudepts) from Cucum, (05°15'55" N; 95°39'02,6" E), dan Oxisols (Plinthic Kandiudox) from Lembah Seulawah (05°36'36,6" N; 95°35'12,2" E). Particle distribution (texture) and bulk density (BD) of soils were analyzed in the laboratory. The structure and consistency of the soil were observed directly in the field.

2.2.2. *Clay Mineral Analysis.* Analysis of clay minerals was used to identify the composition of soil minerals for soil families determination. The composition and type of clay minerals were analyzed by using X-ray diffraction [25]. The Fe, Al, and Si-oxide content in soils is extracted with dithionite-citrate solution [26], and measured by atomic absorption spectrophotometer (AAS, Shimadzu 7000). For X-ray diffraction, soil samples are separated first with the flavoring agent, organic matter, and lime. Chemical cementing agents removal and soil particle fractions separation were done according to Mehra and Jackson procedures [27]. Organic matter and carbonate were removed with 30% H<sub>2</sub>O<sub>2</sub> and 1 N HCl, respectively. The clay samples were examined by XRD analysis by comparing the peaks of diffractogram data from XRD analysis [28]. To identify kaolinite mineral in the presence of trioctahedral chlorite, the samples were saturated with potassium (K) and treated with 1 N HCl at overnight of 80°C after drying and heating at 500°C for 4 hours [29].

### 3. Results and Discussion

#### 3.1. Sites Description

Based on profiles morphology, soil physic-chemical properties and clay mineral compositions, the name of soil family at four soil pedons according to USDA classification [24] in the dryland of Aceh Besar District are presented in Table 1. Four soil orders that develop in the dryland of Aceh Besar (Entisols, Andisols, Inceptisols, and Oxisols) are mostly found in the humid climate or the udic regime with the iso-hyperthermic temperature regime. The dominant mineral composition in each soil order is varied between site/location but generally consists of mixed minerals [30].

**Table 1.** Classification of soil order of four pedons in the dryland of Aceh Besar District

Pedon	Site /Soil Order	Soil classification (USDA, 2014)	Relief	Parent materials	Land use
P1	Jantho (Entisols)	Coarse loamy, mixed, udic, isohyperthermic, Typic Udorthents	Hilly	Weathered rocks	Shrubs
P2	Saree (Andisols)	Fine loamy, allophanic, udic, isohyperthermic, Eutric Hydrudands	flat	Volcanic ash	Horticulture land
P3	Cucum (Inceptisols)	Fine silty, mixed, udic, isohyperthermic, Oxic Dystrudepts	Sloping	Sedimentary rocks	Grazing land
P4	Lembah Seulawah (Oxisols)	Fine (clay), ferritic, udic, isohyperthermic, Plinthic Kandiodox.	Hilly	Andesitic-basaltic	Mixed farming

Table 1, it can be seen that the dryland soils of Aceh Besar District have a soil texture varie from fine to medium, and also the soil horizons. Based on the horizon characteristics, it can be said that Entisols Jantho is an undeveloped soil because it only consists of A, AC, and C horizons with the thickness of the solum less than 50 cm. The other orders are relatively developed because these soils have a complete set of horizons, namely A, B, and C) and a deep solum. These horizons are formed by the soil genesis process. Field identification showed that undeveloped soils were Entisols (Lithic Udorthents) Jantho (P1), whereas allegedly developing soil groups are Andisols (Eutric Hydrudands) Saree (P2) and Inceptisols (Oxic Dystrudepts) Cucum (P3) and, while the group that has developed further is Oxisols (Plinthic Kandiodox) Lembah Seulawah (P4).

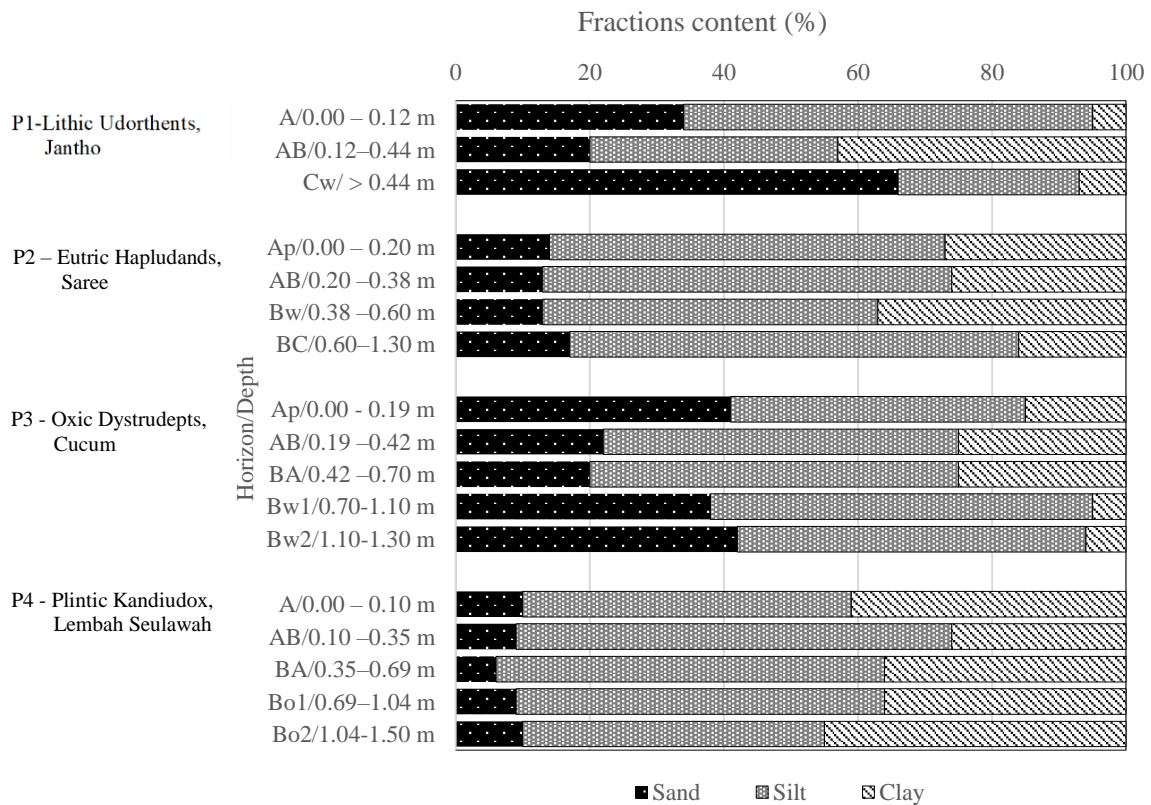
#### 3.2. Particle Size and Soil Textures

Table 2 can be seen that in general the texture of the four subgroups of soil derived from Aceh Besar dryland is relatively no different in top soil (horizon A) that is included in the medium texture (silty loam to silty clay loam). In the layer below there is little difference between horizons but still classified into a medium texture. From the aspect of soil texture, the four subgroups of the soil have a relatively good texture for plant growth. The results of the analysis also found no increase in clay that characterized the argillic horizon in the four subgroups (orders) of soil studied. The comparison of the composition of the sand, silt, and clay fractions in the four soil pedons (orders) in Aceh Besar dryland more clearly can be seen in Figure 1, while the distribution of particle size of soils along the depth shown in Figure 2.

**Table 2.** Physical properties of soil at each horizon layer of the soils in Aceh Besar dryland

Pedon /Subgroup	Depth (cm)	Sand	Silt	Clay	Texture class	Structure	Soil consistency	BD (Mg m <sup>-3</sup> )
		----- (%) -----						
P1-Lithic Udorthents (Entisols) Jantho	A/0 – 12	34	61	05	SiL	Blocky	Breakable	1.34
	AB/12–44	20	37	43	C	Blocky	Breakable	1.28
	Cw/ > 44	66	27	07	SL	Subangular	Massive	1.56
P2–Eutric Hydrudands (Andisols) Saree	Ap/0 – 20	14	59	27	SiL	Crumb	Crumbly	1.01
	AB/20–38	13	61	26	SL	Subangular	Breakable	0.96
	Bw/38 –60	13	50	37	SiL	Subangular	Crumbly	0.98
	BC/60–130	17	67	16	SiL	Subangular	Crumbly	1.02
P3-Oxic Dystrudepts (Inceptisols) Cucum	Ap/0 - 19	41	44	15	SiL	Blocky	Breakable	1.45
	AB/19 –42	22	53	25	SiL	Subangular	Rather strong	1.39
	BA/42 –70	20	55	25	SiL	Prismatic	Rather strong	1.32
	Bw1/70-110	38	57	05	SiL	Prismatic	Strong	1.42
	Bw2/110-130	42	52	06	L	Massive	Massive	1.36
P4-Plinthic Kandiudox (Oxisols) Lembah Seulawah	A/0 – 10	10	49	41	SCL	Blocky	Crumbly	1.24
	AB/10 –35	09	65	26	SiL	Subangular	Breakable	1.22
	BA/35–69	06	58	36	SCL	Subangular	Breakable	1.25
	Bo1/69–104	09	55	36	SiC	Subangular	Strong	1.18
	Bo2/104-150	10	45	45	SiC	Subangular	Strong	1.19

BD = bulk density; SiL = silty loam, C = clay, SL = sandy loam, L = loam, SCL = sandy clay loam, SiC = silty clay

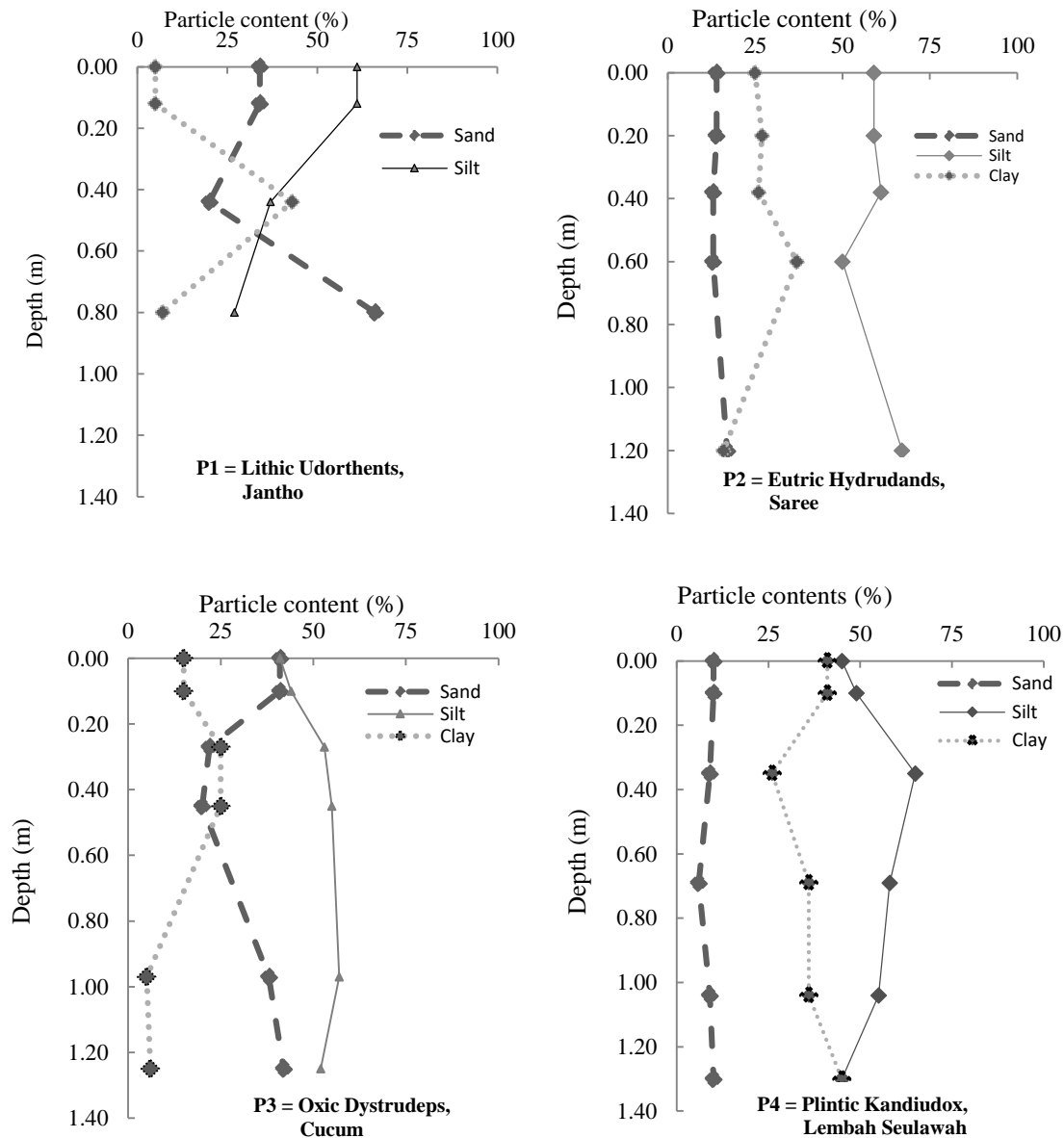


**Figure 1.** The composition of soil fractions on each layer horizon of four soil pedons in the dryland of Aceh Besar

### 3.3. Soil Structure and Consistency

From the nature of soil structure and consistency, it is shown that there is little variation between soil order. Table 2 shows that the soil structure and consistency of Andisols Saree is better than the other three soil order (Entisols Jantho, Inceptisols Cucum, and Oxisols Lembah Seulawah). Soil structure is generally blocky to angular blocky in horizon B, but in the A horizon it tends to have crumb to blocky structure. Soil consistency of four orders of dryland soil in Aceh Besar is relatively good, namely loose to slightly sticky. Based on field observation data and laboratory analysis on several soil orders from

Aceh Besar dryland showed that in general, the distribution of soil particles and soil physics properties such as texture, bulk density (BD), soil structure, and consistency differ between soil orders. The distribution patterns of particles or fractions of sand, silt, and clay in the soil profile also appear to vary between soil orders. In the order Entisols and Inceptisols showed that the sand fraction was relatively higher compared to the silt and clay fractions. In both soil orders, the distribution of sand is increasing with increasing depth of soil, while the clay distribution pattern is the opposite. This is because both soil orders belong to undeveloped soil [33].



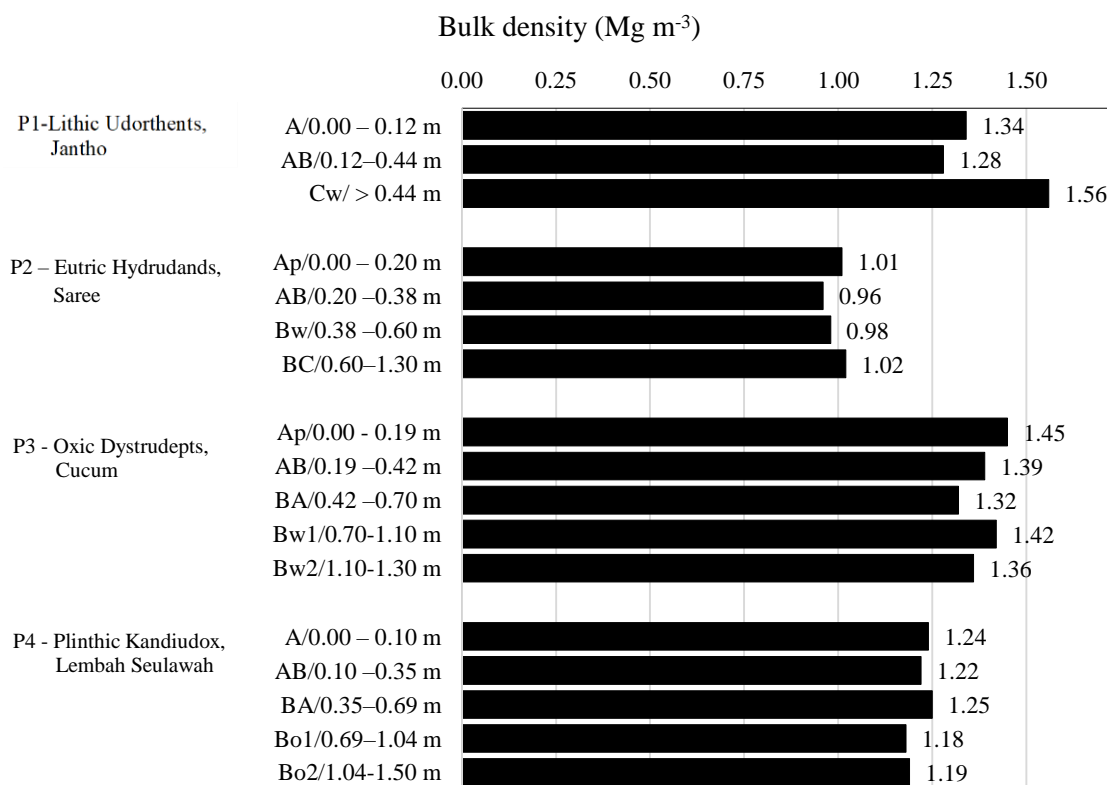
**Figure 2.** Particle size distribution according soil depth of four soil pedons in Aceh Besar dryland

In Entisols Jantho, thickness of the solum less than 44 cm and there was a sharp increase between the clay fraction of layer A and layer AB but not yet formed layer B (Table 2), while in other soil orders (Inceptisols Cucum, Andisols Saree, and Oxisols Lembah Seulawah) did not show a noticeable increase in clay so that to all the order of the soil was not found argillic horizon. Furthermore, when viewed from the class of soil texture, it is seen that the four soil orders have good soil physics properties, especially in the upper layer because it has a relatively balanced proportion between the silt and clay fractions content that produces a good soil texture [34]. However, when viewed more deeply among the four lands, Andisols Saree has relatively better soil physics which is then followed by Oxisols Lembah

Seulawah. In both orders of this soil in addition to having balanced silt and clay fraction content [35], also has a loose soil consistency.

### 3.4. Bulk Density (BD)

From the Table 2 and Figure 3 it can be seen that BD of four soil order from Aceh Besar dryland varies from 0.96-1.45 Mg m<sup>-3</sup>. On the upper layer soil (horizon A) it can be seen that the soil that has high BD is found in pedon P1 (Entisols Jantho) and in pedon P3 (Inceptisols Cucum). In these soils, there have been compaction due to erosion. Based on field observations, both soils are located in the form of hilly to mountainous areas so that erosion is easy. Erosion can lead to the drift of fine particles in the form of clay and organic matter and leave a rather rough fraction, resulting in increased soil BD [31]. In pedon P2 (Andisols Saree), it is seen that BD soil ranges from 0.96-1.02 Mg m<sup>-3</sup>. This BD value is suitable for agricultural land because it will produce good physical properties. This soil is developed from volcanic materials with has an "andic" diagnostic horizon as a characteristic of Andisols [32]. In pedon P4 (Oxisols Lembah Seulawah), the value of soil BD of all horizons ranges from 1.18-1.24 Mg m<sup>-3</sup> (medium). The BD of soils in dryland of Aceh Besar shows that Entisols Jantho and Inceptisols Cucum have a rather heavy BD so it needs to be improved with application of organic matter or need to plow the land (tillage) if cultivated for annual crop farming. In Andisols Saree dominated by amorphous fractions (Tabel 3), the physical properties of soil tend to form crumby and thixotropic soil structures [34]. This is due to the presence of allophane minerals in the soil can bind organic compounds formed a better soil structure or crumbs [13]. In addition, good indications of the physical properties of this soil are seen from the lower soil BD value compared to the other three soil orders ranging from 0.96-1.06 Mg m<sup>-3</sup> (Table 2). Based on this BD value, then if used for agricultural land, then this land does not require soil tillage because of the value < 1.2 Mg m<sup>-3</sup> [36].



**Figure 3.** Bulk density (BD) of soil of four soil pedons in Aceh Besar dryland

### 3.5. Fe, Al, and Si-oxides and Clay Minerals

In Table 3 can be seen that Fe-oxide (Fe<sub>2</sub>O<sub>3</sub>) content on each horizon of four soil subgroups (orders) of the dry land of Aceh Besar is very different. In pedon P1 (Lithic Udorthents or Entisols Jantho), the content of Fe<sub>2</sub>O<sub>3</sub> on the upper soil layer is higher and the lower, while the content of Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> on the same horizon is relatively higher than the content of Fe<sub>2</sub>O<sub>3</sub>. The low content of Fe-oxide indicates

that the Entisols Jantho has not developed and there is no horizon differentiation in the profile [24]. The higher content of Fe-oxide on the top horizon indicates that A horizon of soil is just the beginning of the leaching process [37].

In P2 pedon of Eutric Hydrudans (Andisols) Saree, the Fe<sub>2</sub>O<sub>3</sub> content is relatively small and ranges from 1.09-2.24%, while the Al<sub>2</sub>O<sub>3</sub> content is higher (6.61-9.30%) than the SiO<sub>2</sub> content (2.61-3.64%) and Fe<sub>2</sub>O<sub>3</sub>. This suggests that this soil is dominated by mineral fractions of allophane, imogolite, and ferrihydrite as the character of Andisols soil order [38], [35], [39] as shown from mineral analysis (Table 3). Furthermore, in pedon P3 or Oxic Dystrudepts (Inceptisols) Cucum, it can be seen that the content of Fe<sub>2</sub>O<sub>3</sub> in each layer of the horizon is higher than the content of Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> in the order of Fe>Si>Al. In P4 pedons (Plinthic Kandiodox or Oxisols Lembah Seulawah), the content of Fe<sub>2</sub>O<sub>3</sub> in this soil profile is higher than that of the P3 pedon whereas SiO<sub>2</sub> is the opposite. This indicates that both of these soil pedons (P3 and P4) have been further weathering processes resulting in higher Fe-oxide than the Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> fractions [40], [41].

**Table 3.** The content of Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, and SiO<sub>2</sub> and dominant clay minerals at horizon layers in the soils of Aceh Besar dryland

Pedon /Subgroup	Horizon/ Depth (cm)	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	Clay minerals*
		----- (%) -----				
P1 Lithic Udorthents, Jantho	A/0 – 12	5.31	4.82	6.61	1.37	Quartz, Feldspar, Gibbsite
	AB/12–44	0.25	6.31	3.95	0.63	Gibbsite, Feldspar, Calcite
	Cw/ > 44	0.06	6.01	5.98	1.00	Calcite, Quatz
P2 Eutric Hydrudands, Saree	Ap/0 – 20	1.89	6.61	2.98	0.45	Ferrihydrite, Allophane
	AB/20–38	1.16	8.40	2.61	0.31	Allophane, Imogolite, Gibbsite
	Bw/38–60	1.09	8.11	3.33	0.41	Allophane, Immogolite, Ferryhydrite
	BC/60 –130	2.24	9.30	3.64	0.39	Gibbsite, Metahalloysite, Allophane
P3 Oxic Dystrudepts, Cucum	Ap/0 - 19	3.96	2.36	3.71	1.57	Gibbsite, Feldspar, Kaolinite
	AB/19–42	4.82	2.60	4.09	1.57	Kaolinite, Feldspar, Dickite
	BA/42–70	6.76	2.36	4.13	1.75	Feldspar, Gibbsite, Dickite
	Bw1/70-110	5.85	2.42	4.41	1.82	Feldspar, Polygoskite, Goethite
	Bw2/110-130	5.72	2.39	4.39	1.84	Feldspar, Kaoliniet, Nacrite
P4 Plintic Kandiodox, Lembah Seulawah	A/0 – 10	8.84	2.40	2.73	1.14	Metahalloysite, Gibbsite, Kaolinite
	AB/10 – 35	9.64	1.59	2.70	1.70	Cristobalite, Kaolinite
	BA/35–69	8.02	2.01	2.45	1.22	Metahalloysite, Goethite, Polygorskite
	Bo1/69–104	6.27	1.14	1.83	1.61	Nacrite, Feldspar, Goethite
	Bo2/104-150	4.09	1.68	1.58	0.94	Nacrite, Goethite, Metahalloysite

\*Based on X-ray analysis

Table 3 also prove that the four soil pedons from dryland of Aceh Besar studied have a different composition of clay minerals. In Entisols Jantho (P1) is more dominated by primary mineral quartz and feldspar while in Andisols Saree (P2) is dominated by amorphous alumino-silicate minerals (allophane, imogolite, and ferrihydrite). Inceptisol Cucum (P3) and Oxisols Lembah Seulawah (P4) are dominated by secondary minerals such as kaolinite, metahalloysite, palygorskite, and Al and Fe oxisols such as gibbsite, cristobalite, and goethite. In the other three soil orders (Entisols, Inceptisols, and Oxisols) in general soil physical properties of the soil, especially in the deeper layers are relatively less good because it has a blocky to massive soil structures so that it has a strong soil consistency (hardness). The poor physical properties of soil in these three soil orders are characterized by relatively high soil BD values (>1.2 Mg m<sup>-3</sup>) even at certain depths can reach 1.56 Mg m<sup>-3</sup> as found in Entisols Jantho and Inceptisols Cucum (Figure 3). These three soils require soil tillage or plow if used for dryland farming of seasonal crops such as corn, soybeans, but if used for perennial crops is not required [42]. If it is associated with the composition of soil minerals (Table 3), then soil physical properties of soil on Aceh Besar dryland are related to mineral type. In Entisols Jantho which contains minerals mixed quartz, calcite, and gibbsite and has a dominant sand fraction produces poor soil physics compared to Andisols Saree which is dominated by allophane and imogolite minerals. Inceptisols Cucum which have a mixture of gibbsite, feldspar, and kaolinite also produce poor physical properties characterized by high soil BD values (1.32-1.45 Mg m<sup>-3</sup>). In Oxisols Lembah Seulawah containing clay mineral type 1:1



(metahalloysite, kaolinite) and gibbsite and goethite oxide fractions produce relatively good physical properties characterized by low or medium soil BD ( $1.18-1.25 \text{ Mg m}^{-3}$ ).

Based on the distribution of particle size and the physical properties of the soil, most soil orders such as Entisols, Inceptisols, and Oxisols found in the Aceh Besar dryland agricultural have some physical soil constraints that can inhibit the crops growth, especially for annual crops with short of root system. This physical barrier occurs because the BD value of the soil  $>1.2 \text{ Mg m}^{-3}$  so that good soil management is required soil amendments for example with the addition of organic matter [43], [44]. The addition of organic matter is necessary to decrease the BD value of the soil and improve its physical properties and also include soil chemistry improvement. The results conducted in several areas of Aceh Besar dryland show that soil quality and fertility levels in some soil types in this region are generally low [6], [45]. The main constraint that causes low soil fertility rates of the most soils in the dryland farming system in Aceh is low soil organic matter [5], [8], [9], [10].

#### 4. Conclusions

- (1) Distribution of particle size and soil mineral composition on Aceh Besar dryland generally varies between soil order and soil horizon. The distribution of these particles is related to soil parent material and soil development.
- (2) Andisols Saree is dominated by allophane and imogolite minerals while in Entisols Jantho, Inceptisols Cucum, and Oxisols Lembah Seulawah is dominated by primary mixed minerals (quartz, feldspar, calcite) and clay/secondary minerals (metahalloysite, kaolinite, gibbsite, and goethite).
- (3) Andisols Saree has relatively better physical properties compared to Entisols, Inceptisols, and Oxisols. These soils have constraints namely high soil BD ( $>1.2 \text{ Mg m}^{-3}$ ), so it is necessary to improve the soil physical properties by application of organic amendment.

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