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

S Sufardi*, T Arabia, K Khairullah, I Apriani
Department of Soil Science, Faculty of Agriculture, Universitas Syiah Kuala, Darussalam, Banda Aceh, Indonesia 23111
*Email: sufardi_usk@unsyiah.ac.id

Abstract. Soil particle size distribution is a fundamental physical property affecting other soil properties. 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 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 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 soil bulk density, low water holding capacity and poor soil structures. 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 dependent 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 Sumatra 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 the dryland farming system show that soil fertility rates are generally low [5], and also has a low soil quality index [6], [7]. From the chemical aspect, these soils have 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 systems with steep topography and shallow solum [9], so it has the 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 as distribution of soil particle size (texture), soil structure, aggregate stability index, and soil organic matter [14], [15]. Decreasing 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 influenced soil erosion [18], [19]. The composition of soil minerals also affects chemical properties, plant nutrients, and physical properties in relation to 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. Description of the Study Area.

The studied area is located in the Aceh Besar District, Aceh Province, Indonesia, and geographically located between 5° 2’ – 5° 8’ N latitude and 95° 80’ – 95° 88’ E longitude. The climate is tropics with an average annual precipitation of about 1,251-1,426 mm/years and average air temperature is 23-27°C and classified as dry climate because it has a dry month 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 an 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-basalitic [5]. Four pedons were selected to represent the parent materials and soil orders. The morphological properties of the soils were described in the field [23] and were classified according to the USDA Soil Taxonomy [24].

2.2. Methods

2.2.1. Physical and Chemical Analysis. Field study and samples collection were carried out from May to July 2020. 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 particle size analysis was carried out by the pipette method [25]. Four soil orders from Aceh Besar dryland included in this study are Entisols (Typic Udorthents) from Jantho (05°16’58.41" N; 95°32’51.82" E), Andisols (Typic Hydudands) 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 are observed directly in the field.
2.2.2. Clay Mineral Analysis. Analysis of clay minerals is used to determine the composition of soil minerals that dominate the soil and identification of soil families. 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. Removal of chemical cementing agents and separation of the different size fractions of soils were carried out according to Mehra and Jackson [27]. Organic matter and carbonate were removed with 30% H$_2$O$_2$ and 1 N HCl, respectively. The clay samples were examined by XRD analysis by comparing the relative heights of peaks in the XRD data [28]. The K-saturated samples were studied both after drying and heating at 500°C for 4 hours to identify kaolinite in the presence of trioctahedral chlorite, and samples were also treated with 1 N HCl at overnight of 80°C [29].

3. Results and Discussion

3.1. Sites Description

Based on observations of profiles, soil analysis, and clay mineral analysis, the classification of soil subgroups from four soil profiles from the dryland of Aceh Besar District are presented in Table 1. There are four pedons and soil subgroups that develop in the dryland of Aceh Besar, namely: Typic Udorthents (Entisols), Eutric Hydrandeptss (Andisols), Oxic Dystrudepts, and Plinthic Kandiudox (Oxisols). These soils are mostly found in the humid climate (udic) regime with the iso-hyperthermic temperature regime. The mineral composition contained in the soil is varied between soil orders and generally consists of mixed minerals which are a mixture of primary and secondary minerals [30].

Table 1. Classification of soil subgroup according to Soil Survey Staff (2014) of four soil pedons in the dryland soils of Aceh Besar District

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

From Table 1 it can be seen that the texture of the topsoil of the dryland of Aceh Besar varies from fine to medium, while the arrangement of the horizon also varies. Based on the composition of the horizon, then it can be said that the order of undeveloped soil is Entisols because it is composed of horizon A, AC, and C with the thickness of the solum <50 cm, while the others relatively have developed because it has occurred horizonization process that generates more horizons. Based on the identification of the field, the 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 Kandiudox) 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 the dryland of Aceh Besar is relatively no different in the upper soil layer (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 the dryland of Aceh Besar can be seen more clearly in Figure 1, while the distribution of soil fraction according soil depth shown in Figure 2.
Table 2. Physical properties of soil at each horizon layer of the soils in the dryland of Aceh Besar

| Pedon/Subgroup                | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture class | Structure    | Soil consistency | BD (Mg m⁻³) |
|-------------------------------|------------|----------|----------|----------|---------------|--------------|-----------------|-------------|
| P1 - Lithic Udorthents        | A/0 – 12   | 34       | 61       | 05       | SiL           | Blocky       | Breakable       | 1.34        |
| (Entisols) Jantho             | AB/12-44   | 20       | 37       | 43       | C             | Blocky       | Breakable       | 1.28        |
|                               | Cw/ > 44   | 66       | 27       | 07       | SL            | Subangular   | Massive         | 1.56        |
| P2 - Eutric Hydudands         | Ap0 – 20   | 14       | 59       | 27       | SiL           | Crumb        | Crumbly         | 1.01        |
| (Andisols) Saree              | 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         | Ap0 – 19   | 41       | 44       | 15       | SiL           | Blocky       | Breakable       | 1.45        |
| (Inceptisols) Cucum           | AB/19–42   | 22       | 53       | 25       | SiL           | Subangular   | Rather strong   | 1.39        |
|                               | BA/42–70   | 20       | 55       | 25       | SiL           | Prismatic    | Rather strong   | 1.32        |
|                               | Bw/1/70–110| 38       | 57       | 05       | SiL           | Prismatic    | Strong          | 1.42        |
|                               | BC/2/110–130| 42    | 52       | 06       | L             | Massive      | Massive         | 1.36        |
| P4 - Plinthic Kandiudox       | A/0 – 10   | 10       | 49       | 41       | SCL           | Blocky       | Crumbly         | 1.24        |
| (Oxisols) Lembah Seulawah     | AB/10–35   | 09       | 65       | 26       | SiL           | Subangular   | Breakable       | 1.22        |
|                               | BA/35–69   | 06       | 58       | 36       | SCL           | Subangular   | Breakable       | 1.25        |
|                               | Bo/1/69–104| 09      | 55       | 36       | SiC           | Subangular   | Strong          | 1.18        |
|                               | Bo/2/104–150| 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), 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 the dryland of Aceh Besar

In Entisols Jantho, the thickness of the solum < 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 Table 2 and Figure 3 it can be seen that the bulk density (BD) of soil from the four soil orders from Aceh Besar dryland varies from 0.96-1.45 Mg m⁻³. 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 has 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⁻³. This is because this soil is formed from volcanic ash that produces soil with the characteristic “andic” 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⁻³ (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 factions (Table 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 that can bind organic compounds to form 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⁻³ (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⁻³ [36].

Table 3. Bulk density (BD) of soil at each layer of horizon of four soil pedons in the dryland of Aceh Besar

| Pedon                  | Horizon                | Bulk Density (Mg m⁻³) |
|------------------------|------------------------|-----------------------|
| P1 - Lithic Udorthents, Jantho | Ap/0.00 – 0.12 m   | 1.34                  |
|                        | AB/0.12–0.44 m        | 1.28                  |
|                        | Cw/ > 0.44 m          | 1.56                  |
| P2 – Eutric Hydrudands, Saree | Ap/0.00 – 0.20 m   | 1.01                  |
|                        | AB/0.20 – 0.38 m      | 0.96                  |
|                        | Bw/0.38 – 0.60 m      | 0.98                  |
|                        | BC/0.60–1.30 m        | 1.02                  |
| P3 - Oxic Dystrudepts, Cucum | Ap/0.00 - 0.19 m    | 1.45                  |
|                        | AB/0.19 – 0.42 m      | 1.39                  |
|                        | BA/0.42 – 0.70 m      | 1.32                  |
|                        | Bw1/0.70-1.10 m       | 1.42                  |
|                        | Bw2/1.10-1.30 m       | 1.36                  |
| P4 - Plinthic Kandiudox, Lembah Seulawah | A/0.00 – 0.10 m   | 1.24                  |
|                        | AB/0.10 – 0.35 m      | 1.22                  |
|                        | BA/0.35-0.69 m        | 1.25                  |
|                        | Bo1/0.69-1.04 m       | 1.18                  |
|                        | Bo2/1.04-1.50 m       | 1.19                  |

Figure 3. Bulk density (BD) of soil at each layer of horizon of four soil pedons in the dryland of Aceh Besar

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

In Table 3 can be seen that the content of Fe-oxide (Fe₂O₃) 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 Fe₂O₃ on the upper soil layer is higher and the lower, while the content of Al₂O₃ and SiO₂ on the same horizon is relatively higher than the content of Fe₂O₃. The low content of Fe-oxide
indicates that this soil has not developed and has not formed a differentiation horizon in the profile [24]. The higher content of Fe-oxide on the upper horizon indicates that the A horizon of the soil is just the beginning of the leaching process so that the content of Fe-oxide is higher [37].

In P2 pedon of Eutric Hydrudans (Andisols) Saree, the Fe₂O₃ content is relatively small and ranges from 1.09-2.24%, while the Al₂O₃ content is higher (6.61-9.50%) than the SiO₂ content (2.61-3.64%) and Fe₂O₃. 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 Fe₂O₃ in each layer of the horizon is higher than the content of Al₂O₃ and SiO₂ in the order of Fe>Si>Al. In P4 pedons (Plinthic Kandiudox or Oxisols Lembah Seulawah), the content of Fe₂O₃ in this soil profile is higher than that of the P3 pedon whereas SiO₂ 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 Al₂O₃ and SiO₂ fractions [40], [41].

Table 3. The content of Fe₂O₃, Al₂O₃, and SiO₂ and dominant clay minerals at horizon layers in the soils of Aceh Besar dryland

| Pedon/Subgroup | Horizon/Depth (cm) | Fe₂O₃ | Al₂O₃ | SiO₂ | SiO₂/Al₂O₃ | Clay minerals* |
|----------------|-------------------|-------|-------|------|------------|----------------|
| P1             | A/0–12            | 5.31  | 4.82  | 6.61 | 1.37       | Quartz, Feldspar, Gibbsite |
| Littic Udorthents, | AB/12–44        | 0.25  | 6.31  | 3.95 | 0.63       | Gibbsite, Feldspar, Calcite |
| Jantho         | Cw/44             | 0.06  | 6.01  | 5.98 | 1.00       | Calcite, Quartz |
| P2             | Ap/0–20           | 1.89  | 6.61  | 2.98 | 0.45       | Ferrihydrite, Allophane |
| Eutric Hydrudans, | AB/20–38         | 1.16  | 8.40  | 2.61 | 0.31       | Allophane, Imogolite, Gibbsite |
| Saree          | Bw/38–60          | 1.09  | 8.11  | 3.33 | 0.41       | Allophane, Immogolite, Ferrihydrite |
|                | BC/60–130         | 2.24  | 9.30  | 3.64 | 0.39       | Gibbsite, Metallolysote, Allophane |
| P3             | Ap/0-19           | 3.96  | 2.36  | 3.71 | 1.57       | Gibbsite, Feldspar, Kaolinite |
| Oxic Dystrudepts, | AB/19–42         | 4.82  | 2.60  | 4.09 | 1.57       | Kaolinite, Feldspar, Dickite |
| Cucum          | BA/42–70          | 6.76  | 2.36  | 4.13 | 1.75       | Feldspar, Gibbsite, Dickite |
|                | Bw/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, Kaolinite, Nacrite |
| P4             | A/0–10            | 8.84  | 2.40  | 2.73 | 1.14       | Metallolysote, Gibbsite, Kaolinite |
| Plinthic Kandiudox, | AB/10–35        | 9.64  | 1.59  | 2.70 | 1.70       | Cristobalite, Kaolinite |
| Lembah Seulawah | BA/35–69          | 8.02  | 2.01  | 2.45 | 1.22       | Metallolysote, Goethite, Polygoskite |
|                | 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, Metallolysote |

*Based on X-ray analysis

Table 3 also proves that the four soil pedons from the 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 aluminio-silicate minerals (allophane, imogolite, and ferrihydrite). Inceptisol Cucum (P3) and Oxisols Lembah Seulawah (P4) are dominated by secondary minerals such as kaolinite, meta halloysite, palygorskite, and Al and Fe oxisols such as gibbsite, cristobalite, and goethite. In the other three soil orders (Entisols, Inceptisols, and Oxisols) in general the physical properties of the soil, especially in the deeper layers are relatively less good because it has a blocky to massive soil structure 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⁻³) even at certain depths can reach 1.56 Mg m⁻³ 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 the 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⁻³). In Oxisols Lembah Seulawah containing clay mineral type 1:1 (meta halloysite, kaolinite) and gibbsite and
goethite oxide fractions produce relatively good physical properties characterized by low or medium soil BD (1.18-1.25 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 root system. This physical barrier occurs because the BD value of the soil >1.2 Mg m$^{-3}$ so that good soil management is required for 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], [45-47]. 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
The distribution of particle distribution and soil mineral composition on Aceh Besar dryland generally varies between soil order and soil horizon. The distribution of these particles is related to the parent material and the degree of soil development. 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). Andisols Saree has relatively better physical properties compared to Entisols, Inceptisols, and Oxisols. These three soil orders have constraints namely high soil BD (>1.2 Mg m$^{-3}$), so it is necessary to improve the physical properties of the soil with the application of the organic amendment.

Acknowledgements
The authors thank the technicians of the Laboratory of Soil and Plant Testing, Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh where they were processed for analysis. The authors also thank Rector of Universitas Syiah Kuala and Head of LP2M (Lembaga Penelitian dan Pengabdian Kepada Masyarakat) Universitas Syiah Kuala for support and grant funding.

References
[1] Mulyani A, Nursyamsi D, Las I 2015 Percepatan pengembangan pertanian lahan kering iklim kering di Nusa Tenggara. *Pengembangan Inovasi Pertanian*, 7(4) 187-198.
[2] BPN (Badan Pertanahan Nasional) 2012 Peta Spasial Penggunaan Tanah Tahun 2012. Badan Pertanahan Nasional, Jakarta.
[3] BBSDLNP 2017 Peta jenis tanah Kabupaten Aceh Besar Provinsi Aceh. Balai Besar Sumberdaya Lahan Pertanian. Balingtan Jakarta.
[4] Sahbudin S, Khairullah K, Sufardi S 2020 Kemasaman Tanah dan Sifat-sifat Pertukaran Kation pada Mollisols dan Ultisols di Lahan Kering Kabupaten Aceh Besar. *Jurnal Ilmiah Mahasiswa Pertanian* 5(3) 25-34.
[5] McLeod M K, Sufardi S, Harden S 2020 Soil fertility constraints and management to increase crop yields in the dryland farming systems of Aceh, Indonesia. *Soil Research*, 59(1) 68-82.
[6] Martunis L, Sufardi S, Muyassir 2016 Analisis indeks kualitas tanah di lahan kering Kabupaten Aceh Besar Provinsi Aceh. *Jurnal Budidaya Pertanian* 12(1) 3-40
[7] Sufardi S, Arabia T, Khairullah K, Zainabun Z, Karnilawati K, Suhudin S 2020 Charge characteristics and cation exchanges properties of hilly dryland soils Aceh Besar, Indonesia. *Aceh International Journal of Science and Technology* 9(2) 90-101.
[8] Fajrina C, Arabia T, Sufardi S 2019 Distribusi Fe-dan Al-humus serta C organik tanah pada Entisol dan Inceptisol di Lahan Kering Jantho, Kabupaten Aceh Besar. *Jurnal Ilmiah Mahasiswa Pertanian* 4(1) 664-676.
[9] Sufardi S, Khalil M, Darusman D, Husni M, Zakaria S, Zaitun Z, Karmil T 2018 Soil fertility on dryland areas of Bireuen District Aceh Province, Indonesia. In *Proceedings of the First International Graduate Conference (IGC) On Innovation, Creativity, Digital, & Technopreneurship for Sustainable Development*. European Alliance for Innovation (EAI).
[10] Sufardi S, Arabia T, Khairullah, Karnilawati, Fuadi Z 2019 Soil physical and chemical properties on several soil orders of dryland areas of Aceh Besar District (Indonesia). *Proceedings of International Workshop and Seminar*, 18-22 September. Surakarta, Indonesia.

[11] Arsyad S 2010 *Konservasi Tanah dan Air*. Institut Pertanian Bogor, Bogor.

[12] Chen H, Zhang X, Abla M, Lü D, Yan R, Ren Q, Yang X 2018 Effects of vegetation and rainfall types on surface runoff and soil erosion on steep slopes on the Loess Plateau, China. *Catena*, 170 141-149.

[13] Lal R 2018 Erosion impact on soil quality in the tropics. In *Soil quality and soil erosion* (pp. 285-305), CRC Press.

[14] Martínez-Hernández C, Rodrigo-Comino J, Romero-Díaz A 2017 Impact of lithology and soil properties on abandoned dryland terraces during the early stages of soil erosion by water in southeast Spain. *Hydrological Processes*, 31(17) 3095-3109.

[15] Pan J, Bai Z, Cao Y, Zhou W, Wang J 2017 Influence of soil physical properties and vegetation coverage at different slope aspects in a reclaimed dump. *Environmental Science and Pollution Research*, 24(30) 23953-23965.

[16] Mani S, Merino A, García-Oliva F, Riottte J, Sukumar R 2018 Soil properties and organic matter quality in relation to climate and vegetation in southern Indian tropical ecosystems. *Soil Research*, 56(1) 80-90.

[17] Robertson A D, Zhang Y, Sherrod L A, Rosenzweig S T, Ma L, Ahuja L, Schipanski M E 2018 Climate change impacts on yields and soil carbon in row crop dryland agriculture. *Journal of environmental quality*, 47(4) 684-694.

[18] Salem H M, Meselhy A, Elhagarey M, Ali A M, Wu W 2020 Soil erosion control and wheat productivity are improved by a developed ridge-furrow and reservoir tillage systems. *Archives of Agronomy and Soil Science*, 1-10.

[19] Telak L J, Dugan I, Bogunovic I 2021 Soil management and slope impacts on soil properties, hydrological response, and erosion in hazelnut orchard. *Soil Systems*, 6(1) 5-6.

[20] BPS (Statistical Center Office) Aceh Besar 2019 Aceh Besar Dalam Angka. Kantor Pusat Statistik Kabupaten Aceh Besar.

[21] Brilyan I, Munawar A A, Ichwana 2019 Identifikasi karakteristik iklim dengan menggunakan principal component analysis. *Proseding Seminar Perkebunan*. Syiah Kuala University Press.

[22] Amaluddin A, Basri H, Sugianto S 2014 Analisis Perubahan Tipe Iklim dan Dampaknya Terhadap Produksi Padi Sawah di Kabupaten Aceh Besar. *Jurnal Manajemen Sumberdaya Lahan*, 3(2) 467-471.

[23] Soil Research Center 2005 *Procedures for Soil Analysis*. Balai Besar Sumberdaya Lahan Pertanian, Balitbang, Bogor.

[24] Soil Survey Staff 2014 *Keys to soil taxonomy*. USDA, Soil Survey Staff. Ames, USA.

[25] Huluka G, Miller R 2014 Particle size determination by hydrometer method. *Australian Cooperative Series Bulletin* 419 180-184.

[26] Whittig L D, Allardice W R 1986 *X‐ray diffraction techniques*. Archives of *Soil Science and Environmental Research*, 5 331-362.

[27] Holmgren A 1976 Dithionite-and oxalate-extractable Fe and Al as aids in differentiating various classes of soils. *Canadian Journal of Soil Science*, 46 13–23.

[28] Mehra O P, Jackson M L 2013 Iron oxide removal from soils and clays by a dithionite–citrate system buffered with sodium bicarbonate. In *Clays and clay minerals* (pp. 317-327). Pergamon.

[29] Moghimi A H, Hamdan J, Shamshuddin J, Samsuri A W, Abtahi A 2013 Physicochemical properties and surface charge characteristics of arid soils in Southeastern Iran. *J. Aplied and Environmental of Soil Science*. https://www.hindawi.com/journals/aess/2013/252861/#B21

[30] Afrizani I, Arabia T, Sufardi S 2019 Identifikasi mineral tanah dengan menggunakan difraksi sinar-X pada Inceptisol Aceh Besar. *Jurnal Ilmiah Mahasiswa Pertanian*, 4(3) 157-165.

[31] Lal R, Shukla M K 2004 *Principles of soil physics*. CRC Press.

[32] Chorover J 2017 *Andisol*. In *Encyclopedia of soil science* (pp. 130-133), CRC Press.

[33] Zhao C, Jia X, Zhang C 2016 Particle size distribution of soils (0–500 cm) in the Loess Plateau, China. *Geoderma Regional*, 7(3) 251-258.
[34] Mohammadi M, Shabanpour M, Mohammadi M H, Davatgar N 2019 Characterizing spatial variability of soil textural fractions and fractal parameters derived from particle size distributions. *Pedosphere* **29**(2) 224–234.

[35] Abera G, Wolde-Meskel E 2013 Soil properties, and soil organic carbon stocks of tropical andosol under different land uses.

[36] Bogunovic I, Pereira P, Kistic I, Sajko K, Sraka M 2018 Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia). *Catena* **160** 376-384.

[37] Sufardi S, Arabia T, Khairullah K, Numikmat T Z 2019 Distribution of Al, Fe, and Si oxides in three soil orders in dryland of Aceh Besar, Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 393, No. 1, p. 012081). IOP Publishing

[38] McDaniel P A, Lowe D J, Arnalds O, Ping C L. 2012 Andisols. In P M Huang Y Li & M E Summer (Eds.), *Handbook of Soil Sciences: Properties and Processes* (pp. 29–48). CRC Press.

[39] Pizarro C, Escudey M, Gacitua M, Fabris J D 2017 Iron-bearing minerals from soils developing on volcanic materials from Southern Chile: Mineralogical characterisation supported by Mössbauer spectroscopy. *Journal of soil science and plant nutrition* **17**(2) 341-365.

[40] Costa E U C D, Araujo J K S, Neves L V D M W, Araujo Filho J C D, Sousa J E S D, Corrêa M M, ... Souza Júnior V S D 2019 Genesis and classification of Nitisols from volcano-sedimentary lithology in Northeastern Brazil. *Revista Brasileira de Ciência do Solo*, **43** 34-42.

[41] Catt J A 2020 Soil particle size distribution and mineralogy as indicators of pedogenic and geomorphic history: examples from the loessial soils of England and Wales. In *Geomorphology and soils* (pp. 202-218). Routledge.

[42] Van Ranst E, Qafoku N E, Noble A, Xu R 2017 Variable charge soils: Mineralogy and Chemistry”; in *Encyclopedia of Soil Science. 3rd Edition*, edited by R Lal (CRC Press, Florida, 2017), pp. 2432-2439.

[43] Al-Shammary A A G, Kouzani A Z, Kaynak A, Khoo S Y, Norton M, Gates W 2018 Soil bulk density estimation methods: a review. *Pedosphere* **28**(4) 581-596.

[44] Mahawish A, Bouazza A, Gates W P 2018 Effect of particle size distribution on the bio-cementation of coarse aggregates. *Acta Geotechnica* **13**(4) 1019-1025.

[45] Helmii H, Basri H, Sufardi S 2017 Analysis of soil quality as a hydrological disaster mitigation effort in Krueng Jereu Sub-Watershed, Great Aceh. *Malaysian Soil Science Journal* **6**(2) 75-85.

[46] Helmii H, Munawar A A, Bakhtiar B and Zulfahrizal Z 2021 Comparisons among soil tillage system and their impacts to the tested rice varieties on lowland rainfed alluvial in aceh jaya *Food Res.* **5** 173–8

[47] Darusman D, Juwita I R, Munawar A A, Zainabun Z and Zulfahrizal Z 2021 Rapid determination of mixed soil and biochar properties using a shortwave near infrared spectroscopy approach *IOP Conf. Ser. Earth Environ. Sci.* **667**