The study of Aluminum (Al) fractionation on forest land, agroforestry, and dryland agriculture in west java

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Abstract. The aims of this study were to evaluate the distribution of Aluminum fraction (Al) on the horizon of forest land, agroforestry, and dryland agriculture in West Java highland soils and looking correlation with soil chemical fertility, is pH, CEC, organic-C, total N, total P, available P and soil texture. The evaluation was carried out on the results of the analysis of soil samples taken at four soil horizons (Ao or Ap, A1 or A2, B1, and B2) in each land use. Al fractionation using extraction methods with different chemicals to find exchangeable Al (Alex), amorphous Al (Alo), amorphous Al organic (Alp), amorphous Al bound weakly to organically (Alcu), Amorphous Al bound strongly to organic (Alop), and amorphous Al inorganic (Alpcu). The results showed that the Alo fraction dominated the other Al fractions in each land use. In forest land Alo fraction (> 58.61%) with a fluctuating distribution pattern, in agroforestry (54.45%) with a declining distribution at the depth of the soil horizon, then on dryland agriculture (> 89.86%) it increases fluctuatively with the depth of the soil horizon. The addition of organic material/compost must be done to increase the organic-C content in the soil.

1. Introduction
The decreasing crop productivity or deteriorating soil properties indicate that soil has been degraded. The general degradation is the result of one or more processes of the ability of actual and potential land to produce goods and services [1]. This will have an impact on changes in regional community ecosystems if that continuously happened. Land degradation in Indonesia is caused by soil erosion due to the intensity of high rainfall, steep slopes, mining and urban activities, monoculture plantations, and industrial pollutants [2,3]. Soil degradation because of high rainfall, used and management of land without conservation rules causes leaching of nutrients, reduced content of organic matter, transfer of clay, damage to soil structure, compaction, and soil erosion [1].

The intensity rainfall in western Indonesia is generally high, so that the leaching rate of bases in the soil is high, causing alkaline contents to be low and the soil acidic [4], besides polyvalent cations such as Fe²⁺, Al³⁺, and Si⁴⁺ accumulates to form new particles such as mineral 1:1 and oxides Al, Fe, and Mn [5]. In acid soils, Aluminum and hydrogen are cations that cause acidity because they tend to hydrolyze. The level of solubility of exchangeable Al (Alex) is very high so that plant growth is disturbed because the root roaming area becomes narrow. Aluminum in the soil is part of the structure of soil clay minerals (aluminum-silicates), and parts of clay layers/dissolution of silicate minerals.
Besides, there are loose/free Al which is bound to organic materials and so on. Aluminum is found in the octahedral form \((\text{Al} (\text{H}_2\text{O})_6^{3+})\), or \(\text{Al}^3+\) ion and is very dangerous for plants [6].

The solubility of Al in soil according to [7], are classified into several forms, is: exchangeable Al (Alex), amorphous Al (Alo), organic amorphous (Alp), inorganic amorphous (Alpcu), Al-amorphous bound with weak-medium and organic (Alcu), and amorphous Al bound strongly to organics (Alop). Vegetation plays an important role in the physical, biological, and chemical properties of soil fertility. Al balance in soil solution is determined by soil pH, ion strength, type and concentration of organic and inorganic ligands, and solid phase.

The toxication and saturation Al is a major problem in acid soils, directly hurting plant roots, inhibiting plant growth, and blocking the taking and translocation of macronutrients such as calcium (Ca) and phosphorus (P). The measurement of degraded lands, in general, is comparing with non-degraded soils (forest land). Therefore, studies related to Al concentrations and their solubility in soils upland soils need to be done to find out the management of problem-solving solutions.

2. Methods

2.1. Time and Place.
The soil sample takes on forest land, agroforestry, and dryland agriculture in Cisarua District, Bogor Regency. Forest lands are at latitude 6°69'443" LS and 106°98'889" BT, agroforestry at latitude 6°69'737" LS and 106°97'673" BT, while dryland agriculture is at latitude 6°69'530" LS and 106°98'726" BT. Analysis of soil samples was carried out at the Laboratory of Chemical and Soil Fertility, Department of Soil Science and Land Resources, Bogor Agricultural University (IPB), and Testing Laboratory of Soil Research Institute, Agricultural Research and Development Agency (BBSDLP), Bogor. This research was conducted from May 2017 to February 2018.

2.2. Materials and methods of soil analysis.
The types and methods of soil analysis are presented in table 1. Analysis of soil using representatives of four soil horizons (Ao or Ap, A1 or A2, B1, and B2) in each type of land use (forest, agroforestry, and dryland agriculture). Each type of land use is represented by two land profiles. Relationships concentrations of Al soil fractions with selected soil chemical properties were evaluated based on the results of the Pearson correlation analysis using SPSS version 21.0 software.

| Alfractionation procedure. |
|---------------------------|
| The procedure Al fractionation showed in Table 2. Measurements were made using an Atomic Absorption spectrophotometer (AAS) type AA-6300 SHIMADZU brand. |
Table 2. Al fractionation procedure

| Al Fraction                        | Chemical                              | Weight sample | pH  | Shaker (Hour) |
|------------------------------------|---------------------------------------|---------------|-----|--------------|
| exchangeable Al (Alex)             | 50 mL 1 M ammonium chloride (NH₄Cl)  | 5 g           | 5.8 | 24           |
| amorphous Al (Alo)                 | 50 mL 0.2 M acid oxalate (C₂H₂O₄)    | 5 g           | 3.0 | 4            |
| amorphous Al organic (Alo)         | 20 mL 0.05 M Natrium pyrophosfat (Na₄P₂O₇) | 5 g           | 1.0 | 1            |
| amorphous Al bound weakly to organically (Alcu) | 50 mL 0.5 M CuCl₂ | 5 g           | 2.0 |              |
| amorphous Al bound strongly to organically (Alo) | Result of Alo – Alp |               |     |              |
| amorphous Al inorganic (Alpcu)     | Result of Alp – Alcu                  |               |     |              |

3. Result

3.1. Evaluation of Soil Chemical Property and Fisic.

The results of the analysis of soil physical and chemical properties of the study location (forest, agroforestry, and dryland agriculture) in the soil profile are presented in Table 3.

Table 3. The chemical properties of soil on forest land, agroforestry, and dryland agriculture

| Landuse               | Depth (cm) | Soil Horizon | pH H₂O | Clas. | CEC | Org-C % | Total-N (%) | Total-P | P ava. | Sandy | Silt | Coarse Clay | Fine Clay | Texture Class    |
|-----------------------|------------|--------------|--------|-------|-----|---------|-------------|---------|--------|-------|-----|-----------|-----------|------------------|
| Forest                | 0-15       | Ao           | 4.0    | 4.0   | Very acid | 27.57  | 12.9       | 1.11         | 386.57 | 6.62  | 38.4 | 15.1 | 7.6        | 38.9      | Sandy loam       |
|                       | 15-30      | A1           | 4.8    | 4.7   | Acid | 34.13  | 3.8        | 0.66         | 278.95 | 5.90  | 45.5 | 26.8 | 6.7        | 20.9      | Sandy clay       |
|                       | 30-110     | B1           | 4.8    | 4.8   | Acid | 26.07  | 3.3        | 0.29         | 372.10 | 5.90  | 30.6 | 24.2 | 9.8        | 35.4      | Sandy loam       |
|                       | 110-150    | B2           | 4.5    | 4.5   | Acid | 24.11  | 0.8        | 0.2          | 421.96 | 5.81  | -    | -    | -         | -        | Sandy loam       |
| Agroforestry          | 0-15       | Ap           | 4.2    | 4.2   | Very acid | 36.01  | 2.2        | 0.22         | 244.43 | 4.61  | 17.1 | 46.9 | 12.6       | 23.4      | Clay loam        |
|                       | 15-40      | A2           | 4.5    | 4.5   | Acid | 34.01  | 0.3        | 0.08         | 232.10 | 4.52  | 23.5 | 48.4 | 9.5        | 18.6      | Sandy loam       |
|                       | 40-70      | B1           | 4.4    | 4.4   | Very acid | 32.74  | 0.1        | 0.06         | 166.31 | 4.70  | 20.6 | 47.3 | 9.7        | 22.4      | Clay loam        |
|                       | 70-100     | B2           | 4.3    | 4.3   | Very acid | 33.2   | 0.2        | 0.06         | 163.86 | 3.66  | -    | -    | -         | -        | Sandy loam       |
| Dryland agriculture   | 0-25       | Ap           | 4.4    | 4.4   | Very acid | 25.91  | 4.2        | 0.46         | 498.10 | 5.68  | 46.6 | 25.4 | 2.2        | 25.8      | Sandy loam       |
|                       | 25-50      | A2           | 4.7    | 4.7   | Acid | 25.68  | 4.1        | 0.51         | 548.09 | 6.68  | 22.4 | 45.8 | 13.8       | 18.1      | Sandy loam       |
|                       | 50-75      | B1           | 4.7    | 4.7   | Acid | 22.42  | 1.6        | 0.24         | 427.32 | 6.38  | 11.1 | 55.8 | 18.1       | 15.1      | Clay loam        |
|                       | 75-110     | B2           | 4.3    | 4.3   | Very acid | 21.07  | 0.6        | 0.18         | 429.71 | 5.61  | -    | -    | -         | -        | Sandy loam       |

The soil reaction (pH) in each land use is generally acidic in the study location. In line with research by [8], that the pH of land in West Java is classified as acidic due to the high intensity and rainfall of around 2 216.1 mm per year [9]. The H₂O pH value shows the actual acidity of the soil, while the analysis uses KCl to determine the potential acidity of the soil.

The soil texture class in the forest land at the Ao and B horizons is textured by sandy loam, while at horizon A1 is sandy clay. On agroforestry, at the horizon, Ap and B1 are clay loam texture, while at
A2 horizon is sandy loam texture. While the dryland agriculture is clay texture on AP horizon and A1, while in the B1 horizon it is texture class is clay loam.

The results of the analysis soil cation exchange capacity (CEC) indicate that the distribution pattern decreases with the depth of the soil horizon in each land use. Based on the chemical parameters of soil fertility [10], soil CEC in each land use classified as high. This is supported by the acidity of the land in each land use classified as an acid. According to [11], the magnitude of land CEC is influenced by the nature and characteristics of the land, is soil pH, organic matter, soil texture, and types of clay minerals.

The sequentially the highest CEC concentration was on agroforestry land, forest land, and then in dryland with a declining distribution pattern based on soil horizon depth in each land use. Organic matter plays a role in increasing the absorption and exchange of cations, the availability of N, P, and S, as well as the nutrient dissolution of minerals by humic acid. Soils with higher CECs have a greater capacity to store nutrients such as Ca\(^{2+}\), Mg\(^{2+}\), and K\(^{+}\) which have the potential to be available to plants, so that reducing leaching from the soil [12].

The highest content of organic-C is forest land, then agroforestry, and dryland agriculture with a decreasing distribution at the depth of the soil horizon in each land use. In general, the topsoil has higher levels of organic matter than the subsurface layer. In agroforestry land, the organic matter content is lower than in moor. This is due to the intensity of tillage on dry land is higher than agroforestry, and the age of forestry plants in agroforestry is classified as young. In upland land, organic matter originates from the remnants of crop yields, while in forest land naturally comes from the decomposition of organic matter around it.

The total N-distribution pattern decreases with the depth of the soil horizon (from Ao horizon/ Ap to horizon B2) in each land use. On forest land the total N-content is classified high to very high at the Ao horizon of 1.11% then decreases to 0.2% on the B2 horizon. On agroforestry land, the N-total concentration is classified as moderate, which is equal to 0.22% at the Ap horizon decreasing to 0.06% on the B2 horizon. On the other hand, in the upland field, it is classified as low, which is at the Ap horizon of 0.46%, decreasing to 0.18% on the B2 horizon.

### 3.2. Evaluation of Al fraction.

The results of analysis concentration and percentage Al in soil horizon on land use forest, agroforestry, and dryland agriculture are presented in Table 4. The results showed that the highest Al concentrations were in agroforestry, then forests and dryland agriculture. Distribution of Alex fraction in forest land has fluctuated around 0.022% at the Ao horizon, then increases to 0.047% at the A1 horizon, and decreases again at the B1 horizon around 0.009%, and increases around 0.200% on the B2 horizon. However, in agroforestry and dryland agriculture, the pattern of distribution decreases based on the depth of the soil horizon. The Alex fraction concentration in agroforestry decreased significantly from 0.546% in the Ap horizon to 0.367% on the B2 horizon, while in dryland agriculture decreased from 0.006% on the AP horizon to 0.001% on the B2 horizon. The lowered Alex concentration in dryland agriculture is suspected to have added lime through fertilizing activities by farmers. The Alex fraction is part of the Aluminum fractionation which is measured using the Atomic Absorption Spectrophotometer (AAS). Measurements using AAS are quantitative elemental analysis methods based on the absorption of light with a certain wavelength. The AAS method has high sensitivity and accuracy because it can measure the metal content by ppm, analyze it quickly with a small sample, and can be used to determine the metal content with a small concentration without being separated first [13].

The Alo fraction is known by extracting soil using oxalate acid (C\(_2\)H\(_2\)O\(_4\)) 0.2 M with a very acidic pH (pH 3.2), to head dissolve the active Al compounds. Alo fraction is total aluminum which binds to organic (Alp) and inorganic (Alpcu) amorphous compounds in the soil. In general, the Alo fraction dominates more than the other Al fractions. Sequentially the highest Alo fraction is in dryland agriculture, the forest, and agroforestry. The concentration fraction in the forest around 58.61-73.49%, dryland agriculture around 89.86-92.98% with a distribution pattern increase significantly in-depth...
horizon soil, rather in agroforestry around 54.45-71.46%. According to [14], fine-textured soil contains more clay and topsoil, whereas sand and sandy clay contain less colloidal clay and are also poor in organic matter or humus. While aluminum in soil is part of the structure of soil clay minerals, in several soils large amounts of colloidal and crystalline materials are found, such as part of iron oxide and aluminum in soil is amorphous.

Table 4. The concentration of the Al fraction in forest land, agroforestry, and dryland agriculture.

| Landuse            | Soil Horizon | Al Fraktionation (ppm) |    |    |    |    |    |
|--------------------|--------------|------------------------|----|----|----|----|----|
|                    |              | Alex | % | Alo | % | Alp | % | Alpcu | % | Alcu | % | Alop | % |
| Forest             | AO           | 6.50 | 0.022 | 19800.0 | 67.75 | 9000.0 | 30.80 | 10800.0 | 36.95 | 419 | 1.43 | 8581.5 | 29.36 |
|                    | A1           | 17.1 | 0.047 | 26300.0 | 71.89 | 9600.0 | 26.24 | 16700.0 | 45.65 | 665 | 1.82 | 8935.5 | 24.43 |
|                    | B1           | 3.85 | 0.009 | 32250.0 | 73.49 | 11200.0 | 25.52 | 21050.0 | 47.96 | 433 | 0.99 | 10767.5 | 24.53 |
|                    | B2           | 58.9 | 0.200 | 17250.0 | 58.61 | 11900.0 | 40.44 | 5350.0 | 18.18 | 221 | 0.75 | 11679.0 | 39.68 |
| Agroforestry       | AP           | 105.15 | 0.546 | 13750.0 | 71.46 | 5200.0 | 27.02 | 8550.0 | 44.43 | 187 | 0.97 | 5013.5 | 26.06 |
|                    | A1           | 75.00 | 0.332 | 15200.0 | 67.23 | 7000.0 | 30.96 | 8200.0 | 36.27 | 336 | 1.48 | 6664.5 | 29.48 |
|                    | B1           | 51.85 | 0.308 | 10200.0 | 60.65 | 6400.0 | 38.05 | 3800.0 | 22.59 | 167 | 0.99 | 6233.5 | 37.06 |
|                    | B2           | 54.90 | 0.367 | 8150.0 | 54.45 | 6300.0 | 42.09 | 1850.0 | 12.36 | 462 | 3.09 | 5838.0 | 39.01 |
| Dry Land Agriculture| AP          | 3.30 | 0.006 | 53600.0 | 90.08 | 5750.0 | 9.66 | 47850.0 | 80.41 | 151 | 0.25 | 5599.0 | 9.41 |
|                    | A1           | 0.90 | 0.001 | 68650.0 | 89.86 | 7200.0 | 9.42 | 61450.0 | 80.44 | 546 | 0.71 | 6654.5 | 8.71 |
|                    | B1           | 0.75 | 0.001 | 65750.0 | 92.98 | 4350.0 | 6.15 | 61400.0 | 86.83 | 616 | 0.87 | 3734.5 | 5.28 |
|                    | B2           | 0.90 | 0.001 | 62000.0 | 92.26 | 4750.0 | 7.07 | 57250.0 | 85.19 | 448 | 0.67 | 4302.0 | 6.40 |

Description: Alex= exchangeable Al, Alo= amorphous Al, Alp= amorphous Al organic, Alpcu= amorphous Al bound weakly to organically, Alop= amorphous Al bound strongly to organically, Alcu= amorphous Al inorganic

The fraction Alp is the form bound to an amorphous organic compound in soil [15]. Fraction Alp obtained from extraction using Na4P2O7 0.2 M. Pattern of concentration Fluctuating Alp fraction in forest land with soil horizon depth around 25.52-40.44%, then agroforestry around 27.02-42.09% is significantly increased in depth horizon soil, and then in dryland agriculture increased with depth in soil horizon around 7.07-9.66%.

Fraction Alpcu is formed Al which bound to inorganic amorphous compounds in the soil, is the difference from the amorphous Al fraction (Alo) with organic amorphous aluminum (Alp) in the soil. Sequentially the highest concentration of Alpcu in dryland agriculture around 80.41-86.83% increases at the depth of the land horizon, then forest around 18.18-47.96% decreases in-depth soil horizon, and concentration the lowest in agroforestry land around 12.36-44.43% with distribution pattern decreasing in the soil horizon depth. This is thought to be influenced by organic matter in the soil. The Alcu fraction is a form Al bound weakly to moderate with organic amorphous compounds, which is known by extraction using 0.5 M CuCl [16]. Sequentially the highest concentration of Alcu fraction was on agroforestry land around 0.97-3.09% with distribution patterns increasing at the depth of the soil horizon, then forest land around 0.75-1.82% with a decreased distribution at the depth of the soil horizon, and the lowest in dryland agriculture around 0.25-0.87% with increased distribution at the depth of the soil horizon. The Alcu reaction is related to the organic matter in the soil, generally the deeper the soil horizon the lower the organic content.

The Alop fractions are Al forms that are strongly bound to organic compounds in the soil [7]. Alop fraction is the difference between Alo and Alp. The sequential concentration of highest Alop fraction on forest land, then agroforestry, and dryland agriculture. On forest land and dryland agriculture patterns of distribution, Alop fractions decrease based on the depth of the soil horizon, on the other hand on agroforestry land. Alop concentration in the forest land around 29.36% at the Ao horizon.
decreases at the B1 horizon around 24.53% and increases again in horizon B2 around 39.68%. On agroforestry land Alop fraction around 26.06% in horizons, Ap increased to 39.01% in horizons B2, whereas in the dry land agriculture the concentration of Alop fraction decreased from 9.41% in horizon Ap to 6.40% in horizon B2. This shows that the deeper the soil horizon the form of the Alop fraction is higher, this is because soil organic matter is lower with the depth of the soil horizon.

3.3. Correlation of Al fraction with chemical properties in soil.

The result of the Pearson correlation show is the intensity of land use real effect on distribution plant nutrition in soils. The relation of the Al fraction with chemical properties showed in Table 5.

| Landuse          | Chemical properties | Al Fraction | pH   | CEC  | organic-C | Total-N | Total-P | P Available |
|------------------|---------------------|-------------|------|------|-----------|---------|---------|-------------|
| Forests          | Chemical properties | Alex        | -0.168 | 0.018 | -0.278 | -0.322  | 0.3 | -0.155 |
|                  |                     | Alo         | 0.491  | 0.173 | -0.22  | -0.092  | -0.597  | 0.016 |
|                  |                     | Alp         | 0.289  | 0.066 | -0.398 | -0.505  | 0.381  | -0.201 |
|                  |                     | Alpcu       | 0.386  | 0.143 | -0.123 | 0.013  | -0.608  | 0.052 |
|                  |                     | Alcu        | 0.275  | .963**| -0.046 | 0.29  | -0.800* | 0.435 |
|                  |                     | Alop        | 0.252  | -0.06 | -0.39  | -0.54  | 0.484  | -0.256 |
| Agroforestry     | Chemical properties | Alex        | -0.413 | -0.001 | 0.338  | 0.376  | 0.664  | -0.029 |
|                  |                     | Alo         | 0.592  | -0.382 | 0.383  | 0.481  | 0.861** | .717* |
|                  |                     | Alp         | 0.556  | -0.629 | -0.467 | -0.401 | 0.153  | 0.32  |
|                  |                     | Alpcu       | 0.503  | -0.267 | 0.504  | 0.592  | 0.874** | 0.685 |
|                  |                     | Alcu        | 0.549  | -0.493 | -0.164 | -0.202 | 0.235  | -0.241 |
|                  |                     | Alop        | 0.47   | -0.564 | -0.47  | -0.388 | 0.108  | 0.411 |
| Dryland          | Chemical properties | Alex        | -0.539 | 0.261 | 0.538  | 0.48   | 0.091  | -0.343 |
| agriculture      |                     | Alo         | .733*  | 0.315 | -0.097 | -0.124 | -0.02  | 0.406 |
|                  |                     | Alp         | 0.338  | 0.337 | 0.625  | 0.682  | 0.011  | 0.18  |
|                  |                     | Alpcu       | 0.69   | 0.269 | -0.188 | -0.224 | -0.022 | 0.383 |
|                  |                     | Alcu        | 0.419  | -0.232 | -0.409 | -0.32  | 0.02   | 0.65  |
|                  |                     | Alop        | 0.269  | 0.36  | 0.664  | 0.707* | 0.008  | 0.083 |

Description: * Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed), Alex= exchangeable Al, Alop= amorphous Al, Alp= amorphous Al organic, Alcu= amorphous Al bound weakly to organically, Alop= amorphous Al bound strongly to organically, CEC= capacity exchangeable cation

The results of data analysis using the Pearson correlation (Table 5) showed that on forest land there was a positive correlation at Alcu fraction and the CEC soil, and negative correlation Alcu fraction with the total P in the soil. Alcu fraction is a form of amorphous Al which is weakly bound to organic matter, so that the higher the soil organic matter, the lower the Alcu reaction causes total P to increase due to competition between Al and organic matter [17], meanwhile, if Alcu in soil high while the organic matter is low, P is more strongly fixation. In the agroforestry land, a positive correlation occurred between the Alop fraction with the total P and P available, and there was a real positive correlation between the Alpcu fraction and total P in the soil. The high P fixation is thought to be caused by the content of hydrous oxide Fe and Al in high soil. According to [14], most of the Fe and Al Hydrus oxide ions in the soil are amorphous, especially the soils formed from volcanic ash parent. In this study place soil parent materials at from the volcanic ash of Mount Pangrango. Whereas in dryland agriculture there is a positive correlation between Alop fraction and soil pH, and Alop fraction with Total N. The soils with high CEC have a large capacity to store nutrients cations such as Ca++, Mg++, and K+ so that they are potentially available to plants, and reduce leaching from the soils [12].
4. Conclusion
The highest Al fraction in each land use is Alo fraction. Distribution of Alo fraction on forest land > 58.61%, agroforestry > 54.45% with decreasing distribution at the depth of the soil horizon, and dry land > 89.86% with increasing distribution patterns at the depth of the soil horizon. The lowest concentration of Al fraction is in the form of dry land agriculture around 0.001-0.006%, then forest around 0.009-0.200%, and agroforestry around 0.308-0.546%. Level of lability Al fraction in each land use is fraction Alex < Alcu < Alop < Alp < Alpcu < Alo. Organic matter plays an important role as a competitor of Al in the soil, causing Al to P fixation to be reduced so that P available for plants.

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