Comparison of appropriate cation exchange capacity (CEC) extraction methods for soils from several regions of Indonesia

L Purnamasari, T Rostaman, L R Widowati and L Anggria

Indonesian Soil Research Institute, Bogor, Indonesia
Email: laili.purnamasari@gmail.com

Abstract. Soil-forming factors strongly influence soil diversity in Indonesia. Indonesia is rich in variations of tropical soil types that have distinctive characteristics. Cation exchange capacity (CEC) is an indicator of the soil ability to absorb and supply nutrients so that CEC is used as an index of soil chemical fertility. The factors that affected CEC are the amount of clay texture, organic matter content, and pH. In standard method, CEC is obtained by ammonium acetate 1 N pH 7 method, while the distribution of soil pH in Indonesia is very diverse from pH 4 to pH 8. Also, there are differences in factors that affect CEC, causing the CEC values to be biased or does not reflect the real conditions. The purpose of this study was to obtain the best soil CEC extraction method. 97 soil samples were analyzed with 1 N ammonium acetate extract pH 4.8, pH 6.0, pH 7.0, and compulsive cation exchange extraction method. The result showed that the ammonium acetate pH 7.0 method had a significant correlation to other methods and to pH (H₂O). The ammonium acetate pH 7.0 method could be applied for acidic and alkaline soil.

1. Introduction
Identification of soil chemical properties in agricultural soils needs to be done to predict the potential for soil fertility and prepare a soil management plan such as fertilization [1]. One of the soil chemical properties for soil fertility is the cation exchange capacity (CEC). Cation exchange capacity is the total ability of the soil to hold, absorb and exchange cations in the soil [2].

A high CEC in the soil causes the soil to have the ability to absorb and provide nutrients better than soils with low CEC. This is because these nutrients are in the soil seepage, so they are not easily lost or washed by water. Soils with a high organic matter content of clay have a higher CEC compared to soils with low organic matter or sandy soils [3]. Decreasing levels of organic matter and organic C causes a decrease in soil CEC. The higher the soil CEC, the more alkaline cations that are retained by the soil, so that the possibility of fertile soil will be higher, but on the other hand, if the CEC in the soil is low, the soil ability to hold nutrients decreases so that the nutrients are easily washed away by water [4].

Several factors affect the CEC value's, including organic matter content, pH, clay fraction, and types of clay minerals [5]. Soil pH is a crucial indicator and positively correlated with CEC [6], thus a high pH will increase the amount of negative charge on both colloids and CEC. The high content of organic and clay materials causes an increase in the CEC value because both of them have a lot of negative ion charges on their surface so they can attract and hold cations [7].

There is a positive correlation between soil CEC, organic carbon, and clay content in lime soil [8]. Cations at the surface of the soil can easily be exchanged with cations from the solution. Soil samples
used in this study were a soil that had varied lime content, from low to high. The methods tested included double saturating solution, HCOOLi, and NaOAc-NaCl. Each has advantages and disadvantages in determining soil CEC on high calcareous soils of the four methods tested. Carbonate disturbance could not be avoided in any method, even if the pH was adjusted to 8.0 or more. The fourth method using NaOAc-NaCl in 60% ethanol as a saturating solvent is proven to be entirely accurate and straightforward for calcareous soils.

Research on CEC extraction has been conducted by Ciesielski and Sterckeman [9]. They compared 3 CEC extraction methods, including the cobalt hexamine chloride method, the barium chloride method (compulsive cation exchange), and the ammonium acetate method on soil samples from various regions in France. This research concluded that the cobalt hexamine method can be used as a reagent with a single extraction so that it can replace the barium chloride method. It is proven in this study that the ammonium acetate method makes it difficult to choose an alternative procedure. The use of an unbuffered extractant is also appropriate.

The next research was carried out by Madeira et al. [10], regarding extraction using the ammonium acetate method and the compulsive cation exchange method [10]. This study concluded that the CEC value with compulsive exchange extraction was more significant than the ammonium acetate pH 7.0 method for andisol soil samples from the Azores, Portugal. The next research conducted by Tomašić et al. [7], it showed that the results of soil CEC measurements in the Republic of Croatia using the compulsive exchange method depending on soil type, pH, and organic matter content [7]. Based on this study, the CEC value of soil in the Republic of Croatia ranged from 2.29-33.8 cmol, kg⁻¹.

The ammonium acetate method pH 7.0 is a method commonly used to measure CEC (Metson method) for slightly acidic and neutral soils while soil pH is 8.2 (Bower method) for alkaline soils [11]. The compulsive exchange method proposed by Gillman in 1979 was modified by Gillman and Sumpter in 1986 to measure compulsive exchange CEC. The Soil Science Society of America recommends this method because it has a high repetition rate, precision, and directly measures the significant cation exchange capacity [12]. This method can be used for all types of soil, both acidic and alkaline. However, this method has disadvantages, including producing hazardous waste (BaCl₂,2H₂O), and the analysis time is long, so it is quite a time consuming [13].

The CEC value depends on the extraction method. Currently, CEC determination generally uses the ammonium acetate method of 1 N pH 7.0, while the distribution of soil variations in Indonesia is diverse, ranging from pH 4.8 to pH 8.0. Also, there are differences in factors that affect CEC, which causes the measurement of CEC values to be biased or imprecise so that they do not reflect the real conditions. This study aims were to obtain a soil CEC extraction method suitable for the soil in Indonesia.

2. Materials and methods

Research activities were carried out at the Chemical Soil Laboratory, Indonesian Soil Research Institute. This study used soil samples from several regions in Indonesia. The soil samples were previously analyzed for preliminary analysis. Initial soil analysis included soil pH H₂O parameters (1:5), clay content, and soil CEC value extracted by the ammonium acetate 1 N method (pH 7.0).

After knowing the value of these parameters, then proceed with soil grouping based on pH criteria to clarify the distribution of CEC values of the 97 soil samples used in this study. The criteria for the pH (H₂O) value are very acidic (<4.5-5.5); slightly acidic (5.5-6.5), and neutral - slightly alkaline (6.6-8.5) [14]. In addition, other criteria are very low CEC values (<5 cmolc (+) kg⁻¹), low (5-16 cmolc (+) kg⁻¹), moderate (17-24 cmolc (+) kg⁻¹), high (25-40 cmolc (+) kg⁻¹) and very high (>40 cmolc (+) kg⁻¹). CEC extraction used in this study consisted of ammonium acetate pH 4.8, ammonium acetate pH 6.0; ammonium acetate pH 7.0, and compulsive cation exchange or BaCl₂ method.
2.1. Ammonium acetate method pH 4.8, pH 6.0, and pH 7.0
In this CEC extraction, the materials used are the same as other CEC extracts. The difference is only in the pH of ammonium acetate buffered according to pH 4.8, pH 6.0, and pH 7.0. The sample was measured by the colorimetric method. The formula for calculating CEC is as follows [14]:

\[
CEC = \text{me curve} \times 50 \text{mL} \times (1,000 \text{mL})^{-1} \times 1,000 \text{g} \times (2.5 \text{g})^{-1} \times 0.1 \times \text{df} \times \text{cf}
\]

(1)

Notes:
\[\text{df} = \text{dilution factor},\]
\[\text{cf} = \text{correction factor}.
\]

2.2. Compulsive cation exchange method (BaCl}_2, NH}_4Cl)
This method uses BaCl}_2 0.1 M/0.1 M NH}_4Cl as the extract solution. In this method, the soil is extracted with BaCl}_2 and NH}_4Cl. The sample was weighed 2 g of soil samples into a 50 mL centrifuge tube (recorded as X grams) then added 20 mL of a mixture of 0.1 M BaCl}_2 and 0.1 M NH}_4Cl solution. Then shaken for 2 hours, centrifuged and the filtrate measured as exchangeable cation using Atomic Absorption Spectroscopy (AAS) to determine Ca, Mg, K, and Na. The remaining soil in the centrifuge tube was added with 20 mL of 0.05 M BaCl}_2 to remove NH}_4^+, then shaken, centrifuged, and slowly discarded. A vacuum pump can be used to avoid loss of material (soil and others). Then the soil was washed with 20 mL BaCl}_2 0.002 M, shaken, centrifuged, and the liquid was slowly discarded. Washing is done three times; at the last washing process, the pH of the solution is measured with a pH meter; after shaking, the pH is measured by a pH meter (pH BaCl}_2). Then centrifuged, the liquid is discarded, and the tube containing the remaining soil is weighed (Y gram). Ba^2+ exchange by Mg^2+ occurred after adding 10 mL, 0.005 M MgSO}_4, then shaking it and leaving it for one night. The EC solution is compared with the EC solution of 0.0015 M MgSO}_4 if the EC ratio is as follows:

\[
\text{Conductivity Ratio (CR)} = \frac{\text{EC of sample solution}}{\text{EC of MgSO}_4 \text{ Solution}}
\]

(2)

The solution is left for a while. If conductivity ratio (CR) <1.0, then 0.5 mL of MgSO}_4 0.05 M is added, so that the CR value is >1.5, and if >1, there is no need to add MgSO}_4. Check the pH solution. If the pH > pH BaCl}_2 (0.3 units difference), drop it with H}_2SO}_4 (0.05 to 0.1 M). After leaving it for about 1 hour, the CR value is lowered to about 1.0 by adding aqua dest and leaving it for one night. Sometimes the addition of distilled water can cross the tube limit, so move it to a beaker glass that has been weighed. After one night, the CR value was measured and adjusted to the pH of BaCl}_2 (previously measured the pH) by adding 0.1 M H}_2SO}_4 or other concentrations. The CR value was measured again after one night and adjusted to CR 1.0 ± 0.05 with the addition of distilled water. The addition of H^+ ions causes a reduction of the negative charge on the surface and releases Mg^2+ thereby increasing the CR value. When the pH and ion strength corrections have stabilized, weigh the tube containing soil (Z gram). Where Mg^2+ replaces the CEC value.

The formula for calculating CEC with the compulsive cation exchange method is as follows [15]:

\[
V_1 = 10+(10 \times \text{an amount of 0.05 M MgSO}_4 \text{ was added})
\]

(3)

\[
V_2 = Z - X
\]

(4)

Notes:
\[X = \text{tube weight and soil sample weight (g)},\]
\[Z = \text{weight of tube and soil after extracting with BaCl}_2 \text{ and NH}_4Cl.\]

\[
\text{CEC} = (\text{mmol} \times (1/2 \text{ Mg}_2^+) \text{ which is added}) - (\text{mmol} \times (1/2 \text{ Mg}_2^+) \text{ the remaining x 100/initial of soil weight})
\]

(5)

\[
= 100/2 (0.1V_1 - 0.003V_2)
\]

= me 100g^{-1}
2.3. Data analysis
For experimental data analysis, SPSS 20 was used as data processing tool.

3. Results and discussion

3.1. Soil characteristic
The characteristics of the 97 soil samples are shown in table 1. From the analysis results, the pH soil distributions showed a wide variation. The pH value range from pH 3.79 to pH 8.6. Acidic soils were recorded at the location of Pontianak (West Kalimantan) and the highest pH was recorded from Serang (Banten). Low pH soil causes the decreasing of nutrients availability, so the plant productivity also decrease [16].

| No. | Location            | pH H₂O | Clay (%) | CEC (me 100 g⁻¹) |
|-----|---------------------|--------|----------|------------------|
| 1   | West Sumatera       | 4.91   | 34       | 7.59             |
| 2   | West Sumatera       | 4.87   | 46       | 15.70            |
| 3   | West Sumatera       | 4.96   | 27       | 13.22            |
| 4   | West Sumatera       | 4.56   | 53       | 15.39            |
| 5   | West Sumatera       | 4.64   | 48       | 14.94            |
| 6   | Jambi               | 4.97   | 22       | 9.22             |
| 7   | Jambi               | 4.79   | 52       | 21.68            |
| 8   | Jambi               | 4.70   | 72       | 13.73            |
| 9   | Jambi               | 4.48   | 74       | 9.85             |
| 10  | Jambi               | 4.47   | 30       | 7.61             |
| 11  | Jambi               | 4.23   | 45       | 4.04             |
| 12  | West Kalimantan     | 4.56   | 66       | 23.66            |
| 13  | West Kalimantan     | 4.85   | 20       | 5.65             |
| 14  | West Kalimantan     | 4.94   | 10       | 5.34             |
| 15  | West Kalimantan     | 4.72   | 56       | 17.31            |
| 16  | West Kalimantan     | 4.58   | 3        | 1.67             |
| 17  | West Kalimantan     | 3.79   |          | 54.03            |
| 18  | Batang Central Java | 4.91   | 41       | 20.06            |
| 19  | Lampung             | 4.88   | 23       | 9.34             |
| 20  | Lampung             | 4.88   | 24       | 5.12             |
| 21  | Lampung             | 4.24   | 34       | 6.81             |
| 22  | Lampung             | 4.03   | 26       | 5.04             |
| 23  | Subang              | 4.75   | 40       | 19.73            |
| 24  | Pekalongan          | 4.45   | 37       | 26.99            |
| 25  | Serang, Pandeglang  | 4.95   | 42       | 14.96            |
| 26  | Serang, Pandeglang  | 4.67   | 45       | 17.55            |
| 27  | Sukabumi            | 4.22   | 76       | 19.73            |
| 28  | Jakenan             | 4.91   | 8        | 5.95             |
| 29  | West Sumatera       | 5.09   | 63       | 15.92            |
| 30  | West Sumatera       | 5.29   | 70       | 9.42             |
| 31  | West Sumatera       | 5.00   | 17       | 6.24             |
| 32  | West Sumatera       | 5.50   | 23       | 11.65            |
| 33  | Kerinci & Merangin, Jambi | 5.40 | 16     | 22.58 |
| 34  | Kerinci & Merangin, Jambi | 5.10 | 53    | 10.13 |
| 35  | Kerinci & Merangin, Jambi | 5.04 | 35    | 20.28 |
| 36  | Kerinci & Merangin, Jambi | 5.29 | 40    | 15.26 |
| 37  | West Java           | 5.51   | 40       | 15.26            |
| 38  | Central Java        | 5.46   | 25       | 14.43            |
| 39  | Serang              | 5.70   | 36       | 12.64            |
| 40  | Jambi               | 5.15   | 12       | 29.09            |
| 41  | Lampung             | 5.25   | 29       | 10.13            |
| 42  | Lampung             | 5.95   | 13       | 3.74             |
| 43  | East Java           | 5.89   | 42       | 29.56            |
| 44  | East Java           | 5.55   | 47       | 24.18            |
| 45  | East Java           | 5.37   | 55       | 15.12            |
| 46  | Indramayu           | 5.33   | 74       | 27.63            |
| 47  | Jakenan             | 5.73   | 11       | 4.07             |
| 48  | Purwodadi           | 5.03   | 29       | 12.66            |
| 49  | Pemalang            | 5.81   | 70       | 31.25            |
| 50  | Serang, Pandeglang  | 5.29   | 57       | 20.49            |
| 51  | Serang, Pandeglang  | 5.05   | 65       | 23.86            |
| 52  | Jambi               | 6.10   | 16       | 12.20            |
| 53  | NTB dan Bali        | 6.96   | 68       | 37.83            |
| 54  | NTB dan Bali        | 6.60   | 41       | 27.61            |
| 55  | NTB dan Bali        | 6.85   | 25       | 20.58            |
| 56  | North Sumatera dan Aceh | 6.27 | 19    | 20.65            |
| 57  | North Sumatera dan Aceh | 6.03 | 39    | 23.57            |
| 58  | East Java           | 6.49   | 83       | 63.62            |
| 59  | Lampung             | 6.61   | 38       | 14.66            |
| 60  | Lampung             | 6.37   | 42       | 16.10            |
| 61  | Jember              | 6.17   | 44       | 26.78            |
| 62  | East Java           | 6.75   | 30       | 20.50            |
| 63  | Subang              | 6.04   | 73       | 15.09            |
| 64  | East Java           | 6.45   | 32       | 23.10            |
| 65  | East Java           | 6.08   | 36       | 23.27            |
| 66  | East Java           | 6.29   | 48       | 27.42            |
| 67  | Grobogan            | 6.39   | 63       | 29.04            |
| 68  | Grobogan            | 6.89   | 64       | 31.23            |
| 69  | Pemalang            | 6.28   | 63       | 30.84            |
| 70  | Pemalang            | 6.66   | 54       | 32.49            |
The CEC value range from very low (<5 me 100 g⁻¹ soil) to very high (>40 me 100 g⁻¹ soil). The highest value of CEC was recorded at the location Pontianak, West Kalimantan (3 me 100 g⁻¹), it is classified as very low. The highest CEC value was recorded at the location Kediri, East Java (83 me 100 g⁻¹). A high CEC value could increase soil capability on absorbing and providing nutrients properly. Because the nutrients are inside the soil seepage complex, so the elements are not easily lost or washed away by water. The soil with a high content of organic matter or clay content has a higher CEC value rather than the soil with low CEC value or sandy soil [3].

3.2. Ammonium acetate extraction method pH 4.8, pH 6.0, pH 7.0 and BaCl₂

The CEC analysis results with various concentrations of ammonium acetate and BaCl₂ method (compulsive cation exchange) are presented in table 2. For ammonium acetate extract pH 4.8, pH 6.0, and pH 7.0 indicated almost the same range results for CEC values, it ranges from very low to very high. From table 2, it concludes that the CEC values extracted by compulsive cation exchange were much lower than those extracted by ammonium acetate pH 4.8, pH 6.0, and pH 7.0. It was in line with Madeira’s Research, the CEC values measured by compulsive exchange method were lower than those measured by ammonium acetate pH 7.0 [10].
Table 2. The result of CEC analysis.

| No | Location       | Based on dry soil sample 105°C | Based on dry soil sample 105°C |
|----|----------------|---------------------------------|---------------------------------|
|    |                | pH 4.8 | pH 6.0 | pH 7.0 | BaCl₂ cmol(+) kg⁻¹ | pH 4.8 | pH 6.0 | pH 7.0 | BaCl₂ cmol(+) kg⁻¹ |
| 1  | West Sumatera  | 7.77   | 8.70   | 7.59   | 7.18             | 21.92  | 30.14  | 29.09  | 10.21          |
| 2  | West Sumatera  | 11.38  | 14.86  | 15.70  | 5.76             | 8.76   | 10.45  | 10.13  | 8.49           |
| 3  | West Sumatera  | 12.07  | 13.22  | 13.22  | 8.98             | 2.87   | 3.62   | 3.74   | 2.89           |
| 4  | West Sumatera  | 12.60  | 14.74  | 15.39  | 8.13             | 31.06  | 33.09  | 29.56  | 21.36          |
| 5  | West Sumatera  | 14.69  | 14.56  | 14.94  | 10.55            | 20.31  | 22.17  | 24.18  | 18.14          |
| 6  | Jambi          | 8.37   | 12.06  | 9.22   | 1.41             | 20.68  | 23.31  | 15.12  | 16.28          |
| 7  | Jambi          | 18.14  | 22.17  | 21.68  | 5.80             | 32.26  | 35.75  | 27.63  | 21.81          |
| 8  | Jambi          | 19.34  | 17.11  | 13.37  | 5.68             | 2.75   | 3.01   | 4.07   | 2.92           |
| 9  | Jambi          | 10.23  | 14.29  | 9.85   | 3.14             | 9.74   | 10.29  | 12.66  | 6.38           |
| 10 | Jambi          | 5.02   | 5.76   | 7.61   | 5.34             | 31.35  | 38.79  | 31.25  | 26.24          |
| 11 | Jambi          | 7.20   | 8.40   | 4.04   | 3.74             | 19.42  | 19.69  | 20.49  | 16.22          |
| 12 | West Kalimantan| 20.12  | 23.21  | 23.66  | 5.55             | 24.38  | 22.72  | 23.86  | 19.38          |
| 13 | West Kalimantan| 3.32   | 4.91   | 5.65   | 3.40             | 10.81  | 19.16  | 12.20  | 5.22           |
| 14 | West Kalimantan| 2.12   | 2.93   | 5.34   | 2.47             | 43.59  | 47.88  | 37.83  | 33.85          |
| 15 | West Kalimantan| 8.51   | 10.07  | 17.31  | 5.73             | 26.15  | 25.29  | 27.61  | 24.68          |
| 16 | West Kalimantan| 0.91   | 1.38   | 1.67   | 1.67             | 19.94  | 22.16  | 20.58  | 19.79          |
| 17 | West Kalimantan| 55.44  | 77.90  | 54.03  | 2.94             | 18.72  | 21.15  | 20.65  | 14.74          |
| 18 | Batang Central Java | 18.88 | 20.71  | 20.06  | 15.87    | 21.37  | 24.3   | 23.57  | 17.92          |
| 19 | Lampung        | 9.02   | 9.14   | 9.34   | 6.59             | 11.18  | 12.74  | 63.62  | 8.83           |
| 20 | Lampung        | 3.45   | 4.19   | 5.12   | 2.95             | 20.63  | 22.51  | 14.66  | 10.97          |
| 21 | Lampung        | 5.11   | 6.34   | 6.81   | 4.90             | 15.82  | 16.00  | 16.10  | 8.91           |
| 22 | Lampung        | 3.39   | 5.33   | 5.04   | 3.06             | 27.99  | 32.90  | 26.78  | 20.86          |
| 23 | Subang         | 18.47  | 19.02  | 19.73  | 15.31            | 18.15  | 19.97  | 20.50  | 15.15          |
| 24 | Pekalongan     | 18.36  | 27.35  | 26.99  | 14.83            | 14.08  | 16.40  | 15.09  | 7.83           |
| 25 | Serang, Pandeglang | 14.04 | 14.46  | 14.96  | 11.95           | 25.16  | 21.19  | 23.10  | 21.04          |
| 26 | Serang, Pandeglang | 15.17 | 16.50  | 17.55  | 11.38           | 22.64  | 20.97  | 23.27  | 16.61          |
| 27 | Sukabumi       | 23.05  | 21.10  | 19.73  | 17.50            | 27.03  | 30.40  | 27.42  | 21.20          |
| 28 | Jakenan        | 4.00   | 4.39   | 5.95   | 3.58             | 26.98  | 32.77  | 29.04  | 29.16          |
| 29 | West Sumatera  | 23.62  | 20.78  | 15.92  | 15.05            | 27.39  | 29.90  | 31.23  | 27.85          |
| 30 | West Sumatera  | 9.89   | 12.83  | 9.42   | 8.16             | 29.35  | 37.06  | 30.84  | 24.17          |
| 31 | West Sumatera  | 8.45   | 8.12   | 6.24   | 7.43             | 32.49  | 36.73  | 32.49  | 26.18          |
| 32 | West Sumatera  | 11.30  | 14.14  | 11.65  | 8.02             | 24.17  | 23.07  | 20.28  | 21.40          |
| 33 | Kerinci & Merangin, Jambi | 15.81 | 28.42  | 22.58  | 1.88           | 26.26  | 22.84  | 28.77  | 17.23          |
| 34 | Kerinci & Merangin, Jambi | 8.08   | 14.60  | 10.13  | 20.60           | 12.32  | 17.83  | 25.74  | 5.69           |
| 35 | Kerinci & Merangin, Jambi | 14.34 | 23.80  | 20.28  | 4.26           | 34.02  | 30.59  | 31.83  | 30.69          |
| 36 | Kerinci & Merangin, Jambi | 9.55 | 16.11  | 13.43  | 2.35           | 37.85  | 44.7   | 38.88  | 26.26          |
| 37 | West Java      | 14.36  | 17.05  | 15.26  | 5.75             | 40.02  | 51.91  | 36.22  | 28.93          |
| 38 | Central Java   | 12.99  | 17.36  | 14.43  | 3.32             | 42.64  | 54.46  | 30.03  | 29.08          |
| 39 | Serang         | 12.38  | 13.89  | 12.64  | 11.8             | 22.33  | 24.98  | 23.91  | 16.19          |
### 3.3. Correlation between ammonium acetate pH 7.0 method and other methods

Based on the r-value, the highest correlation was ammonium acetate pH 7.0 and pH 6.0 method (Fig. 1b). The correlation between CEC extracted by ammonium acetate pH 7.0 and compulsive cation exchange method (BaCl$_2$ method) were the lowest correlation (r = 0.601). Methodological differences between compulsive cation exchange (BaCl$_2$ method) and ammonium acetate was connected with the pH of extract solution and soil. CEC ammonium acetate has measured the soil CEC buffered at pH 7.0, so this condition gives high inflated for CEC value (this method could be accurate for netral and alkaline soil), while the CEC barium chloride was measured the soil CEC at actual pH (effective CEC).

### 3.4 Correlation between compulsive cation exchange method with ammonium acetate pH 4.8 and 6.0

The correlation between BaCl$_2$ and ammonium acetate pH 7.0 was smaller than ammonium acetate pH 4.8 and pH 6.0. It is because more samples have pH (H$_2$O) value less than 7 (pH 3 - 5 = 40 samples, pH 6 = 21 samples and pH 7 = 23 samples), so that soil with a low pH (<pH 7) has a higher correlation with the compulsive cation exchange method.

The compulsive cation exchange method has pH BaCl$_2$/NH$_4$Cl (table 3) close to pH (H$_2$O), it means that the soil condition when extracted using BaCl$_2$/NH$_4$Cl has actual pH soil as in the field [17]. The ammonium acetate extraction method pH 7.0 soil conditioned was as adjusted (buffered) as pH 7.0, so it is not based on the actual soil pH conditions. However, the compulsive cation exchange method has many drawbacks, including producing hazardous waste (BaCl$_2$·2H$_2$O), the process is very time consuming and expensive to be applied in routine soil testing laboratories [13].

| No | Location                  | Based on dry soil sample 105°C CEC | Based on dry soil sample 105°C CEC |
|----|--------------------------|-----------------------------------|-----------------------------------|
|    |                          | pH 4.8 | pH 6.0 | pH 7.0 | BaCl$_2$ | pH 4.8 | pH 6.0 | pH 7.0 | BaCl$_2$ |
| 79 | NTB dan Bali             | 24.16  | 26.58  | 27.35  | 28.01    | 33.94  | 42.06  | 30.16  | 13.35    |
| 80 | North Sumatera dan Aceh  | 7.97   | 9.53   | 11.39  | 2.18     | 5.29   | 6.25   | 6.61   | 1.51     |
| 81 | North Sumatera dan Aceh  | 14.49  | 24.02  | 24.09  | 10.97    | 4.67   | 5.27   | 4.76   | 2.24     |
| 82 | North Sumatera dan Aceh  | 33.96  | 44.84  | 49.45  | 22.47    | 35.46  | 35.45  | 32.56  | 15.28    |
| 83 | North Sumatera dan Aceh  | 32.65  | 41.08  | 45.70  | 4.20     | 28.63  | 36.01  | 30.26  | 24.16    |
| 84 | North Sumatera dan Aceh  | 19.88  | 33.77  | 28.38  | 19.39    | 28.93  | 35.21  | 26.42  | -        |
| 85 | North Sumatera dan Aceh  | 31.66  | 36.48  | 34.71  | 10.14    | 26.87  | 35.86  | 25.09  | -        |
| 86 | East Java                | 47.76  | 58.84  | 59.44  | 2.23     | 34.63  | 29.73  | 33.96  | 16.03    |
| 87 | Central Java             | 38.53  | 48.80  | 59.44  | -        | 35.36  | 32.79  | 36.36  | 19.87    |
| 88 | East Java                | 40.43  | 49.74  | 40.55  | 2.24     |         |        |        |          |
Figure 1. The correlation of CEC value (a) Ammonium acetate method pH 7.0 and Ammonium acetate pH 4.8, (b) the Ammonium acetate method pH 7.0 and the Ammonium acetate method pH 6.0, and (c) Ammonium acetate pH 7.0 and compulsive cation exchange (BaCl$_2$) method.

Table 3. Soil characteristics based on pH H$_2$O and pH BaCl$_2$/NH$_4$Cl.

| No | Location       | pH H$_2$O | pH BaCl$_2$/NH$_4$Cl | pH H$_2$O | pH BaCl$_2$/NH$_4$Cl |
|----|----------------|-----------|----------------------|-----------|----------------------|
| 1  | West Sumatera  | 4.91      | 4.62                 | 4.58      | 4.60                 |
| 2  | West Sumatera  | 4.87      | 4.91                 | 3.79      | 3.10                 |
| 3  | West Sumatera  | 4.96      | 4.77                 | 4.91      | 4.26                 |
| 4  | West Sumatera  | 4.56      | 4.38                 | 4.88      | 5.40                 |
| 5  | West Sumatera  | 4.64      | 4.60                 | 4.88      | 4.63                 |
| 6  | Jambi          | 4.97      | 4.41                 | 4.24      | 4.35                 |
| 7  | Jambi          | 4.79      | 4.88                 | 4.03      | 4.34                 |
| 8  | Jambi          | 4.70      | 4.43                 | 4.75      | 4.89                 |
| 9  | Jambi          | 4.48      | 4.27                 | 4.45      | 4.39                 |
| 10 | Jambi          | 4.47      | 4.69                 | 4.95      | 4.68                 |
| 11 | Jambi          | 4.23      | 4.37                 | 4.67      | 4.24                 |
| 12 | West Kalimantan| 4.56      | 4.25                 | 4.22      | 5.55                 |
| 13 | West Kalimantan| 4.85      | 4.60                 | 4.91      | 5.50                 |
| 14 | West Kalimantan| 4.94      | 4.59                 | 5.09      | 4.76                 |
| 15 | West Kalimantan| 4.72      | 4.46                 | 5.29      | 4.75                 |
| No | Location                  | pH H$_2$O | pH BaCl$_2$/NH$_4$Cl | No | Location                  | pH H$_2$O | pH BaCl$_2$/NH$_4$Cl |
|----|----------------------------|-----------|----------------------|----|----------------------------|-----------|----------------------|
| 31 | West Sumatera             | 5.00      | 4.68                 | 66 | East Java                 | 6.29      | 6.01                 |
| 32 | West Sumatera             | 5.50      | 5.15                 | 67 | Grobogan                  | 6.39      | 6.58                 |
| 33 | Kerinci & Merangin, Jambi | 5.40      | 4.65                 | 68 | Grobogan                  | 6.89      | 6.96                 |
| 34 | Kerinci & Merangin, Jambi | 5.10      | 4.49                 | 69 | Pemalang                  | 6.28      | 6.10                 |
| 35 | Kerinci & Merangin, Jambi | 5.04      | 4.68                 | 70 | Pemalang                  | 6.66      | 6.65                 |
| 36 | Kerinci & Merangin, Jambi | 5.29      | 4.62                 | 71 | Banten                    | 6.02      | 5.73                 |
| 37 | West Java                 | 5.51      | 5.60                 | 72 | Banten                    | 6.19      | 6.10                 |
| 38 | Central Java              | 5.46      | 4.99                 | 73 | Banten                    | 6.35      | 4.02                 |
| 39 | Serang                    | 5.70      | 5.14                 | 74 | NTB dan Bali              | 7.21      | 6.60                 |
| 40 | Jambi                     | 5.15      | 5.05                 | 75 | NTB dan Bali              | 7.67      | 7.57                 |
| 41 | Lampung                   | 5.25      | 5.34                 | 76 | NTB dan Bali              | 7.77      | 7.00                 |
| 42 | Lampung                   | 5.95      | 6.33                 | 77 | NTB dan Bali              | 7.71      | 7.23                 |
| 43 | East Java                 | 5.89      | 5.88                 | 78 | NTB dan Bali              | 7.12      | 6.6                  |
| 44 | East Java                 | 5.55      | 5.43                 | 79 | NTB dan Bali              | 7.51      | 6.86                 |
| 45 | East Java                 | 5.37      | 5.48                 | 80 | North Sumatera dan Aceh   | 7.67      | 7.75                 |
| 46 | Indramayu                 | 5.33      | 5.46                 | 81 | North Sumatera dan Aceh   | 7.16      | 7.17                 |
| 47 | Jakenan                   | 5.73      | 5.36                 | 82 | North Sumatera dan Aceh   | 7.76      | 7.59                 |
| 48 | Purwodadi                 | 5.03      | 5.34                 | 83 | North Sumatera dan Aceh   | 7.78      | 7.84                 |
| 49 | Pemalang                  | 5.81      | 5.72                 | 84 | North Sumatera dan Aceh   | 7.05      | 6.72                 |
| 50 | Serang, Pandeglang        | 5.29      | 5.00                 | 85 | North Sumatera dan Aceh   | 7.63      | 7.81                 |
| 51 | Serang, Pandeglang        | 5.05      | 4.84                 | 86 | East Java                 | 7.99      | 6.19                 |
| 52 | Jambi                     | 6.10      | 5.60                 | 87 | Central Java              | 7.99      | 7.90                 |
| 53 | NTB dan Bali              | 6.96      | 6.30                 | 88 | East Java                 | 7.42      | 7.66                 |
| 54 | NTB dan Bali              | 6.60      | 6.26                 | 89 | Ngawi                     | 7.73      | 7.70                 |
| 55 | NTB dan Bali              | 6.85      | 6.63                 | 90 | Serang                    | 7.36      | 7.21                 |
| 56 | North Sumatera dan Aceh   | 6.27      | 5.97                 | 91 | Serang                    | 7.37      | 7.02                 |
| 57 | North Sumatera dan Aceh   | 6.03      | 5.81                 | 92 | Madiun                    | 7.40      | 7.04                 |
| 58 | East Java                 | 6.49      | 6.35                 | 93 | Grobogan                  | 7.45      | 7.59                 |
| 59 | Lampung                   | 6.61      | 6.10                 | 94 | Grobogan                  | 7.59      | 7.98                 |
| 60 | Lampung                   | 6.37      | 6.36                 | 95 | Grobogan                  | 7.63      | 8.06                 |
| 61 | Jember                    | 6.17      | 5.91                 | 96 | Serang, Pandeglang        | 7.69      | 7.60                 |
| 62 | East Java                 | 6.75      | 6.42                 | 97 | Serang, Pandeglang        | 8.06      | 7.69                 |
| 63 | Subang                    | 6.04      | 5.83                 |                               |            |                      |
| 64 | East Java                 | 6.45      | 6.02                 |                               |            |                      |
| 65 | East Java                 | 6.08      | 5.77                 |                               |            |                      |

3.5. Correlation of CEC value of various methods and pH H$_2$O and clay texture
The results of the correlation of CEC value, soil pH (H$_2$O), and clay texture showed a high correlation between the ammonium acetate pH 7 method and clay texture, pH H$_2$O and CEC (table 4). The CEC correlation and pH value were very significant for all extract solution, where the ammonium acetate extract pH 4.8 and pH 7.0 had almost the same value as the other extract solution.
CEC correlation and clay texture values were very significant for all extract solution with high correlation values for ammonium acetate pH 4.8 and pH 7.0. This is in line with the research of Wang, which stated that there was a positive correlation between soil CEC and soil organic content and soil clay content [8].

Table 4. The correlation of CEC value, soil pH (H$_2$O), and clay texture.

|                | pH H$_2$O | Clay Texture |
|----------------|-----------|--------------|
| CEC Am. Acetate pH 4.8 | 0.52**   | 0.62**       |
| CEC Am. Acetate pH 6.0  | 0.49**   | 0.57**       |
| CEC Am. Acetate pH 7.0  | 0.53**   | 0.61**       |
| CEC BaCl$_2$           | 0.45**   | 0.42**       |

** real at 1% level.

4. Conclusions

The value of cation exchange capacity (CEC) determine with the compulsive cation exchange (BaCl$_2$) method was much lower than that obtained by ammonium acetate 1 N pH 4.8, pH 6.0, and pH 7.0 methods. CEC measured by ammonium acetate pH 7.0 method had significant correlation to ammonium acetate pH 4.8, pH 6.0 and compulsive cation exchange (BaCl$_2$). Ammonium acetate pH 7.0 also had the best correlation to pH (H$_2$O). Ammonium acetate pH 7.0 could be applied for both acid and alkaline soil.

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