

CHARACTERISTICS OF MECHANICALLY FRACTIONATED AGGREGATES OF TWO CONTRASTING SOILS

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Abstract

Tillage often decreases physical condition of agricultural land, especially aggregate degradation which causes land and environmental quality decreased. As aggregates disperse into single particles, chemical properties of the soil could change. The objective of this research was to study whether or not mechanical fractionation causes soil dispersion indicating by different chemical properties. Aggregates of two soils, Vertisol and Oxisol, were degraded by using puddler at 3 different energy rates (40, 60, and 150 J kg⁻¹ soil minute⁻¹) and then were separated into 3 different sizes (2000-20, 20-2, <2 µm). Therefore, each soil sample would have 15 soil separates at different energy and aggregate size. The result showed that aggregate fractionation especially the fraction size, in general, affected EC, ESP, and CEC but not pH of both soils. The pattern of EC and CEC values seemed to be equal, the highest values were found at the smallest aggregate size (< 2 µm). The CEC values of Oxisols did not affected by fractionation, while CEC values of Vertisols increased by decreasing aggregate size, and decreased by increasing energy applied. This indicated that Vertisol is easier to disperse than Oxisol.

Keywords: mechanical degradation, dispersion, bonding mechanism, bonding energy

INTRODUCTION

The dynamics of soil structural degradation due to energy input applied to land surfaces will be different among soils. It does not only depend on the the soil characteristics but also by the bond strength. Since the aggregates have different strength due to their bonding agents and mechanisms, the amount of soil broken or dispersed will be different among different soil types. Therefore, introducing the same amount of energy input to different soils should result in different degrees of degradation or breakdown.

The physical fractionation of soil aggregates may assist in investigations to understand how different size fraction of soil can have different chemical characteristics. As soil particles develop into aggregates in a hierarchical manner, fractionation should produce smaller aggregates that are natural components of the larger ones. For example as an impact of intensive cultivation, the large aggregates will be destroyed and broken into smaller aggregates. If the process persists for a long

time, it is not impossible that the aggregates are dispersed into single particles, as the aggregates are arranged from single particles.

The first process of aggregation is flocculation of single clay particles which creates domain. Then, the domain will interact to other domains or bigger size particles with a help of binding agent to form compound soil structure as explained by Dexter (1988) through an arrangement presented in Figure 1. Therefore, if the soil aggregates are dispersed into single particles, the characteristics will be different from the aggregated particles. This is due to the fact that the surface area of the single particles will have free surfaces, while the aggregated ones have been associated with other cations or bonding agents. As a consequence, the ability of the single particles should be higher than those of aggregated ones to bind cations. Therefore, this research is aimed to study whether or not mechanical fractionation causes soil dispersion indicating by different chemical properties.

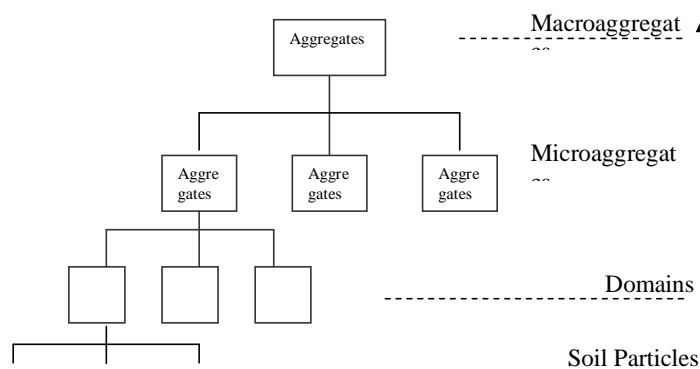


Figure 1. Hierarchical arrangement of soil aggregates (after Dexter, 1988)

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METHODOLOGY

Two (2) soil types, Vertosol and Ferrosol (=Vertisol and Oxisol based on USDA Classification) (Isbel, 2002) were used in this laboratory study. The soils were sampled from 0-10 cm depth of different sites (Lawes Gatton and O'Reilly's Lamington, Queensland, Aust.) with different land use (annual cultivated and permanent pasture), respectively. Both soils have different dominant clay mineralogy, smectite and kaolinite, besides they have also different annual rainfall, 750 and 1900 mm, respectively for

Soil samples were puddled (broken) by using puddler (Figure 2) at different energy levels (Fig. 3) and sizes into 15 different fractions (Fig. 4). Each soil fraction was analyzed for the pH (Hendershot, Lalonde, and Duquette, 1993), EC (Janzen, 1993), CEC (Summer and Miller, 1994). ESP was calculated from the percentage of Na concentration to the CEC of the soils (Janzen, 1993), as follows:

$$ESP = Na_{-exch} * 100/CEC$$

Then, besides analyzing the fractionated and the bulk soils, the mean weighted value of fractionated soils was calculated, based on the soil fraction weight, as follows:

$$Weighted\ Mean = \frac{\sum (X * Wt)}{\sum Wt}$$

- X = individual data
- Wt = individual soil weight
- n=15
- = Sum of the 15 fractions
- 1

The results were compared to the unfractionated bulk soils and a regression analysis was conducted to check how good the fractionation process was. The slope of the regression line should be close to 1 if the weighted average of the fractions is representative of the bulk soil, and no significant material loss occurred during fractionation.

For detail, characteristics of soils used are given in Table 1.

Vertisol and Oxisol (Stace et al.,1968).

Table 1. Characteristics of soils used in this experiment

No.	Code	Great ¹⁾ Soil Group	Austr. ¹⁾ Soil Class	USDA ¹⁾ Class	Clay ³⁾ Type Dominant	OC ⁴⁾ Conten %	Annual Rainfal (mm)	Texture ⁵⁾ (%)		
								sand	silt	clay
1	BE	Black Earth	Vertosol	Vertiso	Smectite	1.3	±750 ³⁾	25	22	53
2	ORP	Krasnozem	Ferrosol	Oxisol	Kaolinite	5.5	±1900 ⁴⁾	9	21	70

Note: 1) Isbel (2002); 2) Soil Survey Staff (1998); 3) Stace et al. (1968); 4) Dalal et al. (1986); 5)Yulnafatmawita (2004)

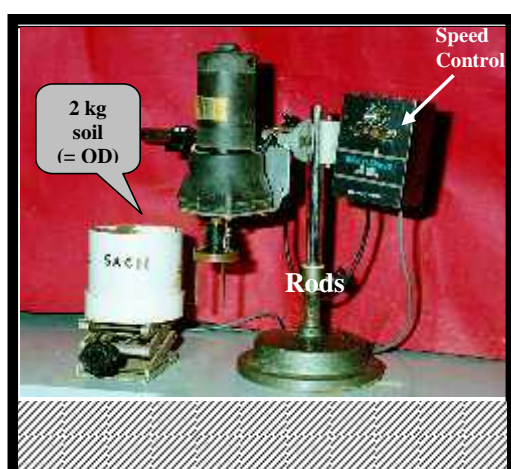


Figure 2. The puddling apparatus used to break soil aggregates in the laboratory at determined energy (Kirchhof and So, 1994)

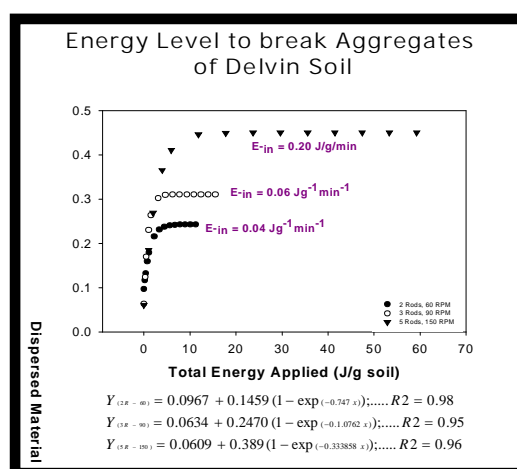


Figure 3. Energy level used to break soil aggregates

RESULTS AND DISCUSSIONS

1. pH Values

In general, there was no effect of energy input rate and size of soil fractions on the pH values of both soils. Table 1 shows that the pH value of ORP was slightly lower than that of BE soil. ORP is a Ferrosol soil under a pasture land use in Lamington National Park, with 70 % clay. It is developed from basic igneous rocks under high (750-2250 mm) annual rainfall, therefore some of the basic cations was leached (< 50% base saturation) (Stace et al.,1968), and high [H⁺] results in low pH of this soil. As this soil is permanently pastured, high free Fe content, especially at B2 horizon with > 5% in fraction < 2 μm (Isbell, 2002), combined with root

exudates from the grass, the soil has become slightly acidic than BE soil. Stace et al. (1968) stated that Oxisols may be mildly acid in the surface soil and may stay the same or decreases in the subsoil. Vertisol had pH values ranging from neutral to weakly basic. This agreed with the pH values of Vertisols which may be acid, neutral or alkaline reaction, but neutral and alkaline are more common (Clement et al., 1996).

Within each soil type, soil fractions did not show significant differences in pH. The relationship between weighted mean of the fractions and the bulk soil showed a strong linear correlation with a slope 0.97 and the R = 0.97 (Figure 7). It means that puddling did not significantly affect the pH values of the bulk soil samples.

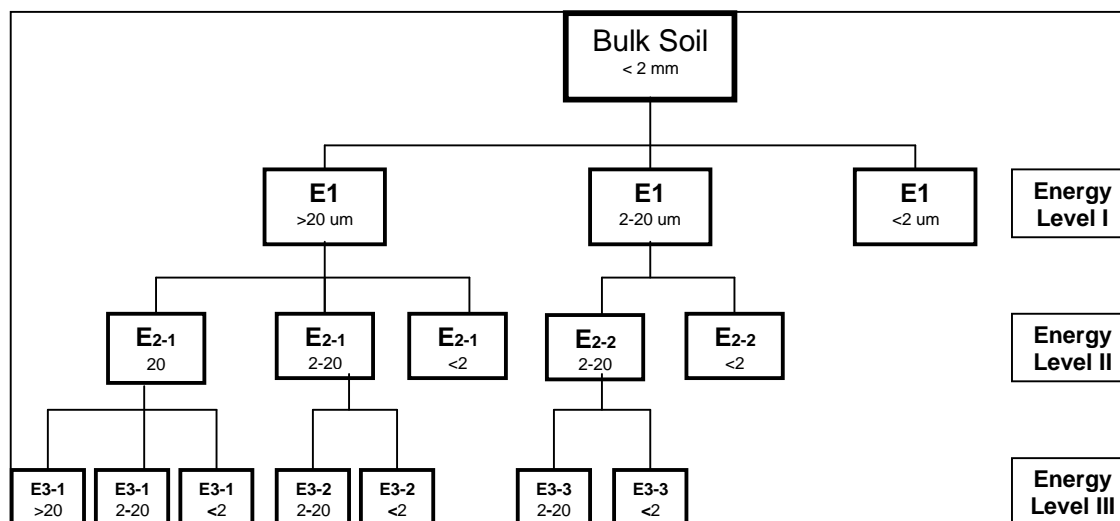


Figure 4. Fifteen (15) soil fractions resulted from fractionation process

2 Electrical Conductivity (EC)

Table 2 also presents the EC values of bulk and fractionated soil samples. The EC values of both soils shows the same pattern, significantly increased at the smallest soil fraction (<2 μm). The values tended to decrease by increasing energy input rate. It was believed that this was affected by two factors: the 1st was due to the fractionation process which liberated the ions entrapped or associated with the mineral particles within the aggregates of the bulk soils. Especially, fraction < 2 μm (= clay size) is assumed to collect all clay particles from the bulk soil, and therefore, to retain more cations than those of the larger fractions due to its much higher cation exchange capacity and specific surface area. The 2nd might be due to an artifact during aggregate size separation, because the water soluble salt will be accumulated in the < 2 μm fraction. When soil was suspended in water for the EC measurement, the deposited salts will be dissolved and remained in suspension causing high EC values.

Highest EC values of < 2 μm fraction was clearly presented on Figure 5. For both BE and ORP soils, the EC values of the bulk soils were between the EC values of < 2 and > 2 μm fractions. There was no

significant difference in the EC values between > 20 and 2-20 μm fractions, but both were significantly ($P < 0.01$) lower than the < 2 μm fraction for BE soil. However, the EC value of the bulk soil was close to the values of fractions > 2 μm. This indicates that the EC values of fraction > 2 μm were very much similar to the bulk soil while fraction < 2 μm determined the weighted mean of the EC values. The highest EC values of < 2 μm fraction resulted in poor correlation between weighted mean of the fractionated soils and the bulk soils (Figure 7).

3 Cation Exchange Capacity (CEC)

Table 3 presents the CEC values of the bulk and fractionated soils. CEC values of ORP either the bulk or the individual fraction was lower than 15 cmol kg⁻¹, while BE bulk soil was higher than 15 cmol kg⁻¹. Low CEC (<15 cmol/kg) of ORP is associated with kaolinite (low surface area and low cation exchange capacity) (Filep, 1999) as the dominant clay mineral in the soil. The different size fraction did not cause different CEC values of ORP. This can be inferred that most of the fraction in each size was still aggregated.

CEC values of BE soil, on the other hand, ranged between 9 – 66 cmol kg⁻¹, due to the dominant smectitic clay mineral, which has large surface area and CEC. Those values were significantly ($P < 0.01$)

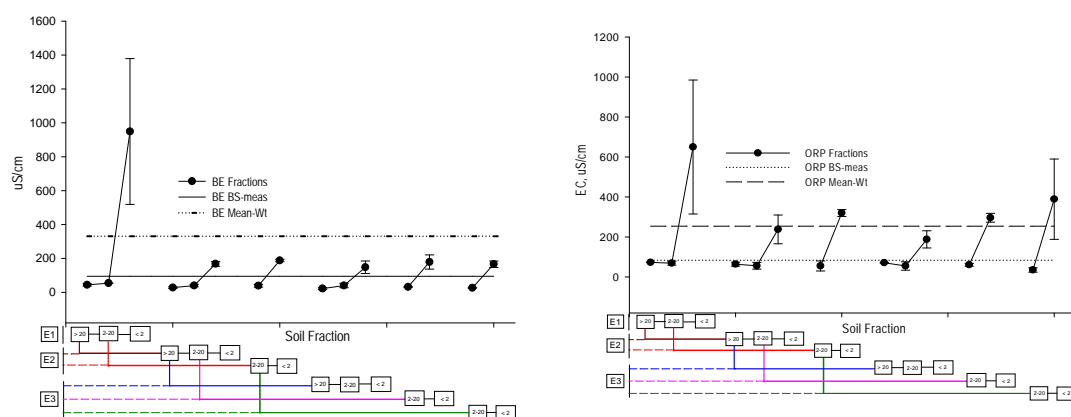


Figure 5. Electrical conductivity (EC) of fractionated BE and ORP soils (= SD with n=2)

higher than the CEC values of the kaolinite soil group. CEC value of smectitic colloid ranges between 60-120 c mol kg⁻¹ (Filep, 1999). Generally, CEC values of surface Vertisols were 37±8 and Oxisols 5±3 c mol kg⁻¹ soil (Sposito,1989). The CEC values of the bulk soil samples in this project were consistent with the values reported.

Table 3. CEC (c mol kg⁻¹ soil) values of fractionated soils

Soil Fraction			CEC (c mol kg ⁻¹)		ESP (%)	
Energy	Sub-Energy	Size (µm)	BE	ORP	BE	ORP
E-I	1	> 20	25.4	6.9	1.08	0.60
		2-20	39.9	7.8	0.62	0.49
		< 2	65.9	9.4	5.72	3.23
E-II	1	>20	15.5	8.1	1.03	0.36
		2-20	35.3	8.6	0.42	0.27
		<2	63.7	9.9	2.28	6.01
	2	2-20	35.8	9.3	0.27	1.09
		< 2	63.5	8.6	1.35	1.63
E-III	1	>20	8.8	9.3	1.06	0.15
		2-20	32.1	9.2	0.30	0.31
		<2	63.0	9.7	1.68	2.47
	2	2-20	27.8	8.1	0.22	0.10
		< 2	62.5	9.1	1.28	0.57
3	2-20	22.7	7.7	0.17	0.09	
	< 2	61.5	8.8	0.97	0.78	
Bulk Soil			28.3	8.7	1.42	1.85
Weighted Mean			34.4	8.8	1.12	1.35

Within soil type, CEC values of both soils showed an opposite pattern, as presented in Figure 6 for the individual and the pooled CEC values of both soils. CEC values of BE soil fractions increased by decreasing fraction size, but there is no effect of fraction size on CEC values of ORP soil. High average CEC values (Table 4) of the smallest (< 2 μm) size particle in BE soil could be an indicator of high clay particles instead of clay size aggregates in this fraction. In other words, most of the aggregates were dispersed into clay particles of BE soil (Vertisol) after applying energy input up to 150 J kg⁻¹ soil. Since it is dominated by smectite (montmorillonite), being swelled and shrunk by water content, the soil is very susceptible to degradation as water is introduced. Therefore, it will have problem with cultivation.

It is assumed that ORP was still mostly aggregated at all levels, since the CEC values were not significantly different among the three size fractions at all energy levels applied. This could be due to high bond strength of the aggregates due to OM and Fe association (Krull and Skjemstad, 2003). As reported by Yulnafatmawita (2004) that the ORP (Oxisol) had high OC content (5.6%) since it is permanently pastured (\pm 100 years) and the soil originally has high Fe content which is classified into Ferrosol or Oxisol (Isbel, 2002; Stace et al, 1968). Additionally, the percentage of fraction < 2 μm was still lower than the percentage of pure clay and the percentage of fraction > 20 μm was still higher than the pure sand

in the bulk soil (Yulnafatmawita, 2004). On the other hand, most of BE soil aggregates were broken into smaller ones and dispersed into single particles. It was identified from the percentage of fraction > 20 μm was about the percentage of pure sand after the third energy rate applied. The percentage of pure sand increased as energy rate increased (Yulnafatmawita, 2004). Therefore, CEC values increase with decreasing size particles. This implies that the smaller the fraction size, the wider the surface area and the possibility to interact with OM, therefore, the higher the chance of SOM to accumulate and be protected in that soil. However, since the characteristics of the smectitic mineral dominated this soil, the aggregates are easily to degrade while being wet.

In the > 20 μm fraction of BE soil, there was a tendency of decreasing CEC values from 25.4 to 15.5 and to 8.8 c mol/kg as energy input increased from 40 to 60 and to 150 J kg⁻¹ soil min⁻¹, respectively. This decrease correlated to the increase of the pure sand (49, 62, 79%), meaning less aggregated fractions, in this fraction size. As soil aggregates were not strongly bound due to the nature of the clay mineral dominant, smectite, which is affected by water content, the BE aggregates were intensively degraded as energy applied increased. The possibility of the BE soil aggregates to be dispersed into single particles is higher than the ORP soil.

Even though CEC values of fractionated soils showed different trends for different soil types, there was a good correlation between the weighted mean of the aggregate

Tabel 4. Pooled CEC data of BE and ORP soils

Fraction Size (μm)	CEC (cmol kg ⁻¹)	
	BE	ORP
2000-20	12 (\pm 3.3) *	11 (\pm 0,4)
20-2	30 (\pm 4,3) **	10 (\pm 0,3)
< 2	66 (\pm 2,0) **	10 (\pm 0,8)

Note: Values in brackets are SD with $n=3$ (*); $n=6$ (**)

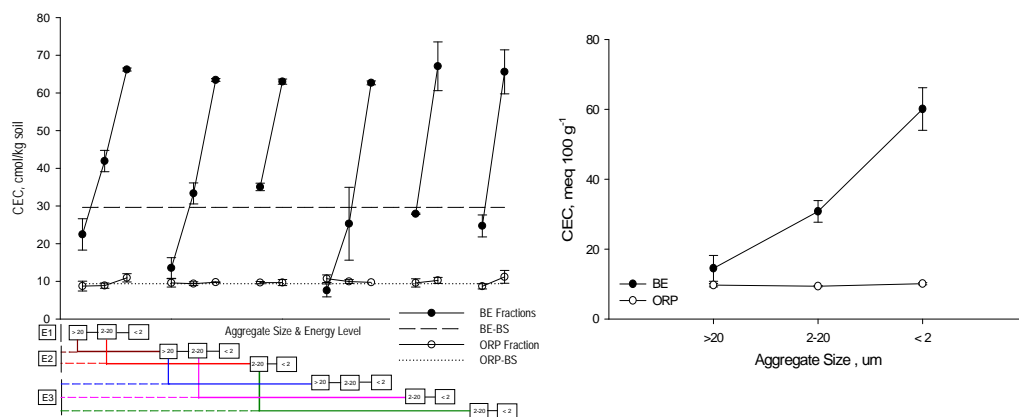


Figure 6. Cation exchange capacity values (c mol kg⁻¹ soil) of fractionated-BE and -ORP soils for the each fraction and the pooled data (= SD with n=2)

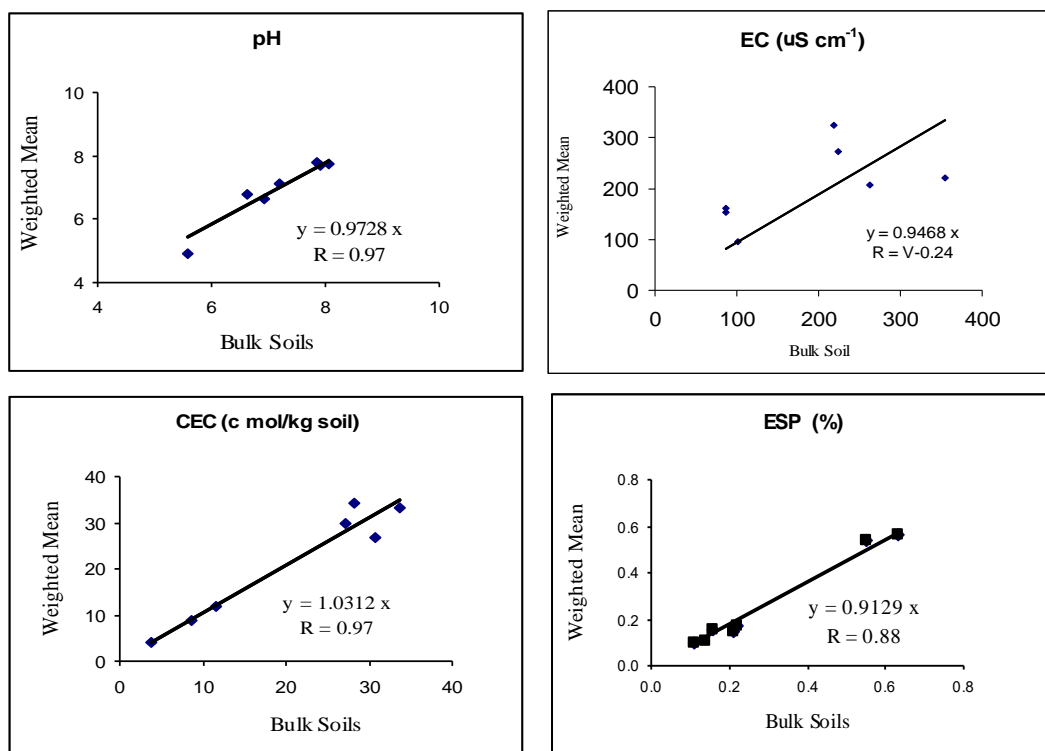


Figure 7. Correlation between the weighted mean and the bulk soils for (a) pH, (b) EC, (c) CEC, and (d) ESP through the origin

fractions and the bulk soils with an R = 0.97 and slope 1.03 (Figure 7). This indicates that the fractionation procedure did not cause significant material to be lost.

4. Exchangeable Sodium Percentage (ESP)

Table 3 also presents ESP values of bulk and fractionated soils as well as the weighted mean. The ESP values of the bulk soils were

slightly higher than the weighted mean values for both soils, and the coefficient correlatiwas R=0.88 and slope 0.91 (Figure 7). It means that fractionation did not caused sodium lost, even though the percentage among the size fractions showed a big difference. There was a tendency of high ESP pesentase at the smallest (<2 um) soil fraction for both soils and lowest at the largest (>20 um) fraction size.

CONCLUSIONS

It can be concluded that:

2. In general, except EC, the values of soil characteristics showed a good correlation between the weighted mean and the bulk soils of aggregate fractions, this confirms that the fractionation method did not result in significant material losses.
3. Other than pH values which did not show a specific pattern for both soils, in general, fraction size tends to affect soil characteristics, but not energy input except for CEC values of Vertisol.
 - a. CEC Vertisol increased from 12 (± 3.3) to 30 (± 4.3) and to 66 (± 2.0) by decreasing fraction size from > 20 to 20-2, and < 2 μm , and decreased from 25.4 to 15.5 and to 8.8 cmol kg^{-1} as energy input applied increased from 40 to 60 and 150 J kg^{-1} soil, respectively. CEC Oxisol, on the other hand, tended to be similar for all energy level applied and fraction
 - b. EC and ESP values showed the same pattern for both soils, highest in smallest fraction (< 2 μm) at all energy level.
4. Soil chemical characteristics (especially CEC values) indicated that Vertisol was easier to degrade than Oxisol under the same energy input applied. However, it still needs more works to prove it.

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