

Effect of Ground Basalt on Chemical Properties of an Ultisol and Oxisol in Malaysia

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ABSTRACT

Highly weathered soils in Malaysia need to be amended to rejuvenate their chemical fertility. In particular, soil pH should be increased sufficiently, while exchangeable Al eliminated in order to make them productive. A glasshouse study was conducted in Malaysia to determine changes in the chemical properties of Ultisol and Oxisol (highly weathered, infertile soils) treated with ground basalt under moist condition. The results showed that soil pH increased and exchangeable Al decreased significantly due to basalt application within 6 months, whereas the value registered was determined by the rate of application. At the application of 10 t basalt/ha, it was observed that available P and exchangeable K, Ca, and Mg were increased to the level sufficient for crop growth. Meanwhile, chemical reactions (increase in pH and decrease in pHo) in the soils had resulted in an increase of the cation exchange capacity (CEC). This means that the soils are now able to reduce the loss of basic cations via leaching under high rainfall. Thus, basalt is a good soil ameliorant with the efficacy comparable to that of limestone, which is commonly applied to eliminate acid soil infertility in the tropics.

Keywords: Basalt, cation exchange capacity, exchangeable cation, Oxisols, Ultisols

ABBREVIATIONS

CEC : cation exchange capacity
RCBD : randomized complete block design

INTRODUCTION

About 70% of Peninsular Malaysia is covered by soils which have deep and highly leached profiles. These highly weathered soils, which are taxonomically classified as Ultisols and Oxisols (Soil Survey Staff, 1999), are dominated by kaolinite, gibbsite, and goethite in the clay fraction (Tessens and Shamsuddin, 1983; Anda *et al.*, 2008). Ultisols are defined by the presence of an argillic horizon in the B-horizon, depicting the accumulation of clay in that zone. On the other hand, Oxisols are defined by the presence

of oxic horizon in the subsoil. By definition, an oxic horizon contains predominantly oxides of Fe and Al and it has low CEC (as cmol_c/kg clay). These tropical soils are infertile due to low pH and low basic exchangeable cations, but high in exchangeable aluminium. Crop production on these soils is limited by these soil constraints infertilities.

For sustainable crop production on these soils, the soil chemical fertility needs to be substantially improved by applying suitable amendments. Research shows that soil fertility is

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significantly improved after limestone is applied onto the soils at appropriate rate due to the increase in soil pH, Ca, and Mg (Shamshuddin *et al.*, 1991; Shamshuddin *et al.*, 1998). Studies in Queensland, Australia indicated that ground basalt is a good alternative to limestone as a soil ameliorant (Gillman *et al.*, 2001; Gillman *et al.*, 2002). Other than Ca and Mg, basalt contains K and P in adequate amounts. Thus, using basalt as a soil ameliorant, P- and K-fertilizers application can be reduced so as to lower the cost of crop production.

Basalt outcrops are found sporadically throughout the Malay Peninsula (Gobbett, 1972). The best basalt outcrop is located on the beach at Beserah, Pahang (in the east coast state of Peninsular Malaysia). This basalt can be mined and ground to pass through a 2-mm sieve, and used for rejuvenating highly weathered tropical soils such as the Ultisols and Oxisols. When ground basalt is applied onto the soils under tropical conditions, it disintegrates and consequently weathers under prevailing high temperature and rainfall, releasing substantial amounts of Ca, Mg, K, P, and S into the soils. Its ameliorative effects are known to last for more than 2 years (Anda, 2006). The effects of ground basalt, on the chemical properties of soils in Queensland, Australia, have been studied (Gillman *et al.*, 2001; Gillman *et al.*, 2002). However, there is still a dearth of information on the chemical reactions of ground basalt in soils dominated by kaolinite, gibbsite, and goethite under tropical environment. Furthermore, the mechanism by which basalt ameliorates infertile tropical soils needs to be investigated and explained.

The objective of this study was to determine the changes in the chemical properties of Ultisol and Oxisol which were treated with ground basalt in Malaysia.

MATERIALS AND METHODS

A pot experiment was carried out at Universiti Putra Malaysia (UPM) in 2007/2008 to evaluate the effects of ground basalt in Ultisol and Oxisol found in Malaysia.

Soil Used

The soils used for this pot experiment were the Bungor (Typic Paleudult) and Munchong (Haplic Hapludox) Series, which are respectively classified as Ultisols and Oxisols. The topsoil (0-15 cm depth) was sampled from the University Research Park, UPM Serdang. The samples were air-dried, ground to pass through a 2-mm sieve and kept in the glasshouse before they were treated with ground basalt in the pot experiment.

Basalt Composition

Ground basalt used in this experiment was obtained from a commercial mineral company based in Australia. According to Gillman *et al.* (2002), this particular basalt contained 216,000 ppm Si, 65,400 ppm Ca, 64,400 ppm Mg, 12,500 ppm K, 3,030 ppm P, and 2,150 ppm S. Out of the three macronutrients (N, P, K) and secondary nutrients (Ca, Mg, S) needed for crop growth, only N is not supplied by basalt.

Experimental Design

A randomized completely block design (RCBD) experiment was set up in the glasshouse. There were two separate experiments in this study, and these were done using Ultisol and Oxisol (Bungor and Munchong series), respectively. Ground basalt was mixed thoroughly with the soil samples in the pots. The rates of the basalt application were 0, 5, 10, and 20 t/ha. In addition, water was also added into the soil mixture regularly in order to maintain the soil moisture content at the field capacity (equivalent to the matric suction of 10 kPa) throughout the experiment, and this was conducted for a period of 6 months. The sub-samples were taken from each pot (of the 2 experiments) every 2 month for the soil chemical analyses.

Analytical Methods

Soil pH was measured in water at the soil to water ratio of 1:2.5 using pH meter. Exchangeable bases (Ca, Mg, K, Na) were extracted by 1M NH₄OAc

buffered at pH 7 (Sumner and Miller, 1996) and the cations in the solution were determined by atomic absorption spectrophotometry (AAS). Exchangeable aluminium was extracted by 1 M KCl (Bertsch and Bloom, 1996) and the aluminium in the solution was also determined by AAS. In order to determine the CEC of the soils at the soil pH, a method of CEC determination, using non-buffered 1 M NH₄Cl proposed by Sumner and Miller (1996) and tested earlier by Tessens and Shamshuddin (1983) for a wide range of Malaysian soils, was adopted. Available P was determined using the method proposed by Pixen and Grove (1990).

Statistical Analysis

The data obtained from this study were subjected to statistical analysis (using SAS), using the Tukey's test for comparison.

RESULTS AND DISCUSSION

Initial Soil Properties

The Bungor and Munchong soils used in this experiment are classified as Ultisols and Oxisols, respectively according to the soil taxonomy (Soil Survey Staff, 1999). Both these soils were developed from shale; they only differ in their degree of chemical weathering. The Munchong soil is an Oxisol (clayey, kaolinitic, isohyperthermic family of Haplic Hapludox) and therefore by definition, it is more weathered than the Bungor soil which is

an Ultisol (clayey, kaolinitic, isohyperthermic family of Typic Paleudult). These two soil types are very common in Peninsular Malaysia and often used for rubber and oil palm cultivations. According to Tessens and Shamshuddin (1983), the soils of Bungor and Munchong series are dominated by kaolinite, gibbsite, and goethite minerals in the clay fraction. Hematite can also be present in the Munchong soil as it is reddish in colour (Anda *et al.*, 2008). Soil pH is low, but exchangeable aluminium is high (Paramanathan, 2000). Compounded these infertilities with low exchangeable Ca, Mg and K, the two soils need to be properly amended for sustainable crop production. In the present study, basalt was used to amend the soils.

Basalt Dissolution and Reactions

In order to determine how fast ground basalt reacts with moist soils under glasshouse conditions, the changes in both soil pH and exchangeable aluminium within 6 months for the soils added with 20 t basalt/ha were studied and discussed in detail. Table 1 shows the relevant data for discussion. Based on the data presented in Table 1, soil pH had changed from 4.33 in month 2 to 5.13 in month 6 for the Bungor soil. Meanwhile, the soil pH of Munchong soil had also been reduced accordingly.

Aluminium with a pK_a value of 5.0 hydrolyzes in water. Therefore, when the soil pH goes up beyond 5, Al in the soil solution starts to precipitate as gibbsite which is inert.

TABLE 1
Effect of applying 20 t basalt/ha on the soil pH and exchangeable Al with time

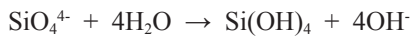
| Month | pH | Exch. Al cmol/kg | pH | Exch. Al cmol/kg |
|---------------------|---------------|---------------------|-----------------|---------------------|
| | Bungor Series | | Munchong Series | |
| 0 | 4.45 | 1.47 | 4.55 | 1.89 |
| 2 | 4.33 | 1.52 | 4.91 | 1.44 |
| 4 | 4.89 | 0.93 | 4.44 | 1.43 |
| 6 | 5.13 | 0.68 | 4.98 | 0.33 |
| HSD _{0.05} | 0.32 | 0.28 | 0.28 | 0.30 |

In the beginning (untreated soil), the exchangeable Al in the Bungor soil was 1.47 cmol_c/kg soil. After 6 months of incubation, the exchangeable Al was found to significantly reduce to 0.68 cmol_c/kg soil. Within the same period, exchangeable Al in the Munchong soil was reduced from 1.89 to 0.33 cmol_c/kg soil.

Important minerals in basalt are olivine and pyroxene. When they come into contact with water at low pH under high temperature of the tropics, these minerals disintegrate and dissolve, resulting in pH increase. Olivine dissolves slowly in water as follows:



The SiO₄⁴⁻ then hydrolyzes immediately to produce a large amount of hydroxyl:



The overall reaction of olivine in moist soils can be depicted as follows (De Coninck, 1978):



According to De Coninck (1978), pyroxene can hydrolyze, but less amount of hydroxyl is produced than that of the olivine. This study shows that due to the application of basalt, at 20 t/ha, the soil pH was found to increase to a value above 5. When this happens, the effect of Al toxicity to growing crop is brought to a minimal as most of the Al becomes gibbsite.

Table 2 and Table 3 presents the chemical properties of the Bungor and Munchong series, respectively as affected by the different rates of basalt applications after 6 months of incubation in the glasshouse. For the Bungor soil (Table 2), the soil pH was increased to about 5 due to the application of 10 basalt/ha. At this rate of basalt application, the exchangeable Al was concomitantly decreased to less than 1 cmol_c/kg soil, while the available P, exchangeable Mg and exchangeable Ca in the soil were found to be 20.84 ppm, 0.96 and 2.01 cmol_c/kg soil, respectively. The nutrients (P, Mg, Ca) present in the soils now are probably sufficient for a good growth of normal Malaysian crops such as rubber, oil palm, and cocoa. However, the exchangeable K was below the sufficient level for the crops to grow. The same trend of improvement in the chemical fertility was observed for the Munchong soil (Table 3). It seems that the suitable rate of ground basalt application to alleviate the infertility of Ultisol/Oxisol is 10 t/ha, based on practicality and economic viability. This is consistent with the finding of an earlier study by Anda (2006). Unlike limestone, ground basalt takes longer time to disintegrate and dissolves. According to Boniao *et al.* (2002), it took more than 9 months for basaltic rock to completely dissolve in pot under moist condition. This means that if the present experiment was extended for a longer period of time (> 12 months), the researchers would have seen a better picture of its ameliorative effects.

TABLE 2
Effect of ground basalt application on the chemical properties of Bungor soil after 6 months

| Treatment t/ha | pH | Avail. P ppm | Exch. cations | | | | | CEC |
|-----------------------------------|------|-----------------|---------------|------|------|------|------|------|
| | | | Al | Ca | Mg | K | Na | |
| ----- cmol _c /kg ----- | | | | | | | | |
| 0 | 3.83 | 6.40 | 1.66 | 0.76 | 0.10 | 0.11 | 0.05 | 3.66 |
| 5 | 4.73 | 14.72 | 1.04 | 1.83 | 0.73 | 0.43 | 0.08 | 5.93 |
| 10 | 4.96 | 20.84 | 0.82 | 2.01 | 0.96 | 0.74 | 0.10 | 6.22 |
| 20 | 5.12 | 26.78 | 0.68 | 2.09 | 1.05 | 0.83 | 0.15 | 7.08 |
| HSD _{0.05} | 0.20 | 2.28 | 0.03 | 0.09 | 0.07 | 0.03 | 0.01 | 0.19 |

TABLE 3
Effect of ground basalt application on the chemical properties of Munchong soil after 6 months

| Treatment t/ha | pH | Avail. P ppm | Exch. cations | | | | | CEC |
|-----------------------------------|------|-----------------|---------------|------|------|------|------|------|
| | | | Al | Ca | Mg | K | Na | |
| ----- cmol _c /kg ----- | | | | | | | | |
| 0 | 4.21 | 7.21 | 1.00 | 0.22 | 0.08 | 0.12 | 0.05 | 4.44 |
| 5 | 4.27 | 16.22 | 0.96 | 1.24 | 0.64 | 0.52 | 0.06 | 6.14 |
| 10 | 4.88 | 22.78 | 0.66 | 1.54 | 0.81 | 0.68 | 0.07 | 7.25 |
| 20 | 4.98 | 24.95 | 0.33 | 1.84 | 1.04 | 0.78 | 0.07 | 7.96 |
| HSD _{0.05} | 0.09 | 5.14 | 0.11 | 0.05 | 0.11 | 0.02 | 0.01 | 0.11 |

Changes in Soil pH According to the Rate of Basalt Application

Initially, the pH of the Bungor soil was lower than that of Munchong soil. This is consistent with the finding of Tessens and Shamshuddin (1983) who claimed that the pH of Malaysian Ultisol was usually lower than that of the Oxisol due to the presence of more exchangeable Al in the former. This finding is also proven in the present study. Data presented in Table 2 clearly show that exchangeable Al in the Bungor soil (Ultisol) is 1.66 cmol_c/kg soil for the untreated soil, while the corresponding value in the Munchong soil (Oxisol) is 1.00 cmol_c/kg soil (Table 3).

Nonetheless, applying ground basalt into the soils, at the rate of 5, 10 and 20 t/ha, did not result in the same increase in the soil pH. The pH of the Bungor soil was consistently higher than that of Munchong soil. However, this is not consistent with the higher exchangeable Al in the Bungor soil as compared to that of the Munchong soil. Higher pH is usually reflected by lower Al. Therefore, the difference in pH between the two soils was probably attributed to the differences in chemical reactions which took place because of the differing mineralogy in the clay fraction of the soils. Obviously, Oxisol contains more oxides of Fe and/or Al than that of the Ultisol because the former is more weathered than the latter. Furthermore, Munchong soil is redder in colour than Bungor soil, indicating the presence of more oxides of Fe (hematite) in the

former. Actually, the reason for the phenomenon of lower pH for the Munchong soil as compared to that of the Bungor cannot be confirmed at this stage. Thus, more studies are needed to determine the plausible mechanism.

Changes in Exchangeable Al with the Rate of Basalt Application

The changes in exchangeable Al in the Bungor and Munchong soils with rate are shown in Tables 2 and 3, respectively. First and foremost, the exchangeable Al was lower in Munchong as compared to that of the Bungor soil. This is similar to the finding of Tessens and Shamshuddin (1983) who argued that because of weathering, Al in Oxisols (such as Munchong soil) became gibbsite and there would be less Al existed in its exchangeable form. Nevertheless, the opposite is true for the Ultisols, such as Bungor soil.

In this study, the application of basalt was found to reduce exchangeable Al in both soils; the decrease was more in the Munchong than that of the Bungor soils. This is consistent with the more exchangeable Al in the latter initially. Applying basalt at 10 t/ha had reduced exchangeable Al to less than 1 mol_c/kg soil, a level considered to be of no problem for the growth of crops sensitive to Al toxicity. Thus, it is believed that the recommended rate of basalt application to eliminate Al toxicity in Ultisols and Oxisols is 10 t/ha.

Changes in the Available P with the Rate of Basalt Application

Prior to the treatment with ground basalt, the available P in the two soils was below 10 ppm, which is below the sufficient level for crop growth. As a result of applying 10 t basalt/ha, the available P in the Bungor and Munchong soils was increased to a value above 20 ppm (Tables 2 and 3, respectively), which is well above the crop's requirement. There was less P available in the Munchong as compared to that of Bungor soil at the basalt rate of 20 t/ha. The reason can be explained as follows. Being an Oxisol, the Munchong soil contains more oxides of Fe (as reflected by its red coloration) than that of the Bungor soil. Oxides of Fe are known to fix high amount of P. Hence, more P is fixed in the Munchong than that of the Bungor soil. As such, less available P was present in Munchong soil. Nevertheless, the available P was still enough in the Munchong soil for crop consumption at the basalt application rate of 20 t/ha.

Changes in CEC with the Rate of Basalt Application

The CEC of soil is a measure of its negative charge. In this study, the CEC of both the Bungor and Munchong soils increased significantly after 6 months of basalt application (Tables 2 and 3, respectively). The mechanisms of the CEC increase are as follows:

1. As the soil pH increased, due hydrolysis of the silicate present in basalt, the broken edges of mineral silicate (e.g. kaolinite) began to react. In this case, the proton at the broken edges of the kaolinite started to detach itself, the amount detached depends on the pH increase. As a result, the surface of the kaolinite became negatively-charged. This contributed partially to the increase in the CEC.
2. The other mechanism is related to the reaction of silicate with variable charge minerals, like goethite and hematite. When silicate (basalt) is chemically reacted with variable charge minerals in the soil, its

pH_o is lowered (Uehara and Gillman, 1981). It is important to note that pH_o is a fundamental property of individual mineral in soil, defined as the pH, at which the net charge of the variable charge mineral is zero. Past research in Malaysia showed that the pH_o of Oxisol decreased due to ground basalt application (Shamshuddin and Anda, 2008). When the ionic strength of the soil solution is kept constant, the amount of negative charge (CEC or σ) in the soil is proportional to the difference between pH_o and pH, which can be depicted as $\sigma = k(\text{pH}_o - \text{pH})$, where k is an overall constant. In this study, pH_o was lowered and pH was concomitantly increased as a result of basalt application. These phenomena widened the gap between pH_o and pH, and consequently, the negative charge (σ) in the soil was also increased.

The increase in CEC means that now the soils are able to hold more basic cations, such as K, Ca and Mg, on their newly increased negatively-charged surfaces. As a result of the CEC increase, the loss of these macronutrients via leaching under tropical environment is minimized. The same mechanism has been attributed to the accumulation of Ca and Mg in the topsoil treated with ground magnesium limestone (Shamshuddin and Ismail, 1995). This ameliorative effect is translated as a cost-saving in crop production.

Changes in Basic Exchangeable Cations with Rate of Basalt Application

The exchangeable Na, K, Mg, and Ca in the soils of Bungor and Munchong Series 6 months after ground basalt application are given in Tables 2 and 3, respectively. The lack of Na in basalt is obviously reflected by the insignificant change in the exchangeable Na in the Bungor and Munchong soils after ground basalt was applied at the rates of 5, 10, and 20 t/ha. In response to basalt application, the exchangeable Ca, Mg, and K was found to significantly increase in both soils, and that the increasing rate of

these exchangeable cations are dependent on the amount applied. The exchangeable basic cations in the two soils in the order of decreasing amount are: Ca>Mg>K>Na. This is consistent with the elemental composition of basalt used in the experiment as determined by Gillman *et al.* (2002).

CONCLUSIONS

This study clearly indicates that the application of ground basalt can rejuvenate highly weathered and/or infertile Malaysian soils by improving their chemical fertility. In the presence of water under prevailing high temperature in the tropics, basalt disintegrates and dissolves slowly and this leads to an increase of soil pH and available P as well as exchangeable K, Ca, and Mg. The pH increase would precipitate Al in the soil solution as inert gibbsite. In doing so, Al toxicity is reduced considerably. Basalt is, therefore, a good soil ameliorant, comparable to that of limestone, except that it needs more time to dissolve under moist soil condition. The recommended rate of the ground basalt application for alleviating the infertility of Bungor and Munchong soils, respectively classified as Ultisol and Oxisol, is 10 t/ha.

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REFERENCES

- Anda, M. (2006). Improvement of charge characteristics of oxisols using basalt and rice husk compost for cocoa growth. PhD Thesis, Universiti Putra Malaysia.
- Anda, M., Shamshuddin, J., Fauziah, C.I. and Syed Omar, S.R. (2008). Mineralogy and factors controlling charge development of three Oxisols developed from different parent materials. *Geoderma*, 153, 153-167.
- Bertsch, P.M. and Bloom, P.R. (1996). Aluminum. In D.L. Sparks *et al.* (Ed.), *Methods of soil analysis: Part 3- chemical methods* (pp.517-550). United States: Soil Science Society of America.
- Boniao, R.D., Shamshuddin, J., Van Ranst, E., Zauyah, S. and Syed Omar, S.R. (2002). Changes in chemical properties and growth of corn in volcanic soils treated with basalt pyroclastics and calcium silicate. *Communications in Soil Science and Plant Analysis*, 33, 1219-1233.
- De Coninck, F. (1978). *Physico-chemical Aspects of Pedogenesis*. Ghent: International Training Center for Post-Graduate Soil Scientists, Ghent University.
- Gillman, G.P., Burkett, D.C. and Coventry, R.J. (2001). A laboratory study of basalt dust to highly weathered soils: Effect on soil chemistry. *Australian Journal of Soil Science*, 39, 799-811.
- Gillman, G.P., Burkett, D.C. and Coventry, R.J. (2002). Amending highly weathered soils with finely ground basalt rock. *Applied Geochemistry*, 17, 987-1001.
- Gobbett, D.G. (1972). *Geological Map of the Malay Peninsula*. Kuala Lumpur: Geological Society of Malaysia.
- Paramanathan, S. (2000). *Soils of Malaysia: Their Characteristics and Identification*. Kuala Lumpur: Academy of Sciences Malaysia.
- Pixen, P.E. and Grove, J.H. (1990). Testing for phosphorus. In R.L. Westerman (Ed.), *Soil testing and plant analysis* (3rd edn.) (pp. 141-180). United States: Soil Science Society of America.
- Shamshuddin, J., Che Fauziah, I. and Sharifuddin, H.A.H. (1991). Effects of limestone and gypsum application to a Malaysian Ultisol on soil solution composition and yields of maize and groundnut. *Plant and Soil*, 134, 45-52.
- Shamshuddin, J. and Ismail, H. (1995). Reactions of ground magnesium limestone and gypsum in soils with variable-charge minerals. *Soil Science Society of America Journal*, 59, 106-112.
- Shamshuddin, J., Sharifuddin, H.A.H. and Bell, L.C. (1998). Longevity of magnesium limestone applied to an Ultisol. *Communications in Soil Science and Plant Analysis*, 29, 1299-1313.

- Shamshuddin, J. and Anda, M. (2008). Charge properties of soils in Malaysia dominated by kaolinite, gibbsite, goethite and hematite. *Bulletin of the Geological Society Malays*, 54, 27-31.
- Soil Survey Staff. (1999). *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. Washington DC: United States Department of Agriculture.
- Sumner, M.E. and Miller, W.P. (1996). Cation exchange capacity and exchange coefficient. In D.L. Sparks (Ed.), *Methods of soil analysis: Part 3 – Chemical methods* (pp.1201-1229). United States: Soil Science Society of America.
- Tessens, E. and Shamshuddin, J. (1983). *Quantitative Relationships between Mineralogy and Properties of Tropical Soils*. Serdang: UPM Press.
- Uehara, G. and Gillman, G.P. (1981). *The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays*. Boulder: Westview Press.