Soil Characteristics of Mud From the Indonesian Mud Volcano "LUSI"

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Abstract In Sidoarjo, on the island of Java, Indonesia, a mud volcano nicknamed "LUSI" has been erupting since May of 2006. Although belated efforts were made to contain the mudflow, a region greater than 600 hectares (Jakarta AFP 2008) has been completely inundated. The mud has become the new substrate of the region, so its fertility may influence species recolonization of the area as well as indicate the potential of future land-use. Since most mud volcanoes are studied for their fluid mosaics and gaseous effluxes, no studies have specifically investigated the mud for its nutritive qualities. This study establishes a simple fertility index of LUSI's mud, by testing for three soil properties that are important for plant growth: Carbon to nitrogen ratio (C:N), pH and cation exchange capacity (CEC). LUSI's C:N ratio (12.1 ± 1.01, n = 13) fell at the low end of the of corresponding tropical soil data range (10.3-27) (Trumbore 1993). LUSI's pH was found to be basic (8.22 ± 0.062, n = 13) relative to the range of tropical soil pH (3.9-6.3) (Motavalli *et al.* 1995). LUSI's CEC (19.72 $cmol^+/kg$ ± 1.28, n = 12) was high relative to tropical soil CEC (6.55 $cmol^+/kg$ ± 1.12, n = 9) (Trumbore 1993)More specifically, LUSI's %C (1.293% C ± 0.0448, n = 13) and %N (0.1076% N ± 0.0052, n = 13) were both very low (Motavalli *et al.* 1995, Ewel *et al.* 1991). These values indicate that C and N may need to be fertilized for plant growth because levels are so minimal, and buffering for the basic pH may be necessary as well. The high CEC levels indicate there are reasonable amounts of nutrient cations present in the mud. Together these results indicate that although the mud is not completely infertile, but reutilization of the region for agricultural use will probably require a significant amount of modification to the mud.

Introduction

Unique among mud volcanoes is "LUSI", which erupted May 29th 2006 in Sidoarjo, Java, Indonesia, close to heavily populated regions of the island (Davies *et al.* 2007). Still exuding mud, it is the largest and longest lasting of reported mud eruptions (Mazzini *et al.* 2007). Mud volcanoes usually subside in a few days or weeks (Mazzini *et al.* 2007), but LUSI has been erupting for almost 2 years. Before leveling to its current 130,000-150,000 m^3/day (Jakarta AFP 2008), the flow rate peaked at 180,000 m^3/day (Mazzini *et al.* 2007), an amount equal to 72 Olympic sized swimming pools. Moreover, the volume of this mud has an unusually high percentage of water (~70%), which makes it "an outlier at the dilute watery end of the [mud] volcanoes' viscosity spectrum" (Cyranoski *et al.* 2007). An expected percentage would be approximately 20-40% water (Hovland *et al.* 1997) given its depth of eruption estimated to be between ~1615-1828m (Mazzini *et al.* 2007). Furthermore, there is heavy subterranean pressure buildup; therefore, the core eruption column has not clogged allowing for continued mud expulsion (Cyranoski *et al.* 2007). The magnitude and length of the eruption has been so great that mud and water have inundated an area of approximately 600 hectares, an area equal to 2200 football fields (Jakarta AFP 2008), and has displaced over 30,000 people (Mazzini *et al.* 2007). This is significant considering only 900 of the 1700 known mud volcanoes are terrestrial (Jerosch *et al.* 2007) and none of comparable scale has been documented before (Davies *et al.* 2007).

Most mud volcanoes are studied during periods of dormancy after they have already been established (Mazzini *et al.* 2007), whereas LUSI has been monitored since its origin as a "pioneer mud volcano" (Davies and Stewart 2005). Interestingly, this has lead to a heated political and scientific debate as to whether the eruption was catalyzed by drilling operations (Cyranoski *et al.* 2007, Davies *et al.* 2007) or by a recent 6.3 magnitude earthquake (Mazzini *et al.* 2007). Aside from its unclear origins, LUSI does not categorize well into the three typical mudflow types (Lokbatan, Chikishlyar, and Schugin) as described by Dimitrov (2002, taken from Kalinko, 1964), which are summarized as follows: Lokbatan type: explosive with flames from ignited gasses and long periods of dormancy, well formed cones with high water content; Chikishlyar type: weak continuous eruption that lacks explosiveness, many vents emitting gasses and mud, pool-like, or only very slightly conic; Schugin type: represents the transitional type of mud volcano, weak activity during the periods of eruption, predominantly composite craters, presumably with minimal mudflow. Comparing these characteristics to LUSI's makes it clear that LUSI does not fit in with any of these three classifications. Like the Lokbatan type, LUSI has high water content, but LUSI has had no long periods of dormancy, nor is LUSI conic in shape. Although LUSI is flat and not conic in shape, unlike the Chikishlyar type LUSI is not represented by weak activity, nor does it have more than one distinguishable epicenter. LUSI has least in common with the Schugin type, with neither weak activity, nor minimal mudflow. Since LUSI does not categorize well into the three established mud volcano types, it is plausible that its mud characteristics are also anomalous relative to other mud volcanoes.

Numerous other mud volcanoes have been studied at the Alaskan Mountains (Sorey *et al.* 2005), Azerbaijan (Gallagher 2003), the Gulf of Cadiz (Hensen *et al.* 2007), Mt.Etna (Giammanco *et al.* 2007) etc. Usually such studies test or monitor gaseous effluxes (Giammanco *et al.* 2007) and fluid mosaics (Hensen *et al.* 2007), which refers to the variety of fluids (oil, brine, etc.) that may be present in the mud, and their possible origins from underground. Despite being new, even LUSI has had its gas and water composition extensively analyzed by Mazzini and colleagues (2007), but LUSI's mud composition has not yet been investigated other than for the purpose of determining the depth of its epicenter (Mazzini *et al.* 2007). Some trends do emerge from studies of other mud volcanoes that could be seen in LUSI's mud composition such as a basic pH of the mud (Ginsburg *et al.* 1999, Kopf 2002). Despite a few potential points of commonality with other mud volcano studies, there are few, if any, mud volcano studies with data relevant to my study. The reason for this lack of comparability is because gaseous efflux and fluid mosaic data are measured in units different than those measured in this study; this study investigates characteristics of the mud itself. For example, carbon levels are not typically presented with respect to nitrogen levels, but rather as a component of carbon dioxide levels (Dimitrov 2002, Giammanco *et al.* 2007, Mazzini 2007). Hence, carbon is typically measured as a component of a gas and is therefore incomparable to carbon levels present in mud itself. This study explores factors that are more applicable to tropical soil studies because this data will ultimately provide more useful information about the ecology and restoration of the area.

There are a number of environmental factors relating to the recovery of the region that could be influenced by the composition of the mud. Alteration of the substrate, species recolonization, and habitat restoration are a few issues that will eventually have to be considered in order to utilize the land again. Each of these factors is likely to be dependent on the ability for plants to recolonize the area, and the ability of plants to do so will be in turn affected by the mud itself. Since the land is still barren nearly 2 years later, (except for a few patches of grass and struggling palm trees in the swampy areas, see Fig. 1) it appears that it is difficult for plants to colonize the mud. To better understand why plants may have difficulty colonizing the mud, this study investigates soil characteristics that may facilitate or hinder plant growth. Identifying factors that affect plant growth is particularly important because previous to the mudflow rice paddies characterized some of the area (Davies *et al.* 2007, see Fig. 2) and the decline in local availability of such a staple food has probably caused further negative impact on the economy. Factors that may indicate whether rice farming can be successful on the new substrate will be very important in determining the agricultural usefulness of the land. If rice is unlikely to be successful because of the mud's characteristics, it may be possible to identify other crops that are better suited for the land, such as wheat or corn. Furthermore, since the mud has destroyed so many villages, potential alternative uses of the mud (such as housing materials) would greatly benefit the displaced. Although this study is not directly aimed at categorizing the mud for this intention, it may indicate advantages or disadvantages of using the mud for such purposes. Most importantly, however, are characteristics of the mud that will influence plant recolonization because these characteristics will ultimately affect the recovery of the entire ecosystem.

Figure 1. Patches of grass, and short palm trees grow in the more swampy areas of the mudflow. Photo by Jody Champlin.

Figure 2. A rice paddy only minimally affected by the mudflow. Similar rice paddies were common in the area that was covered by the mudflow. Photo by Jody Champlin.

This study specifically focuses on three characteristics of LUSI's mud: the carbon to nitrogen ratio (C:N), pH and cation exchange capacity (CEC). These specific factors were chosen because each one can have a significant influence on plant growth and they are relatively easy to test for given the sampling constraints (discussed in Methods). C:N was chosen because nitrogen (N) is the most important element for plant growth (Marschner 1995), and C:N is a useful indicator of N availability to plants (Kirschbaum *et al.* 2008) More specifically, if C:N is found to be high, then N would be immobilized by soil microbes and therefore be less available to plants. (This is because microbes are better competitors for available soil N.) Such a situation would require either N fertilization or planting nitrogen-fixing species to solve the low problem. Alternately, if C:N is found to be low, then this would indicate that there is not much competition for N between microbes and plants, so more N would be available for plants. LUSI's mud comes from deep underground so it has not been exposed to biological N inputs and so may have low N. The next factor, pH was chosen because the pH of LUSI's mud will probably differ significantly from the pH of the original substrate, and this could be a problem for plants accustomed to the pre-mudflow conditions. The pH of most tropical soils tends to be on the acidic side (3.9-6.3, from Motavalli *et al.* 1995) and LUSI's mud is probably basic because like other mud volcanoes, LUSI has a clayey composition that tends to correlate with basic pH (Ginsburg *et al.* 1999). Finally, CEC is important because many cations are essential nutrients for plant growth (Marschner 1995). The CEC of a soil can also be important in maintaining stable pH levels (Landon 1984). Since plants extract cations for uptake by exchanging them with hydrogen ions (H^+), the level of H^+ in the LUSI's mud is probably low since the mud came from belowground. Therefore, LUSI's CEC is probably going to be high relative to tropical soil data.

To test C:N, pH and CEC characteristics of LUSI I had samples shipped to me, and I tested the mud in the Silver Laboratory located on The University of California, Berkeley campus. Each test was conducted under the instruction and guidance of a laboratory technician or graduate student, and the results were compared to tropical soils to place them within a context (described in more detail in Methods). The overall objective of this study is to develop a general fertility index of LUSI's mud by testing for C:N, pH and CEC. The particular questions that this study addresses are: What are the C:N, pH and CEC of LUSI's mud? How do they compare to tropical soil data? What are the implications for species recolonization and future land use? For reasons indicated above, I hypothesized that LUSI's C:N would be low, pH would be high (basic), and CEC would be high.

Methods

In order to test LUSI's mud, samples were taken from various locations within the LUSI mud volcano site in Sidoarjo, Java. Due to political problems pertaining to the eruption and Indonesia's current position on the U.S.'s Travel Warning list, I was unable to take my own samples. Three individuals collected sets of samples for me, which were sent to the Silver lab at The University of California, Berkeley. All tests were conducted in the Silver and Firestone laboratories. The first set of samples was provided from Adriano Mazzini's field exploration of LUSI. Jody Champlin, my aunt, provided the second set of samples, which were taken under strict instructions. Prajna Murdaya, a family friend provided the third sample set. There are six samples from Mazzini, seven samples from Champlin and the one large sample from Murdaya. Mazzini's samples were taken using excavators and refrigerated before they were mailed directly to the Silver lab. Champlin's samples were taken using clean spoons, and each sample was placed into clean double zip-loc bags, sent to me and then taken directly to the Silver lab. Murdaya's sample was taken using a clean empty bottle and mailed directly to the Silver lab. All samples were kept refrigerated when not in transit. Mazzini's samples were collected from more central locations close by the epicenter, whereas Champlin's and Murdaya's samples were collected from sites around the more accessible perimeter regions. Samples taken by Champlin represent sites from all around the perimeter of the mudflow, including sites at the Porong River where the mud is being diverted via storm drains (see Fig. 3). Murdaya's sample was taken from the northeast edge of the flow. One of the samples from Mazzini (C6) probably does not represent LUSI mud. C6 was taken to determine if it represented an outcrop of LUSI mud and so far, all tests indicate that it is not LUSI mud (Mazzini 2008, pers. comm.).

Figure 3. A network of storm drains divert mud from the eruption site into the nearby Porong River to prevent overflow and breakage of the dykes, which keep the mud from further expansion. Photo by Jody Champlin.

To better understand the implications of my results, I conducted a focused literature review of tropical soil studies and drew comparisons from the most representative papers. I decided to compare LUSI's data to tropical soil data because Java is originally a tropical region, and even though some areas were converted to cropland (mostly rice paddies), the fundamental, unaltered soil type is generally tropical. Attempting to account for unquantifed variations within the former soil type of the area (which is now covered by the mudflow) is well beyond the scope of this study. Also, since tropical soils are typically very nutrient poor (Silver 1994, Vitousek and Sanford 1986), comparing LUSI's mud to the most depleted soils will help indicate the relative fertility of LUSI's mud.

In order to determine C:N ratios, carbon and nitrogen levels were tested using a NC 2100 Carbon and Nitrogen analyzer (CE Instruments, Lakewood, NJ, U.S.A.). Samples were first dried and then ground to a fine material using 2mm sieves and a porcelain mortar and pestle. In between samples these were cleaned using de-ionized water, hydrochloric acid and acetone. Subsets of these were wrapped in tin foil and then placed in the analyzer for successive incineration at 1000°C and 600° respectively. To confirm accuracy, blanks were conducted every eight samples and the C:N standard error (S.E.) of LUSI samples (.966%) was well within the allowed S.E. of 5%. Soil pH was measured twice for each sample to ensure accuracy. pH was measured with an Ultra Basic pH/mV Meter (Denver Instruments, Denver, Colorado, U.S.A.) in a solution of 1:1 ratio of sample mud to de-ionized water. CEC testing was divided into two days because it took about ten hours to complete CEC testing for eight of the samples; samples were tested under the guidance graduate student Katherine Smetak. Total CEC, was tested to determine the amount of total nutrient cations present in the mud. Samples were dried and ground using the same methods described for the C:N samples and five grams of each sample were tested. The CEC was tested using an unbuffered salt extraction method (Sparks 1996); NH_4Cl saturating solution was used to displace exchangeable Na, K, Ca, Mg, and Al.

Since LUSI's mud comes from a single epicenter the mud should be fairly homogenous throughout the site, so the limited number of samples should not limit accuracy. A slightly greater variation among the perimeter samples is to be expected because of possible additions of other soils and contaminants due to foot and road traffic along the perimeter. Despite these potential inputs the samples should still be a good representation of the mudflow's characteristics because LUSI is still erupting and fresh mud is constantly spreading throughout the site.

Results

LUSI's samples were found to have fairly similar C:N ratios, varying no more than 4%. This comparison excludes the data point C6 because its C:N ratio (20.59) was almost one and a half times higher than the perimeter samples and almost twice as high as the central samples. Despite some variation among LUSI's C:N data, its C:N mean = 12.1 ± 1.01, n = 13, correlates with the low end of Trumbore's (1993) tropical soil C:N ratio range = 10.3-27. The low C:N for LUSI's samples are explained by the low % nitrogen values (0.1076% N ± 0.0052, n = 13) they exhibited. C6 has the highest C:N value because its % carbon (2.903%) is over one and a half times greater than any other sample. The rest of the samples had low % C (1.293% C ± 0.0448, n = 13), even when compared to tropical soil %C (2.129% C ± .475, n = 7). Tropical soils have comparatively higher % N averages than LUSI's mud by up to 1.6% N (see Fig. 4). All LUSI samples were found to have basic pH, mean = 8.22 ± 0.062, n = 13. The C:N outlier C6 fell within the middle of this range with a pH of 8.21, although it was not included in the calculation. LUSI's pH values are more basic than tropical soil pH's, which range on the acidic side (see Table 2b and Fig. 5). LUSI's CEC data had a somewhat more varied range, from mean = 19.72 $cmol^+/kg$ ± 1.28, n = 12. Due to a procedural error, sample P6 had an erroneous value for CEC (96.91 $cmol^+/kg$) and has therefore been omitted from calculations along with the outlier C6. LUSI's mean CEC is almost several times higher than the representative tropical soil CEC (6.55 $cmol^+/kg$ ± 1.12, n = 9) (Motavalli *et al.* 1995). Below are tables of LUSI and tropical soil data.

Figure 4 Nitrogen averages from tropical soil studies from various countries and LUSI (Java). Brazil data from Trumbore 1993, Costa Rica data from Heaney and Proctor 1989, Jamaica data from Tanner 1977 (Cited in Vitousek 1984), and Venezuela, Brazil and Colombia data from Vitousek and Sanford 1986.

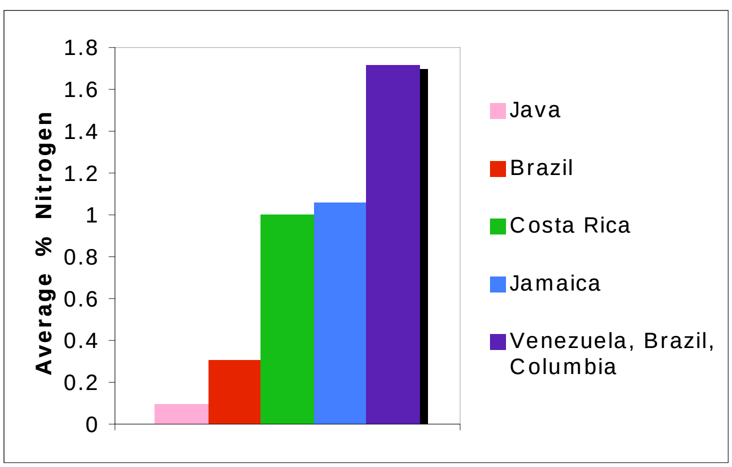

Table 1. Carbon and Nitrogen percentages, C:N ratio, pH and CEC for different LUSI samples. P1= Perimeter-Murdaya-1, C1= Central-1, C2= Central-2 and so on. *A procedural error occurred during CEC testing for P6 that resulted in a wildly erroneous value, so it is not included in calculations.

Sample Name	Sample Description	Collector	Year collected	Nitrogen (%)	Carbon (%)	C:N	pH	CEC
C1	Northern part of crater, old mud flow, partly dried	A. Mazzini	2006	0.1123	1.338	11.91	8.06	20.65
C2	Northern part of crater, oily seep	A. Mazzini	2006	0.1112	1.283	11.53	8.53	19.32
C3	Southern part of crater, fresh	A. Mazzini	2007	0.1136	1.306	11.50	7.94	21.49
C4	Southern part of crater, fresh	A. Mazzini	2007	0.1136	1.320	11.62	8.14	26.71
C5	Sample from hot and fresh mud flow	A. Mazzini	2007	0.1121	1.286	11.47	8.04	19.88
C6	Sandy outcrop of clay, probably not LUSI mud	A. Mazzini	2007	0.1410	2.903	20.59	8.21	13.76
P1	Mud from rice paddy affected by flow	J. Champlin	2007	0.1046	1.177	11.25	7.87	15.65
P2	Somewhat near the epicenter at perimeter	J. Champlin	2007	0.0971	1.198	12.34	8.27	18.72
P3	Before storm drains at perimeter	J. Champlin	2007	0.1610	1.741	10.81	8.44	20.98
P4	Before storm drains at perimeter	J. Champlin	2007	0.0877	1.282	14.62	8.23	18.86
P5	After storm drains exit at Porong river, under storm drains	J. Champlin	2007	0.0976	1.262	12.93	8.64	16.01
P6	After storm drains exit at Porong river, under storm drains	J. Champlin	2007	0.0966	1.332	13.80	8.29	96.91*
P7	Random location near perimeter	J. Champlin	2007	0.0795	0.962	12.09	8.30	19.04
P8	Somewhat near epicenter at perimeter	P. Murdaya	2007	0.1118	1.325	11.85	8.14	19.33

Table 2a Carbon and Nitrogen percentages, C:N ratio, pH and CEC for Tropical soil data. Carbon and Nitrogen data taken from Trumbore, 1993.

Soils 1	Depth (cm)	Nitrogen (%)	Carbon (%)	C:N
Oxisol 1, Curua Una, 1959	0-22	0.18	3.9	22
Oxisol 1, Curua Una, 1959	22-60	0.11	1.3	12
Oxisol 2, Belem, 1959	0-32	0.03	0.9	27
Oxisol 4, Reserva Ducke, 1986	4.7-7.5	0.28	4.2	15
Oxisol 4, Reserva Ducke, 1986	7.5-12.7	0.19	2	10.3
Oxisol 4, Reserva Ducke, 1986	20-25	0.12	1.4	11.7
Oxisol 4, Reserva Ducke, 1986	38-50	0.11	1.2	10.9

Table 2b pH and CEC taken from Motavalli *et al.* 1995. Soil depth applies for pH and CEC. CEC is measured in centi-moles per kilogram. pH method- 2.5:1 soil-water v/v ratio. CEC exchange procedure with NH_4NO_3 and KCl.

Soils 2	Soil Depth (cm)	pH	CEC ($cmol^+/kg$)
Yurimaguas (Peru)	0-8	6.3	10.88
Manaus (Brazil)	0-8	3.9	3.20
Colonia (Brazil)	0-8	4.2	2.68
Valenca (Brazil)	0-8	4.4	3.58
Ouro Preto (Brazil)	0-12	4.9	2.60
Una (Brazil)	0-12	5.7	3.06
Birrisito (Costa Rica)	0-12	4.3	2.23
Tierra Blanca (Costa Rica)	0-10	4.8	6.35
Popayan (Colombia)	0-8	5.7	7.67

pH of LUSI's Mud Versus Tropical Soil

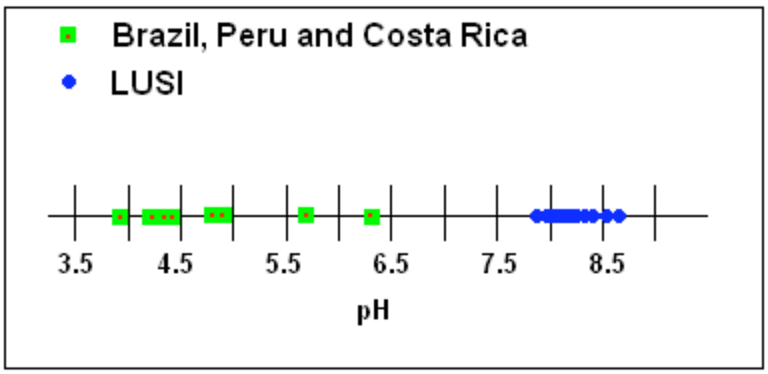

Figure 5. pH values for LUSI mud samples compared to tropical soil pH's taken from various tropical forests in Brazil, Peru, and Costa Rica from Motavalli *et al.* 1995.

Discussion

LUSI's C:N ratios were quite low even when compared to tropical soil C:N ratios, which confirmed my hypothesis about C:N. As discussed in the introduction, low C:N ratios indicate that N should be more available to plants because microbes are not competing for it. However, there is a flaw in applying this comparison to my data that I did not foresee; the actual %N of LUSI's mud is extremely low, even when compared with depleted tropical soils. Therefore a low C:N ratio is not a good indication of N availability in LUSI's mud because there is so little N to begin with. LUSI's %C is also low compared to tropical soil %C, but was only less than half the tropical soil %C (1.293% / 2.129% = 0.607). This is contrasted to LUSI's %N, which was nearly one third of the smallest tropical soil %N (0.1076% / 0.303% = .355) and over fifteen times smaller than the largest tropical soil %N (0.1076% / 1.71% = .0629). What these results indicate is that LUSI's mud is generally poor in both carbon and nitrogen. While the low nitrogen is more of a problem, fertilization of both elements may be necessary for effective plant recolonization.

LUSI's pH is not only basic relative to tropical soil pH from Motavalli *et al.* (1995), but is actually on the basic side of the pH spectrum, which confirms my hypothesis about pH. The potential problems that could arise from the mud's basic pH are not as immediately evident as the low nitrogen issue. However, intuitively, a pH that is significantly different than the original substrate's pH is going to be a problem. If the region's native plants have adapted for an acidic pH (which seems likely considering Java's climate and the typical acidity of tropical soil pH, Motavalli *et al*. 1995, Ewel *et al*. 1991) then the plants would have a difficult time recolonizing the mud. The same issue would be true for crops. To restore some of the area to rice paddies or cropland would probably require alteration of the substrate's pH. If nothing is done to modify the basic pH of the mud, then only plant species that tolerate basic pHs will be able to grow successfully (Chapin 1980).

The total CEC of LUSI's mud turned out to be fairly high compared to tropical soil CEC, which confirmed my third hypothesis. A high CEC indicates that there is a reasonable amount of nutrient cations present in the mud, which may make plant recolonization less problematic, unlike LUSI's C:N and pH results. LUSI's CEC was three times greater than tropical soil CEC (6.55 $cmol^{+}kg^{-1}$ / 19.72 $cmol^{+}kg^{-1}$ = .3321) (Motavalli *et al.* 1995). The only problem with the CEC data is that the test did not exclude the cation aluminum, which is not a plant nutrient, and can even be toxic to plants. Aluminum was not specifically excluded for because the descriptions of the mud and its sources by Mazzini *et al.* (2007) and Mazzini pers. comm. (2008) indicate that aluminum should not be a significant factor in the total CEC. Therefore, the high CEC for LUSI's mud will probably facilitate more successful plant recolonization.

A fourth characteristic that may also prove to be a problem for LUSI's habitat restoration is the extreme hardness of the desiccated mud. This was an unanticipated observation that I made after I began grinding my samples through the 2mm sieves. The few plants that have been able to grow in the mud are only seen in the areas that are still lake-like (see Fig. 1) and this of might be because the dried mud is too dense for roots to grow in. LUSI's mud is primarily composed clay and silt (Mazzini *et al.* 2007), so when the mud desiccates the small particle sizes compact together very tightly. While this factor may pose an issue for plant colonization, it may point to another alternative use for the mud. Since so many people had their homes submerged in the mud, investigating potential methods to alter the mud into a building material could provide an extremely valuable use for the mud. Building materials in this area are so scarce that workers have been salvaging lumber by disassembling the partially submerged homes in the mudflow (Cyranoski 2007). Such an alternative use of the mud could provide a new source of building materials as well as income for the homeless if they were allowed access to the mud. Unfortunately, widespread use of the land and mud for housing materials will have to wait until the eruption stops. Despite the enormous volume erupting daily, which is causing the surface to subside by as much as 50cm a day (Mediacenter 2008), no study has estimated an end to the eruption (Mazzini *et al.* 2007, Davies *et al.* 2006, Cyranoski 2007). Ultimately, widespread restoration of the site will be next to impossible because the mud has completely destroyed the entire ecosystem.

Conclusions

LUSI's mud has highly unusual characteristics, with a low C:N ratio, basic pH and high CEC. Specifically, the low % N and basic pH will likely impede effective plant growth in the mud. Even compared to depleted tropical soils, the mud's characteristics seem to render it rather inhospitable, despite having a high CEC. Considering how hard the desiccated regions of the mudflow are, the mud could be an used as an effective housing material. Investigating potential methods to use the mud as a housing material could provide a significant source of capital for the displaced individuals. This is especially important because there is so little federal money available for mudflow victims because the Indonesian government has spent hundreds of millions of dollars dealing with the issue (Harsaputra and Nugroho 2007) and has no more money left for the victims. Even the food supply the government has been supplying to the victims was stopped as of May 1, 2008 (Radar Sidoarjo 2008). With this setback, the families displaced by the mudflow will have to fend for themselves until the eruption ceases. Only once the eruption stops will the victims of the mudflow be able to rebuild their lives.

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