

Amelioration of Soil Fertility in Variable-Charge Dominated Soils**

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Variable-charge dominated soils generally refer to the highly weathered and intensively leached Oxisols, if not the relatively young soils with andic properties, which are developed from volcanic parent materials. The main characteristic of these soils is that they have constituents that are highly reactive with the environment, which is expressed by a high variable surface charge. They are constituents that have amphoteric surfaces, such as the oxides and hydroxides of Fe and Al, complexes of Fe and Al with organic matter, and short-range order minerals, such as allophane and imogolite (Dahlgren et al., 1993; Parfitt, 1980; Zhang and Zhao, 1997). The net charge depends on the

environmental conditions with such parameters as pH_0 and pH, electrolyte concentrations, and valence of the counterions (Van Wambeke, 1991 and Wada, 1980). The fertility of these soils, therefore, may be improved with an increment of negative charge by working on the variable parameters stated above. The basis of the assumption is the Uehara-Gillman equation (Uehara and Gillman, 1981): $s_v = (2neRT/p)^{1/2} \sinh 1.15 z (pH_0 - pH)$.

This equation shows that the sign of the net charge is determined by the solution pH relative to pH_0 , its magnitude by the difference between pH and pH_0 and the by the composition and concentration of the contacting electrolyte solution (Van Ranst, 1991). Among the parameters in the equation, $(pH_0 - pH)$ is the most interesting to achieve a possible net charge improvement. Raising the pH was reported to be nearly improbable because of the inherent buffering capacity of the soils of this nature. Lowering pH_0 , however, with such materials as phosphates, silicates and organic matter is highly probable and recommended (Van Ranst et al., 1998). Lowering pH_0 means increasing CEC. Phosphate and silicate anions lower pH_0 by being specifically adsorbed on positively charged sites, which contain AlOH and FeOH groups (Hingston et al. 1972; Gillman, 1980; Van Ranst et al. 1994).

Organic matter has a low pH_0 , lower than the pH of most soils with Andic properties, so that an overall lowering of the soil pH_0 can be achieved by sorption of large organic anions onto particle surfaces, thereby masking some positive charge (Van Ranst, 1995 and Van Ranst et al., 1998).

This study discusses the changes in chemical properties and surface charges that occur when these soils are cultivated and when amelioration materials are added, and also whether the changes brought about by incubation materials on the soils can sustain plant growth.

Materials and Methods

Soils collected from the southern part of the Philippines and another from Kuantan, West Malaysia were used in this study. For studying the effect of cultivation on surface charges, only an Oxisol and soils of volcanic origin collected from the Philippines were used. The samples were taken from profiles dug from different sites. At each site, cultivated and virgin soils were sampled. From these samples, the determination of the surface charge properties of the soils was carried out following the methods outlined by Gillman (1984) and Gillman and Sumpter (1986 a, b).

For assessing the effect of ameliorants on surface properties, an Oxisol from Kuantan, Peninsular Malaysia and two soils of volcanic origin from the Philippines, CAM2 and CAM5, were used in the study. All samples were collected from cultivated soils. These soils were incubated with peat (0.M), calcium silicate, and ground basaltic pyroclasts to study the changes in soil charge characteristics, CEC and pH_o over a period of time. Two hundred grams of soil (air dried) were weighed into a plastic bag and incubated with peat (0.M), ground basaltic pyroclasts, and silicate ($CaSiO_3$) materials for nine months at the rate of 200 t (oven dry weight material) ha^{-1} . There were four treatments in four replicates involving volcanic soils in one experiment and the same treatments in three replicates using Oxisol in another and these experiments were laid out in CRD. Surface charges were determined using the methodology proposed by Uehara and Gillman (1980) and further modified by Gillman and Sumpter (1986b), while CEC was determined by the Ammonium Acetate method buffered at pH 7. The methods are described in details in the cited references.

The effect of amelioration on the growth of corn was evaluated through a glasshouse experiment in which corn was grown in CAM2 and CAM5 soils incubated for nine months with peat and ground basaltic pyroclasts at four different rates: 20, 10, 5, and 0%. These incubated soils were placed in pots in which corn was planted and allowed to grow for 40 days. A basal application of 5 g 12-12-17-2 complete fertilizer (N- P_2O_5 - K_2O -MgO) per pot was done to help plants

through their first few days of growing period. At harvest, the soils were air-dried, sieved and analyzed for CEC and exchangeable cations by the NH_4OAc method (Van Reeujwijk, 1993). The parameters measured in Corn (*Zea mays* L.) included among others the following: height (measured three times during the growing period; 2nd, 4th and 6th week after planting and at harvest) and weight of vegetative materials at the end of the experiment. Routine tissue analyses were carried out for N, P, K, Ca, and Mg. There was a total of 16 pots serving as treatments units. The treatments were replicated 4 times and laid out in a Randomized Complete Block Design (RCBD).

Results and Discussion

Effect of cultivation on chemical and charge properties of the soils

Selected chemical and charge properties of the soils studied are given in Table 1. In general, the soil reaction is acidic to slightly acidic with pH (H_2O) ranging from 4.9 to 5.8 of which the cultivated soils have slightly lower values than the uncultivated ones. In all cases, uncultivated soils have higher organic carbon contents than their cultivated counterparts. The same trend is observed for exchangeable cations (not shown). This shows that when land under natural vegetation is cleared for cropping, irrespective of the farming system, often the critical constituent that gets lost is organic matter. It is very fragile and disappears when after clearing it is exposed to erosion and high temperatures that accelerate its decomposition.

The CEC and ECEC of the soils range from 8.2 to 16.6 and 0.6 to 8.4 $\text{cmol}_c\text{kg}^{-1}$ soil, respectively (Table 1). These values are relatively too low for soils to be productive. Uncultivated soils, with 0.C contents higher than their cultivated counterparts, expectedly have higher CEC and ECEC values than the latter. The upper horizons of all soils have higher values when compared to the lower horizons. This trend confirms several studies relating cation exchange capacity positively to organic matter (Baert, 1995; Van Dijk, 1971; and Van Ranst, 1995).

The position of pH_o on the pH scale determines CEC and such a position is influenced in particular by the presence of organic matter and non-crystalline constituents of the soils. Organic matter lowers pH_o , while oxides and oxyhydrates of Fe and Al (the constituents of non-crystalline materials) tend to increase pH_o . In this study, higher pH_o values are obtained from cultivated soils where the O.C content is reduced by cultivation. The same is true in subsoils where O.C. is observed to be less compared to topsoils.

The permanent charge density (ρ_p), defined as the excess CEC_T over AEC at pH_o , simply means the excess cations or anions adsorbed at the pH value where the variable charge components adsorb equal quantities of each. The simple model adopted by Uehara and Gillman (1980) has been used to estimate the amounts of net permanent charge and was computed from the charge curve of the soil. The amounts are presented in Table 2. The values, ranging from 0.04 to 6.80 $cmol_c kg^{-1}$ soil are generally low in all samples indicating the dominance of variable charge in the soils. No trend can be established either between cultivated and uncultivated topsoil and subsoil.

The pH_o and Other Charge Properties After Amelioration

Charge properties of CAM2 and CAM5 after a period of incubation with amendment materials are presented in Tables 2. The data for the soil from Kuantan, are given in Table 3.

In general, the results showed that the trend of response to treatments was about the same in all soils. Peat treatment lowers pH_o significantly in all soils, more specifically over a longer period of incubation. In Oxisols (Kuantan), however, the decrease relative to the control was higher reflecting a more significant contribution of organic material in such type of soil. Organic matter, with predominantly carboxyl functional groups, has a low pH_o (Uehara and Gillman, 1981). The point zero charge, therefore, decreases with the addition of organic matter. It was reported that the lowering of pH_o was partly the result of negatively charged organic matter bonding to protonated oxidic sites in the case of a highly weathered soil (Gillman, 1985) and to protonated

edges of noncrystalline aluminosilicates in the case of soils of volcanic origin.

Application of ground basaltic rock brought no significant changes in pH_0 in the studied soil. The material being a freshly ground rock, although containing high amount of silicate compounds, seems to need more time of incubation before any effect could be observed. Obviously, the nine-month period employed on this study was not sufficient.

Meanwhile, a marked increase in pH_0 is observed in all soils amended with calcium silicate. It seems to indicate that a mechanism of adsorption other than purely electrostatics is involved. The addition of silicate materials was supposed to lower the pH_0 due to the masking effect of SiO_3^{2-} on the positive charge sites of these soils (Gillman, 1985; Van Ranst, 1995). In the present study, an entirely different phenomenon may have occurred. According to Gillman (by personal communication, May 1999), with the high rates of silicate used, we have a precipitate of silicic acid coating all particles. Silicic acid has a high pH_0 .

The results (Tables 2 and 3) also show that charge properties such as the total CEC (CEC_T), the basic cation exchange capacity (CEC_B) and AEC of the soils improved with addition of peat and more significantly with calcium silicate. The improvement generated by peat addition could be attributed to its being a source of negative charge itself apart from making protonated oxidic sites of noncrystalline aluminosilicate edges. As to the calcium silicate application, the phenomenon as discussed above may explain partly. Any value recorded for 'permanent charge' or CEC is a result of the high, but surely anomalous pH_0 .

Growth of Corn After Amelioration

The effect of soil amendments on plant height is presented in Table 4. In CAM2 with peat, the average plant height after 6 weeks was 142 cm. The tallest plant (149 cm.) was harvested from a soil treated with 10% peat, not with 20%, indicating that the optimum rate is around this level and 20% may be excessive. In CAM5, the effect of peat incubation on plant heights was also observed but the trend was less consistent. Nevertheless, it showed that with an increasing amount of peat added the height increased. As in CAM2, the optimum rate seemed to be reached at 10% peat. Meanwhile, in basalt added soils, there were indications the plants were taller with basalt or with an increasing amount of it. But the increase was not significant. Basalt dissolves relatively slower than peat, hence its effect may not be observable in one growing period.

In both soils, neither peat nor basalt showed a statistically significant difference in fresh or dry weight of the corn compared to the control. Actual values of these parameters, however, indicated that the application of either one of the treatments, and especially peat, produced more biomass than the control. Treatment with 20% peat produced a heavier corn plant than with 0% peat after 6 weeks of planting. With basalt, the difference was not as big as with peat but it nevertheless showed that the plant benefited from the application.

When relative values of height and weight were calculated by treating the actual highest height or weight as the maximum, i.e., as 100%, these values showed that they were positively correlated with Mg in the soil solution (Fig. 1). The graph shows that the relative height and weight (%) of corn increased as the soil solution Mg concentration increased. The linear increase indicates that Mg in the soil solution may not be sufficient for corn (Shamshuddin et al., 1991). It was also shown that the relative critical values for Mg, i.e., the magnesium concentration corresponding to 90% relative height and weight, were about 3900 and 5200 mM, respectively.

Conclusion

The present study proved that the pH_0 increase is attributed to the %O.C reduction in the soil which, of course, is ascribed to the destructive process of cultivation. Application of peat, in fact, corrects the problem, i.e., reduces the pH_0 and raises the CEC. For basalt applications, it is believed that nine months incubation is too short to detect the effect, but there were certain indications that it brought about changes in the soils. Thus, although there was an immediate effect of peat on the surface charge properties of the soils, ground basaltic rock needs time to have effect. The results demonstrated that the benefits produced by the application of the latter increased and should continue for a considerable period of time. In addition, the application of a large amount of ground basalt rock may act as a convenient source of Ca, Mg and K for many years.

Plant responses to changes brought about by incubation with amendment materials were less definite. These could be attributed to the very short observation time. Despite this observation, there were indications that the plants have benefited from the amendments.

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Table 1. Selected charge and chemical properties of the studied soils

Profile No.	Horizon No.	Depth cm.	%O.C	pH (H ₂ O)	CEC cmol _c kg ⁻¹ soil	ECEC cmol _c kg ⁻¹ soil	pH _o	σ ⁺ cmol _c kg ⁻¹ soil
HIP2 (uncul)	A	0-14	5.2	4.9	18.04	3.32	4.2	6.17
	B	85-110	0.5	5.3	12.45	0.63	7.1	6.26
HIP3 (culti)	A	0-16	3.0	5.4	18.61	6.37	4.7	5.98
	B	84-100	0.4	5.3	12.25	0.75	6.8	6.80
CAM1 (uncul)	A	0-15	8.1	5.4	14.15	4.46	3.8	3.28
	B	55-85	1.4	5.9	8.66	0.80	4.6	0.04
CAM2 (culti)	A	0-20	3.8	5.3	8.26	1.24	4.0	0.99
	B	20-23	2.0	5.6	7.33	0.64	4.6	0.71
CAM5 (culti)	A	0-12	1.9	5.8	12.10	6.13	3.4	2.21
	B	12-40	1.5	5.7	12.98	6.49	3.4	3.55
CAM6 (uncul)	A	0-15	2.5	5.6	13.86	8.49	3.4	5.29
	B	15-40	0.9	5.8	16.62	8.42	3.6	4.77

Table 2. Charge properties of soils after 9 months incubation with amendment materials¹.**A. CAM2**

Treatment	Soil pH (0.002M)	pH _o	Charges at soil pH*		
			CEC _B	CEC _T	AEC
			cmol _c kg ⁻¹ soil		
Control (C)	4.8 ^C	4.0 ^B	1.89 ^A	2.07 ^A	0.23 ^A
Ground Basaltic Pyroclasts (B)	5.0 ^B	3.8 ^C	2.18 ^A	2.27 ^A	0.08 ^A
Peat (P)	4.6 ^D	3.7 ^C	4.43 ^B	5.06 ^B	0.08 ^A
Calcium Silicate (S)	8.5 ^A	6.7 ^A	50.61 ^C	50.61 ^C	0.04 ^A

B. CAM5

Treatment	Soil pH (0.002M)	pH _o	Charges at soil pH*		
			CEC _B	CEC _T	AEC
			cmol _c kg ⁻¹ soil		
Control (C)	5.1 ^C	2.8 ^C	7.1 ^A	7.1 ^A	0.00 ^B
Ground Basaltic Pyroclasts (B)	5.5 ^B	3.2 ^B	7.7 ^A	7.6 ^A	0.00 ^B
Peat (P)	4.4 ^D	2.7 ^C	11.7 ^A	12.2 ^A	0.15 ^B
Calcium Silicate (S)	8.6 ^A	6.5 ^A	67.0 ^B	67.0 ^B	0.52 ^A

¹ Means with the same letters are not significantly different at 5% level of significance

* Measured from charge curves (Charge Fingerprint method)

Table 3. Charge properties of Oxisol (Kuantan) after 3 months incubation with amendment materials. ¹

Treatment	Soil pH (0.002M)	pH _o	Charges at soil pH*		
			CEC _B	CEC _T	AEC
			cmol _c kg ⁻¹ soil		
Control (C)	4.3 ^C	3.7 ^C	1.02 ^A	1.22 ^A	1.78 ^B
Ground Basaltic Pyroclasts (B)	4.6 ^B	3.8 ^B	1.32 ^A	1.44 ^A	1.43 ^B
Peat (P)	4.1 ^D	2.6 ^D	33.3 ^A	3.33 ^A	1.52 ^B
Calcium Silicate (S)	8.4 ^A	6.3 ^A	28.54 ^B	28.54 ^B	2.55 ^A

¹ Means with the same letters are not significantly different at 5% level of significance

* Measured from charge curves (Charge Fingerprint method)

Table 4. Height of Corn in Soil treated with Different Rates of Peat and Basalt Pyroclasts**a. CAM2**

Rate (%)	Height of the Corn (cm) during Planting Period					
	Soil treated with peat			Soil treated with basalt		
	2 nd week	4 th week	6 th week	2 nd week	4 th week	6 th week
20	43.6 b*	84.0 a	147.2 a	42.0 a	68.3 a	128.7 a
10	48.9 a	82.2 a	149.0 a	41.9 a	67.3 a	123.3 a
5	43.5 b	82.3 a	142.0 ab	42.3 a	56.2 a	124.5 a
0	41.3 b	65.5 b	130.3 b	42.4 a	64.5 a	123.5 a

b. CAM5

Rate (%)	Height of the Corn (cm) during Planting Period					
	Soil treated with peat			Soil treated with basalt		
	2 nd week	4 th week	6 th week	2 nd week	4 th week	6 th week
20	48.5a	86.3 a	141.7 ab	44.7 a	76.7 a	142.2 a
10	47.9 ab	81.3 ab	145.2 a	38.9 a	69.7 a	138.0 a
5	42.5 b	76.2 b	133.2 b	39.4 a	72.3 a	138.3 a
0	48.3 ab	78.3 ab	141.2 ab	140.1 a	75.7 a	141.5 a

* Means with the same letter are not significantly different at 5% level.

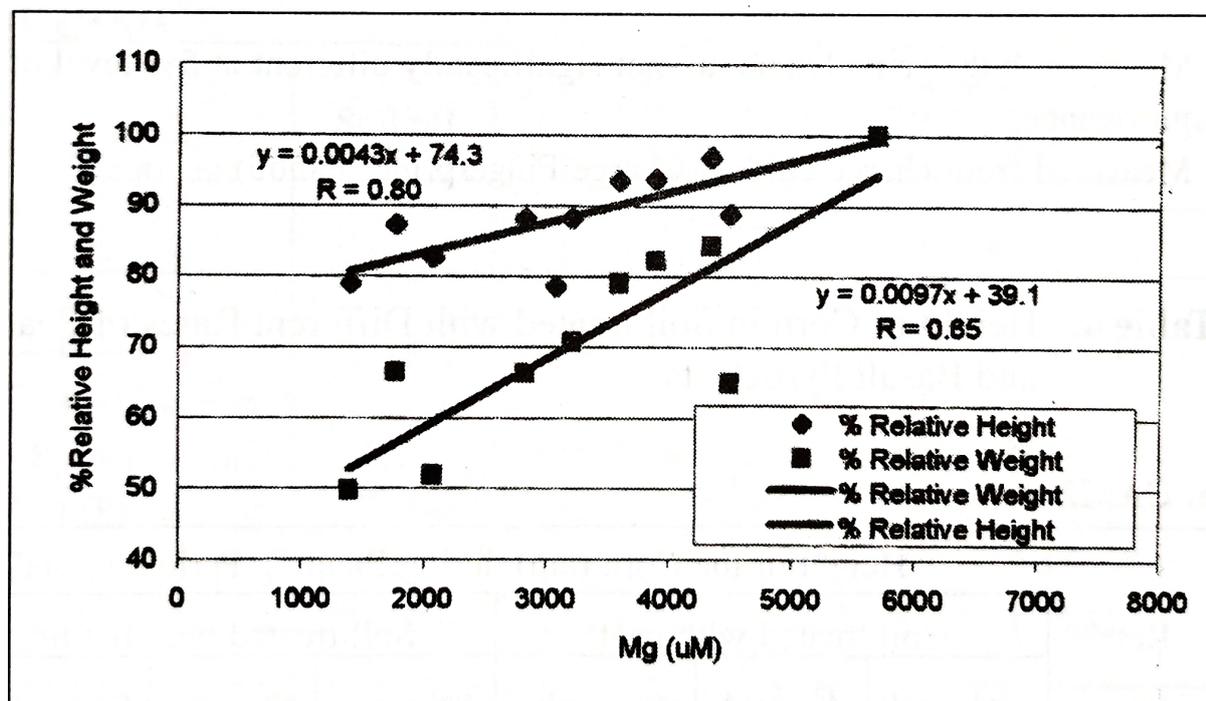


Figure 1. Relationship between relative height and weight (%) and solution Mg concentration

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