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THE COEFFICIENT OF LINEAR EXTENSIBILITY OF MAJOR SOILS OF PUERTO RICO

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ABSTRACT

The coefficient of linear extensibility (COLE) is a quantitative expression of the capacity of a soil to swell when moist and to shrink and crack when dry. COLE values are used to characterize soils in their natural condition and to group them according to their swelling tendencies. They are useful in predicting potential swelling problems with agricultural and engineering connotations in given soil areas. The relationship of COLE to other soil parameters was studied using data from 68 horizon samples of Vertisols, Mollisols, Ultisols, and Oxisols from Puerto Rico. Soil parameters studied were percent clay, silt and organic carbon. While for Mollisols and Vertisols COLE values were highly correlated with percent clay (R^2 = 0.743 and 0.637, respectively, $p < 0.01$), in Ultisols the most significant variable was found to be percent organic carbon (R^2 = 0.511), with negligible contributions of silt and/or clay. For Oxisols, an interaction between percent organic carbon and clay was found to be highly significant ($p < 0.01$), accounting for 85% of the variability in COLE values. Other factors, such as clay minerals may have an effect on the COLE values observed.

INTRODUCTION

The volume of most soil fabrics changes with changes in water content, that is, the soils have the capacity to swell significantly when moist and to shrink and crack when dry. This is important not only because it affects the physical conditions of the soil surface (large, deep cracks in dry seasons) but also because it is the resultant of a genetic process which is of considerable importance in soil classification. Soil scientists and engineers have realized the need for measuring actual and potential soil swelling. They use potential swelling measurements to characterize and classify soils and to predict their behavior for a diversity of agricultural and engineering uses.

This quality is quantified through the use of a Coefficient of Linear Extensibility (COLE) which is defined as follows (Grossman et al., 1968; SCS-USDA, 1972):

$$COLE = (Lm/Ld) - 1$$, where Lm = length of moist sample and Ld = length of dry sample

The coefficient is actually calculated from differences in bulk density of plastic-coated clods (Grossman et al, 1968; SCS-USDA, 1972):

$$COLE = \sqrt[3]{Dbd/dbm} - 1$$

where: Dbd = bulk density, dry and Dbm = bulk density, moist

Some uses made and inferences drawn from COLE data are:

1- If COLE exceeds 0.09, significant shrink-swell activity can be expected (SCS-USDA, 1972).

2- If COLE exceeds 0.03, a significant amount of montmorillonitic clay is present (Grossman et al., 1968).

Franzmeier and Ross (1968), in a study of soils in their natural state, found that COLE depends on the amount of clay, the nature of the clay minerals, and soil fabric, but not to an appreciable extent on the nature of the adsorbed cations. McNeal et al. (1966), related the swelling of extracted soil clays to salt concentration in the soil solution, and to the sodium-calcium ratio in this solution. Nayak and Christensen (1971) studied the swelling characteristics of compacted expansive soils and concluded that the swelling potential was a function of plasticity index, percent clay, and the initial moisture content. Saatchyan (1961) studied the swelling of compacted soils and agreed that it depended on the initial moisture content. He did not find it to be related to initial compactness.

COLE values have been reported for some Puerto Rican soils (SCS-USDA, 1967), but have not been related to any soil parameters. The purpose of this paper is to illustrate the range of COLE values obtained for four major soil orders found in Puerto Rico, i.e., Vertisols, Mollisols, Ultisols and Oxisols; and to attempt to relate swelling potential to soil parameters such as percent organic carbon, silt and clay.

METHODS

Bulk densities used to determine COLE values were calculated from the oven-dry soil weight of a saran-coated clod and its volume at 1/3-bar suction and at air dryness. Characterization determinations are discussed in Soil Survey Investigations Report No. 1 (1967) under the following index numbers: clay, 3A1; bulk density, 4A1; organic carbon, 6A1a; and linear extensibility, 4D1.

The soil parameters studied were percent organic carbon, clay and silt. The effects of the soil variables on COLE were evaluated statistically by considering the horizon samples individually without regard to their positions in soil profiles. Analyses of variance were calculated for the individual as well as for the combined soil parameters. Mean comparisons were made using least significant differences. Unless a different probability level is indicated, the 0.05 level was used to evaluate statistical significance of treatment effects and interactions in all analysis-of-variance procedures. Multiple regression analyses were determined for the combined soil parameters.

Soils Used

Soil samples were selected to represent four soil orders with a wide range in COLE values, soils and locations, and different minerals. The classification of the soil series is given in the following tabulation:

Soil Series	Great Group
Comerio Clay	Haplorthox
Coto Clay	Haplorthox
Daguey Clay	Tropohumult
Fe Clay	Chromustert
Fraternidad Clay	Chromustert
Humatas Clay	Tropohumult
Ingenio Clay Loam	Tropudult
Jacana Clay	Haplustoll
Mabi Clay	Chromudert
Nipe Clay	Acrorthox
Toa Clay Loam	Hapludoll
Toa Silty Clay Loam	Hapludoll
Series not designated	Haplustoll
Series not designated	Haplustoll
Series not designated	Chromustert

RESULTS AND DISCUSSION

The mean and standard deviation of the selected soil parameters are shown in Table 1. Significant differences ($p < 0.05$) between soil orders were found for the COLE values and silt and clay content. No significant differences were found for the organic carbon content. The highest COLE values were observed for the Vertisols, followed by Ultisols, Mollisols and Oxisols (Figure 1).

Partial results of regression analyses of the data on Table 1 are shown in Table 2. Except for Ultisols, correlations with percent clay were found to be highly significant. For Ultisols, on the other hand, COLE values were highly correlated with percent organic carbon. The silt fraction seems to make a negligible contribution to the shrink-swell potential of the soils, except in Vertisols where

Table 1. Mean, standard deviation (SD), and range of selected soil parameters for soil samples tested.

Soil Order	Soil Parameter	N	Mean	SD	Min.	Max.
Vertisol	COLE	17	0.125	0.032	0.060	0.160
	% O.C.	17	0.326	0.571	0.060	1.960
	% Silt	17	33.365	4.384	24.80	40.00
	% Clay	17	52.441	8.811	33.50	63.70
Mollisol	COLE	17	0.046	0.035	0.010	0.130
	% O.C.	17	1.131	0.716	0.070	2.690
	% Silt	17	42.112	10.793	25.40	54.10
	% Clay	17	33.824	13.298	8.00	68.80
Ultisol	COLE	17	0.074	0.171	0.010	0.730
	% O.C.	17	1.236	1.355	0.170	4.900
	% Silt	17	46.041	16.692	18.20	69.40
	% Clay	17	38.171	9.664	28.10	51.70
Oxisol	COLE	17	0.034	0.021	0.010	0.070
	% O.C.	17	1.517	1.531	0.160	6.040
	% Silt	17	18.241	10.180	5.300	36.30
	% Clay	17	69.571	9.180	54.50	81.90

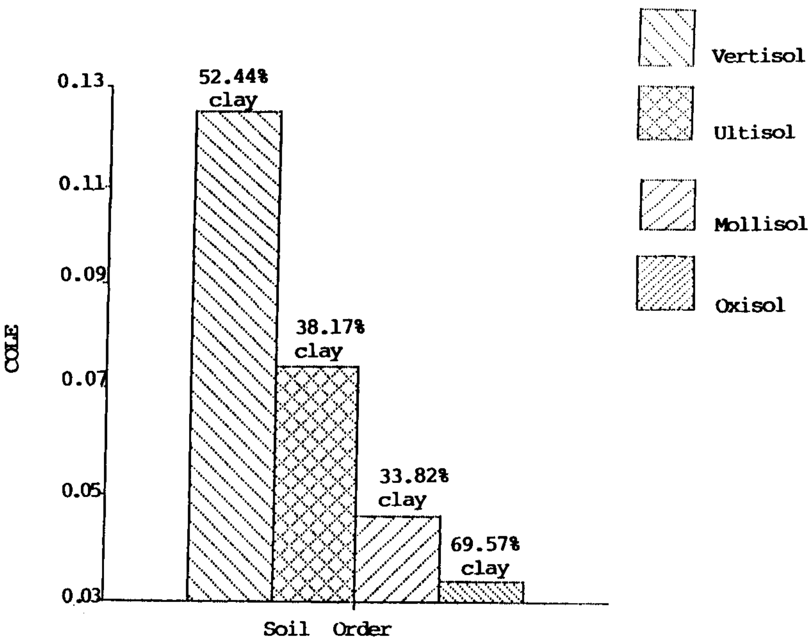

Figure 1. COLE values of selected soil orders from Puerto Rico.

Table 2. Correlation of COLE with other soil parameters.

Soil Order	Independent Variable	r	R^2
Vertisol	% Organic Carbon	-0.436	0.191 NS
	% Silt	-0.655	0.429 **
	% Clay	0.862	0.743 **
	% Org. Carbon, % Silt and % Clay		0.778 **
	% Org. Carbon, % Clay		0.101 NS
	% Silt, % Clay		0.041 NS
Mollisol	% Organic Carbon	0.335	0.112 *
	% Silt	-0.268	0.072 NS
	% Clay	0.798	0.637 **
	% Org. Carbon, % Silt and % Clay		0.306 NS
	% Org. Carbon, % Clay		0.297 NS
	% Silt, % Clay		0.016 NS
Ultisol	% Organic Carbon	0.715	0.511 **
	% Silt	0.320	0.102 NS
	% Clay	-0.248	0.066 NS
	% Org. Carbon, % Silt and % Clay		0.006 NS
	% Org.Carbon, % Clay		0.847 **
	% Silt, % Clay		0.627 **
Oxisol	% Organic Carbon	0.520	0.270 **
	% Silt	0.463	0.214 **
	% Clay	-0.693	0.480 **
	% Org. Carbon, % Silt and % Clay		0.848 **
	% Org. Carbon, % Clay		0.847 **
	% Silt, % Clay		0.627 **

* Significant at the 0.05 level; ** significant at the 0.01 level; NS Non-significant.

a significant correlation was observed. The fact that Vertisols are not highly weathered (Ahmad, 1983; Buol, Hole and McCracken, 1981) and that a considerable amount of expanding minerals could be found in the silt fraction of the soil, could explain this relationship.

To study the possibility of an interaction between the soil parameters and COLE values, multiple regression analyses were performed. The results are shown in Table 2. No significant interactions between the soil parameters studied and COLE values were observed for Vertisols, Mollisols and Ultisols; but for Oxisols a highly significant interaction between the percent organic carbon and clay was observed, accounting for 85% of the variability in COLE values.

The variabilty in the results could be attributable to differences in clay mineral components rather than to differences in clay content. Figure 1 shows that the soil orders with the highest clay content do not necessarily have the highest COLE values. Vertisols, as would be expected, had the highest COLE values; soils in this order have from considerable to moderate amounts of expanding clays such as montmorillonite and vermiculite (SCS-USDA, 1969; Ahmad, 1983; Buol, Hole and McCracken, 1981), which may account for the expanding properties of the soil (Franzmeier and Ross, 1968; Anderson et al., 1973). Oxisols have the highest clay content and the lowest COLE values (Figure 1 and Table 1). Major clay mineral components of Oxisols have been identified as kaolinite, iron oxides and hydroxyoxides, gibbsite, goethite and a small percentage of chlorite (SCS-USDA, 1969; Lugo-López et al., 1973; Jones, et al., 1982). These clay minerals have no expansive properties (Hsu, 1977; Miller, 1983), and are well known to help maintain the soil's structure (iron oxyhydroxides) through their cementing action, which can explain the low COLE values and the good soil structure that characterizes Oxisols.

Clay minerals in Ultisols have been identified (SCS-USDA, 1969; Jones et al., 1982) as kaolinite, chlorite, some gibbsite and mica and vermiculite with iron and aluminum interlayers. It is interesting that even though these minerals have no expanding properties, Ultisols showed the second highest COLE values. A high correlation between COLE and percent organic carbon could explain this behavior. It is possible that organic matter reduced the solubility of aluminum through complex formation resulting in less aluminum in the soil solution (Rich, 1968; Hsu, 1977; Wahab and Lugo-López, 1980). The less aluminum present, the less formation of Al-hydroxy interlayers and therefore the higher amounts of mica and/or vermiculite present, which could account, to a certain extent, for some of the soil's expanding properties.

Linear extensibility of the soils could not be completely explained by the soil parameters studied since there was a high degree of variability that could not be accounted for. An interaction between percent clay, silt, organic carbon, and probably other variables not included in this study, such as the nature of the clay minerals, rather than a direct correlation, should be considered as an alternative hypothesis to explain variability in the COLE values of these soils.

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