# Statistical Relationships among Selected Properties of Northern Cameroon Vertisols and Associated Alfisols

B. P. K. Yerima, L. P. Wilding,* C. T. Hallmark, and F. G. Calhoun

## ABSTRACT

Six Usterts and one Ustalf developed from lacustrine sediments and Precambrian schists in northern Cameroon were characterized for physical, chemical, and mineralogical properties. Correlative statistical relationships were established among physical and chemical properties including surface area (SAT), shrink-swell (COLE), cation exchange capacity (CEC), percent total clay (PCL), percent coarse clay (PCCL), percent fine clay (PFCL), water retention at 33 kPa (WAT), organic carbon (OC), calcium carbonate equivalent (CCE), pH, and exchangeable sodium percent (ESP). In general, upland soils, developed from Precambrian schists and sandstones, yielded lower correlation coefficients among these properties than lowland soils developed from Quaternary fluvial deposits. For the lowland soils, COLE was highly correlated with SAT, PCL, and WAT; simple coefficients of determination ($r^2$) were 0.91, 0.80, and 0.74, respectively. Similar correlations were obtained for COLE for upland soils, but neither CCE for these soils, nor ESP for either upland or lowland soils were significantly correlated with COLE. The CEC of soils studied was highly correlated with SAT and PCL; $r^2$ values ranged from 0.59 to 0.91. The SAT of Usterts in lowlands was very highly correlated with PCL, PFCL, PCCL, CEC, and COLE; these independent variables generally accounted for greater than 90% of the variance in SAT. For Usterts and Ustalfs of uplands, the SAT was not so closely correlated with these parameters, especially PFCL and PCCL, which varied in amount and clay mineralogy with depth. Multiple linear regressions did not generally improve predictive abilities for COLE, CEC, and SAT over simple linear relationships. Regression relationships developed constitute useful predictive indices for estimating engineering and agronomic properties from existing physical and chemical data and soil survey reports of northern Cameroon.

WHILE SOIL CHARACTERIZATION DATA provide useful information to explain agronomic and

B.P.K. Yerima, Soil Science Dep. Univ. Centre Dschang, B.P. 222, R. Cameroon, Africa; L.P. Wilding and C.T. Hallmark, Soil and Crop Sciences Dep., Texas A&M Univ. College Station, 77843; and F.G. Calhoun, Dep. of Agronomy, Ohio State Univ., Columbus, OH 43210. Joint contribution of the Texas Agric. Exp. Stn. Journal no. TA 24752 and US-AID under grant DAN-1311 to Texas A&M Univ. and Semiarid Tropics Soil Management CRSP. Contract no. 1311-G-SS-1083-00. Received 31 Oct. 1988. *Corresponding author.

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engineering behavior, their utility is enhanced if predictive models such as regression relationships can be developed from routine physical and chemical properties. Additionally, these predictive models help in the estimation of chemical and physical properties from current soil surveys at minimal costs and time inputs (Smith et al., 1985). The shrink-swell potential of soils measured as coefficient of linear extensibility (COLE) and CEC are important properties to agricultural and civil engineering specialists. Hence, the objective of this study was to derive statistical relationships among physical and chemical properties of Vertisols and an associated Alfisol in Cameroon, especially COLE, SAT, and CEC.

Physical, chemical, and mineralogical properties of Vertisols have been reported by several investigators (Kunze and Templin, 1956; Nelson et al., 1960; Kunze et al., 1963; Fadl, 1971; Ahmad and Jones, 1969a,b; Ahmad, 1983; Yerima et al., 1985, 1987). It is generally accepted that smectite is the dominant clay mineral although mixed layer clays, kaolinite (Dudal, 1965; Dixon, 1982) and intrastratified kaolinite/smectite (Yerima et al., 1985), have been reported. Correlation relationships among soil physical and chemical properties have been developed by Franzmeier and Ross (1968), Greene-Kelly(1974), McCormack and Wilding (1975), and Smith et al. (1985). Anderson et al. (1973) found a close correlation between COLE, percent clay, and ESP. Smith et al. (1985) found high correlations among liquid limit, specific surface area, CEC, percent clay, and hygroscopic moisture content. Similar correlations were also obtained for COLE and plastic limits with the above variables.

Wilding and Tessier (1988) outlined those mineral properties that control shrink-swell properties. Greene-Kelly (1974) observed that shrinkage is usually positively correlated with expansible mineral content, but found that soils with equal amounts of kaolinite and montmorillonite were similar to those with montmorillonite alone. Observations on El Salvador Vertisols (Yerima et al., 1985, 1987) indicated that kaolinite-rich, fine-clay systems have similar physical behavior to smectitic ones because of their large surface area. The dependency of COLE on type and amount of clay also has been recognized by Franzmeier and Ross (1968). They observed the highest COLE values in soils with high clay contents dominantly of the smectite type. This is consistent with Smith et al. (1985), who observed that montmorillonitic soils with moderately high clay contents had moderate COLEs, while sandy and saline soils had the lowest COLEs.

Cation exchange capacity, an important parameter for predicting fertility behavior, has been correlated with organic matter, fine- and coarse-clay contents, and SAT among soils occurring in toposequences (Wilding and Rutledge, 1966; McCormack and Wilding, 1975).

## MATERIALS AND METHODS

Detailed information on site locations, soil classification, and data sets used in this study have been presented elsewhere (Yerima, 1986). To control mineralogical variability among soils included in this work, the observations were stratified by soil series (landform) and by horizonation. Three Pellusterts and one Chromustert were sampled in a Quaternary lacustrine plain of northern Cameroon and constitute the lowland soils. These soils have developed on nearly level, seasonally flooded, constructional land surfaces of the Chad basin. Parent deposits are comprised of clayey sediments (approximately 1 m thick) overlying loamy and sandy substratum. Upland soils consist of two Pellusterts and one Haplustalf. These soils occupy gently undulating, bedrock-controlled, convex, erosional land surfaces south of the Chad basin in northern Cameroon. Relief is low and slope gradients are commonly 1 to 2%. Bedrock parent materials of upland Vertisols are Precambrian basic metamorphics, with schists predominating. Alfisols in the same region have developed from Precambrian intrusive granites.

Bulk soil samples were air dried and passed between wooden rollers to crush soil aggregates; coarse fragments larger than 2 mm were removed by dry sieving. Particle-size distribution, CEC, extractable bases, soluble salts, $CaCO_3$ equivalent, and pH were determined on the fine-earth fraction by standard procedures (Soil Conservation Service, 1984, as detailed in Yerima, 1986). Organic C was determined as the difference between total C by dry combustion (Nelson and Sommers, 1982) and inorganic C by the Chittick method (Dreimanis, 1962). Saran-coated undisturbed clods (Brasher et al., 1966) were used for bulk-density determination at 33 kPa and air-dry water contents. The determination of COLE from Saran-coated clods utilized the equation of Grossman et al. (1968). Total surface area was determined by the ethylene glycol monoethyl ether adsorption method of Carter et al. (1965). External surface area was determined by the N adsorption BET method described by Brunauer et al. (1938), using a three-point method with premixed gases. The 33-kPa and 1500-kPa water contents were determined on the <2-mm sieved soil samples following Richards (1965). Clay mineralogical studies were determined by the method of Brewer (1976), and Jackson (1956) except sesquioxides. Organic matter and carbonates were not removed.

The relationships among physical and chemical parameters were investigated using correlation and regression analyses (SAS Institute, 1982). Parameters tested and fitted to regression models were based on prior established general relationships among variables. To determine the fit of the model, plots of the dependent vs. the independent variables were made. A linear or curvilinear model was used based on visual observation of the shape of the relationship. Residuals of the resulting regression equations were plotted against the predicted values of the dependent variable. Absence of any trends and random distribution of the residuals about zero were taken to signify aptness of the selected model. A modified $R^2a$ (adjusted coefficient of multiple determination; Neter and Wasserman, 1974), which considers the number of independent variables in the model, was used for multiple regression relationships.

## RESULTS AND DISCUSSION

Ranges in properties of the soils used to develop the regression relationships are given in Table 1. Correlation coefficients for both the upland and lowland soils are given in Table 2. These soils have high clay contents (generally >35%), high external and total surface areas, but generally low organic C and ESPs. The COLE values are comparable to Vertisols of El Salvador (Yerima et al., 1987), Texas (Hallmark et al., 1986) the Sudan, Arizona, and New Mexico (Anderson et al., 1973).

X-ray diffraction studies indicate that the fine clay of the lowlands is dominated by well-crystallized

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smectite or mixed smectite/kaolinite, a relationship essentially constant with depth. The coarse-clay fraction is similar to the fine clay except kaolinite is the dominant phase; additionally, mica and vermiculite occur.

In the uplands, the fine clay exhibits similar mineralogy. However, coarse clay is higher in chlorite, vermiculite, and hydrobiotite and these constituents increase with depth. Also, ratios of coarse to fine clays vary with depth. Because of the difference in the amount, type, and distribution of clay minerals with depth, the upland and lowland soils were considered separately in correlation and regression analyses. Such a procedure was expected to provide better predictive models and would represent the appropriate manner in which these models should be applied to soils on these two geomorphic surfaces.

Linear regression relations between COLE and soil physical and chemical properties for the lowland soils (Table 3) indicated that COLE is highly correlated with SAT, percent total clay (PCL), percent fine clay (PFCL), water retention, and CEC. From the $r^2$ of the equations, COLE vs. SAT, PCL, PFCL, 33-kPa water (WAT), and CEC accounted for 91, 80, 76, 74, and 68% of the total variance of COLE, respectively. The relationships between COLE vs. PCL (Fig. 1a) and COLE vs. SAT (Fig. 1d) appear linear as indicated by plots; the aptness of fit of the regression models was indicated by the plots of residuals vs. the predicted values for these soils (data not shown). In lowland soils, COLE was more highly correlated with PFCL than with coarse clay (PCCL) (Table 2, 3, Fig. 1b,c). This is probably due to the higher amounts of smectite in the fine-clay fraction. These high correlation coefficients indicate two aspects: (i) the similarity in mineralogy suite (smectite and kaolinite) of these soils among all the lowland soils; and (ii) the strong dependence of shrink-swell properties on the fine-clay content, which is also closely allied with SAT.

Linear regression relationships between COLE and soil properties for the upland soils are provided in Table 3. The correlations between COLE vs. independent soil variables are generally lower than those observed for their lowland counterparts (Table 2, 3). The lower correlation of COLE with the soil properties of the uplands is due in part to the changing clay mineral suite with depth in these soils (i.e., the clay mineralogy was not constant among horizons). Also, COLE may not be as closely correlated with soil properties of the upland soils due to the presence of carbonates in variable amounts within the profiles. This is consistent with observations that soils containing $CaCO_3$ demonstrate less shrinkage (Davidson and Page, 1956; Smith et al., 1985). In summary, soils with high clay content and mixed mineralogy (lowland soils) generally had the highest COLE values while upland soils with generally lower clay contents and smectite (or mixed) mineralogy had moderate COLE values (Yerima, 1986).

Regression equations for the lowland soils relating CEC to select physical and chemical properties of northern Cameroon soils (Table 3) indicate that the relationships between CEC vs. SAT and CEC vs. PCL account for 93 and 91% of the variance, respectively.

**Table 1. Ranges in soil properties used to develop the regression models.**

| Properties (units) | Upland soils | Lowland soils |
|---|---|---|
| pH, 1:1 in water | 6.0–8.3 | 5.6–8.1 |
| Organic carbon, % | 0.1–1.3 | 0.1–1.0 |
| Calcium carbonate equivalent % | 0.1–19.5 | NC† |
| Total clay, % | 8.4–53.5 | 19.5–70.3 |
| Coarse clay, % | 4.4–42.3 | 6.7–33.3 |
| Fine clay, % | 2.5–30.0 | 12.2–43.4 |
| Cation exchange capacity, cmol $NH_4^+$/kg | 11.0–38.1 | 11.3–43.9 |
| Exchangeable sodium percent, % | 1.0–28.0 | 1.0–32.0 |
| Total surface area, $m^2$/g | 31.0–278 | 79.0–260 |
| External surface area, $m^2$/g‡ | 5.0–66.0 | 48.0–81.0 |
| Coefficient of linear extensibility, cm/cm | 0.015–0.126 | 0.032–0.152 |
| Water content at 33 kPa, g $H_2O$/100 g soil | 15.6–30.4 | 20.6–50.4 |

† NC = noncalcareous.
‡ Surface horizons only.

**Table 2. Simple correlation coefficient (*r*) matrix among selected properties of soils in Cameroon.**

| Variable (*n*)† | PCL | PCCL | PFCL | CEC | SAT | WAT | OC | ESP | CCE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Lowland Soils | | | | | |
| COLE (22) | 0.894** | 0.818** | 0.869** | 0.824** | 0.954** | 0.861** | 0.532* | −0.350 | |
| PCL (22) | | 0.932** | 0.958** | 0.955** | 0.997** | 0.723** | 0.637** | −0.615** | |
| PCCL (22) | | | 0.790** | 0.880** | 0.945** | 0.720** | 0.658** | −0.434* | |
| PFCL (22) | | | | 0.923** | 0.983** | 0.656** | 0.558** | −0.699** | |
| CEC (22) | | | | | 0.964** | 0.696** | 0.630** | −0.667** | |
| SAT (10) | | | | | | 0.762* | 0.576 | −0.725* | |
| WAT (22) | | | | | | | 0.534 | −0.151 | |
| OC (22) | | | | | | | | −0.335 | |
| | | | | Upland soils | | | | | |
| Variable (*n*)† | PCL | PCCL | PFCL | CEC | SAT | WAT | OC | ESP | CCE |
| COLE (18) | 0.877** | 0.719* | 0.722** | 0.811** | 0.890** | 0.776** | 0.508* | 0.127 | 0.097 |
| PCL (18) | | 0.808* | 0.817** | 0.770** | 0.930** | 0.532* | 0.613** | −0.125 | −0.158 |
| PCCL (18) | | | 0.330 | 0.706** | 0.778* | 0.664** | 0.656** | −0.074 | −0.376 |
| PFCL (18) | | | | 0.564* | 0.630 | 0.238 | 0.345 | −0.117 | 0.061 |
| CEC (18) | | | | | 0.982** | 0.649** | 0.645** | −0.365 | 0.032 |
| SAT (9) | | | | | | 0.414 | 0.684* | −0.446 | 0.548 |
| WAT (18) | | | | | | | 0.459 | 0.231 | −0.282 |
| OC (18) | | | | | | | | −0.382 | −0.282 |
| ESP (18) | | | | | | | 0.016 | | |

*,**Significant at 0.05 and 0.01 levels, respectively.
† COLE = coefficient of linear extensibility, PCL = percent total clay, PCCL = percent coarse clay, PFCL = percent fine clay, CEC = cation exchange capacity, SAT = total surface area, WAT = water content at 33 kPa, OC = organic carbon, ESP = exchangeable sodium percent, CCE = percent calcium carbonate.

These constitute the best models for CEC and the relationships are linear as indicated in Fig. 2a and 2d. Generally there was poorer correlation of CEC with the physicochemical properties of upland soils than with those of lowlands; this reflects the variable mineralogy as a depth function and confounding aspects of variable carbonate contents with depth. Coarse clay was more highly correlated with CEC than was fine-clay content. This is consistent with the higher vermiculite content of the coarse-clay fraction of the upland soils as compared with its lower vermiculite content in the fine-clay fraction.

Regression relationships between SAT and selected physical and chemical properties for the lowlands are presented in Table 3, 4, and Fig. 2d and e. When SAT was regressed against PCL and CEC as independent simple variables, 99% and 93% of the variance, respectively, could be explained. The SAT was more highly correlated with PFCL than with PCCL in lowland Vertisols. This is consistent with the mineralogy of the fine-clay fraction of the lowland soils, which is higher in smectite than coarser-clay fractions. In the upland soils, SAT was highly correlated with CEC and PCL (Table 3) and these variables account for 96 and 86% of the variability in SAT. Poorer correlations were observed between SAT and other soil properties in uplands than lowlands. The SAT appeared more highly correlated with PCCL than with PFCL in the upland soils. This is incongruous because the fine clay is smectitic and present in larger amounts than is the coarse clay. Smectites would be expected to have a higher surface area than vermiculites and kaolinites which are codominant in coarse-clay fractions.

With the exception of COLE for lowland Vertisols, no improvement in predictive inferences of COLE, CEC, and SAT was obtained in developing multiple regression models by introducing PCL, PCCL, and PFCL as independent variables (Table 4). The same was true when CEC, organic C, and WAT were introduced as independent variables (data not shown). For the lowland soils, the best multiple relationship of COLE was as a function of PCL and SAT (Table 4).

**Table 3. Regression relationships between coefficient of linear extensibility (COLE), cation exchange capacity (CEC), and total surface area (SAT) and selected independent soil properties for the lowland and upland soils.**

| Dependent variable | Intercept | Slope | Variable† | $n$‡ | $r^2$ |
|---|---|---|---|---|---|
| | | Lowland soils | | | |
| COLE | 0.0024 | 0.0020 | PCL | 22 | 0.80** |
| | −0.0005 | 0.0032 | PFCL | 22 | 0.76** |
| | 0.027 | 0.0038 | PCCL | 22 | 0.67** |
| | 0.0065 | 0.0032 | CEC | 22 | 0.68** |
| | −0.048 | 0.00045 | WAT | 22 | 0.74** |
| | 0.0027 | 0.0005 | SAT | 10 | 0.91** |
| CEC | 2.21 | 0.524 | PCL | 22 | 0.91** |
| | 1.57 | 0.859 | PFCL | 22 | 0.85** |
| | 8.87 | 1.04 | PCCL | 22 | 0.77** |
| SAT | −2.33 | 3.81 | PCL | 10 | 0.99** |
| | 0.622 | 6.0 | PFCL | 10 | 0.97** |
| | 18.7 | 9.01 | PCCL | 10 | 0.89** |
| | −15.1 | 6 93 | CEC | 10 | 0.93** |
| | 11.0 | 18.30 | COLE | 10 | 0.91** |
| | | Upland soils | | | |
| COLE | −0.0065 | 0.002 | PCL | 18 | 0.77** |
| | 0.018 | 0.0026 | PFCL | 18 | 0.52** |
| | 0.018 | 0.0026 | PCCL | 18 | 0.52** |
| | 0.0021 | 0.0021 | CEC | 18 | 0.66** |
| | −0.054 | 0.0049 | WAT | 18 | 0.60** |
| | 0.0034 | 0.0004 | SAT | 8 | 0.79** |
| CEC | 1.45 | 0.678 | PCL | 18 | 0.59** |
| | 11.55 | 0.776 | PFCL | 18 | 0.32* |
| | 8.01 | 0.998 | PCCL | 18 | 0.50** |
| SAT | 15.8 | 4.61 | PCL | 8 | 0.86** |
| | 108.1 | 4.78 | PFCL | 8 | 0.40 |
| | 68 0 | 5.77 | PCCL | 8 | 0.61* |
| | −2.86 | 6.54 | CEC | 8 | 0.96** |
| | 31.5 | 2204 | COLE | 8 | 0.79** |

*,** Significant at the 0.05 and 0.01 levels, respectively.
† PCL = percent total clay, PFCL = percent fine clay, PCCL = percent coarse clay, WAT = 33-kPa water content.
‡ $n$ = number of observations.

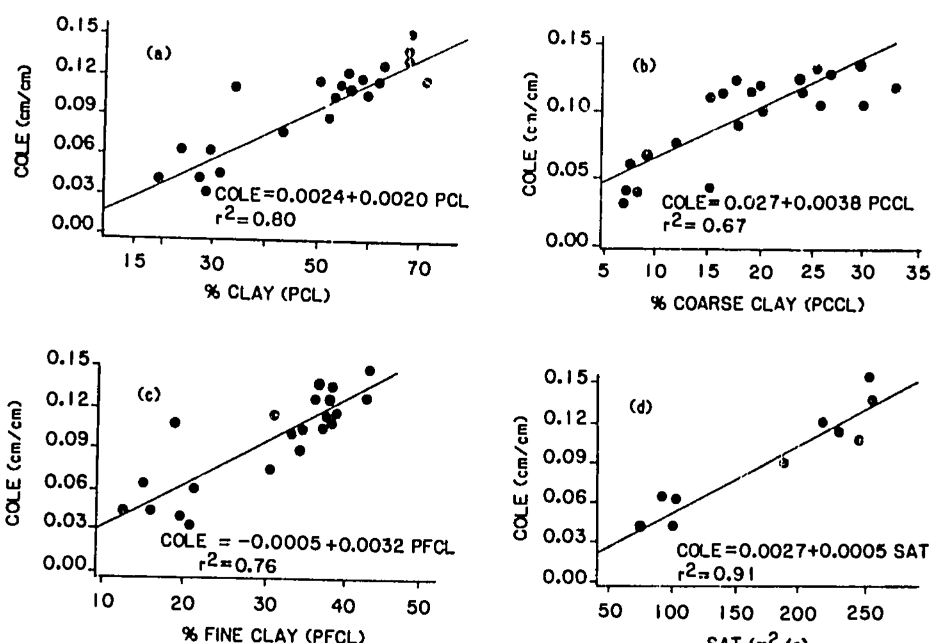


Fig. 1. Relationship in the lowland soils of the shrink-swell potential of soils, measured as the coefficient of linear extensibility (COLE) with (a) percent clay, (b) percent coarse clay, (c) percent fine clay, and (d) total surface area (SAT).

Table 4. Multiple linear regression relationships between coefficient of linear extensibility (COLE), cation exchange capacity (CEC), and total surface area (SAT) and selected independent soil properties for the lowland and upland soils.

| Dependent variable | Intercept ($X1$) | Slope ($X1$) | Variable † ($X2$) | Slope ($X2$) | Variable† | $n$‡ | $R^2$a |
|---|---|---|---|---|---|---|---|
| | | | Lowland soils | | | | |
| COLE | 0.0065 | −0.0045 | PCL | 0.0017 | SAT | 10 | 0.92** |
| CEC | 1.93 | 0.474 | PCCL | 0.563 | PFCL | 22 | 0.90** |
| SAT | −2.97 | 3.36 | PCCL | 0.411 | PFCL | 10 | 0.99** |
| | | | Upland soils | | | | |
| COLE | 0.0045 | −0.0005 | PCL | 0.005 | SAT | 8 | 0.72** |
| CEC | 1.70 | 0.824 | PCCL | 0.511 | PFCL | 18 | 0.57* |
| SAT | 14.2 | 5.19 | PCCL | 3.98 | PFCL | 8 | 0.82** |

*,** Significant at the 0.05 and 0.01 levels, respectively.
† PCL = percent total clay, PFCL = percent fine clay, PCCL = percent coarse clay.
‡ $n$ = number of observations.

This accounted for 92% of the total variance in COLE contrasted with 80% when COLE was a simple function of PCL (Table 3). However, predictions of CEC and SAT were not improved by multiple regression models over the best simple regression relationship (Table 3 and 4).

It is interesting to note that neither $CaCO_3$ (CCE) nor ESP apparently is significantly correlated with COLE in these soils (Table 2). Carbonates were restricted to upland soils and were generally in small quantities except for two horizons with values ranging from 9 to 19%. The ESPs and SARs (sodium adsorption ratios) of these soils, especially upland counterparts, have increasing values with depth and maxima just above or in restrictive layers (sandstone and saprolitic zones). In most horizons where ESPs and SARs are above 10, shrink-swell is restricted by higher electrolyte concentrations (ECs of 2–4 dS/m) or by higher sand and silt contents (sandy loams, silt loams, loams, and clay loams), which interlock the fabric and reduce shrink-swell (Wilding and Tessier, 1988).

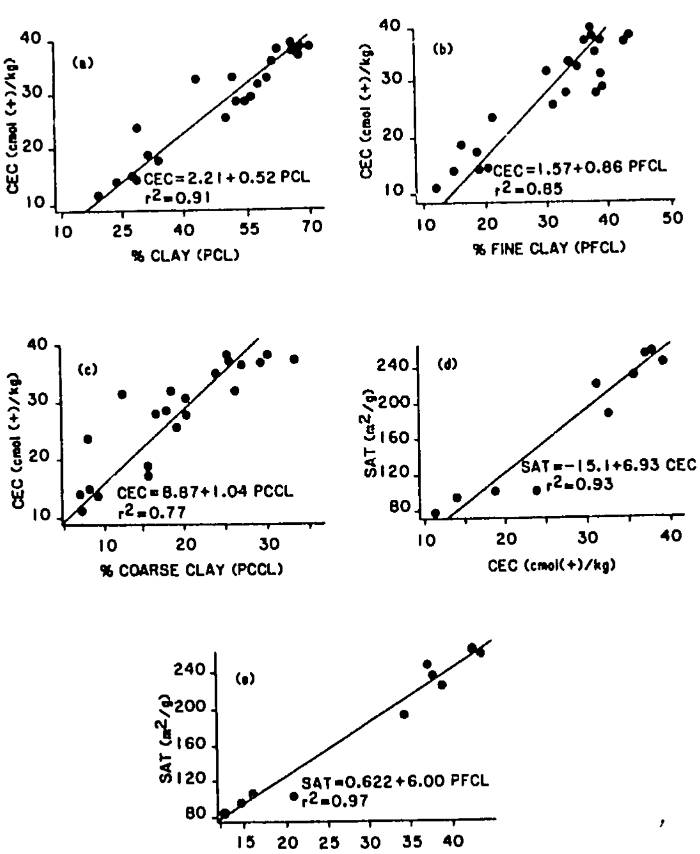


Fig. 2. Relationship in the lowland soils of (a) cation exchange capacity (CEC) with percent clay, (b) CEC with percent fine clay, (c) CEC with percent coarse clay (d) total surface area (SAT) with CEC, and (e) SAT with percent fine clay.

## SUMMARY

In summary, this study represents statistical relationships among selected physical and chemical properties of northern Cameroon Vertisols and associated Alfisols. The data base is limited but, in spite of this fact, the following concluding statements are in order:

1. The COLE, SAT, and CEC can be relatively accurately predicted from PCL, especially for the lowland Vertisol members. Better correlation relationships with lowland soils are attributed to their more-constant clay mineral suite with depth, while in uplands a systematic change in mineral suite occurred with depth above saprolitic zones. This raises a precautionary measure in indiscriminate application of the predictive models developed for soil systems without consideration of mineralogical changes among soils of different physiographic position.
2. Simple linear regression models for COLE, CEC, and SAT were generally equal to or better than multiple linear regression models. Simple linear models can be developed easily and rapidly by hand calculators and do not require sophisticated computer facilities. This is an important consideration in many developing countries such as Cameroon.
3. Development of predictive models illustrated in this paper provides a useful means to estimate engineering and agronomic properties of soils from existing and often sparse physical and chemical data. This represents maximum extension and technology transfer for established characterization data bases in developing countries.

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