Use of Correlation Relationships to Enhance Understanding of Pedogenic Processes and Use Potential of Vertisols and Vertic Inceptisols of the Bale Mountain Area of Ethiopia

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Summary

Five Vertisols and two Vertic Inceptisols developed from basalt and alluvial materials were characterized for physical and chemical properties. Correlative statistical relationships were established among physical and chemical properties including cation exchange capacity (CEC), percent total clay, electrical conductivity (EC), base saturation % (BS), pH-H_2O, pH-KCl, $CaCO_3$ equivalent, organic carbon (OC), total nitrogen (TN), P-Bray and P-Olsen. Correlative relationships were established among parameters for all horizons of the soils studied as well as among parameters within individual horizons. P-Olsen was highly correlated with OC and TN; simple coefficients of determination (r^2) were 0.81 and 0.69, respectively. $CaCO_3$ was highly correlated with pH-H_2O and pH-KCl; r^2 values were 0.68 and 0.60, respectively. Similar correlations were obtained for pH-KCl vs pH-H_2O and pH-KCl vs EC, with r^2 values of 0.92 and 0.70, respectively. Total nitrogen was also very highly correlated with OC (r^2= 0.88). Base saturation was highly correlated with pH-KCl and pH-H_2O giving r^2 values of 0.62 and 0.64, respectively. When correlative relationships were carried out among parameters within individual horizons very high correlation coefficients were obtained for OC vs TN (r= 0.98 - 1.00), OC vs P-Olsen (r= 0.96 - 0.99), BS vs pH-KCl (r= 0.82 - 1.00), BS vs pH-H_2O (r= 0.86 - 1.00). Most of the simple correlation coefficients obtained for EC with pH-KCl and pH-H_2O were > 0.81. High correlation coefficients (0.80 - 1.00) were obtained for % clay vs total CEC for most soils studied. Regression relationships developed constitute useful predictive indices for estimating agronomic properties from existing physical and chemical data and soil survey reports of the Bale Mountain area of Ethiopia. This study has demonstrated that statistical correlation can be used to cross-check the quality of analytical data both among horizons of different soil profiles and within individual soil profiles from prior established relationships.

Résumé

Utilisation des corrélations statistiques pour améliorée la compréhension des processus pédogénétiques et l'utilisation potentielle des vertisols et inceptisols de la région montagneuse de Bale en Ethiopie

Cinq vertisols et deux inceptisols vertiques formés sur basalte et sur alluvions ont été caractérisés physiquement et chimiquement. Des relations de corrélation ont été établies entre les propriétés physiques et chimiques du sol comprenant: la capacité d'échange cationique (CEC), le pourcentage d'argile, la conductivité électrique (CE), la saturation en bases % (SB), le pH-H_2O, le pH-KCl, l'équivalent en $CaCO_3$, le carbone organique (C.O), l'azote total (NT), le phosphore assimilable (Bray et Olsen). Les corrélations ont été établies entre les paramètres de tous les horizons des sols étudiés tout comme entre les paramètres du même horizon. Le phosphore Olsen était fortement corrélé au CO et à NT, les coefficients de détermination (r^2) étaient de 0,81 et 0,69 respectivement. Le $CaCO_3$ était fortement corrélé au pH-H_2O et pH-KCl, les valeurs de r^2 étaient de 0,68 et 0,60 respectivement. Des corrélations similaires ont été obtenues pour le pH-KCl et le pH-H_2O puis pour le pH-KCl et la CE, avec des valeurs de r^2 de 0,92 et 0,70 respectivement. L'azote total était aussi très fortement corrélé au CO (r^2= 0,88). La saturation en bases était fortement corrélée aux pH-KCl et pH-H_2O avec des valeurs de r^2 de 0,62 et 0,64 respectivement. L'établissement des relations de corrélations entre les paramètres du même horizon a permis d'observer de très forts coefficients de corrélation pour le CO et le NT (r= 0,98 - 1,00), le CO et le P-Olsen (r = 0,96 - 0,99), la SB et le pH-KCl (r= 0,82 - 1,00), la SB et le pH-H_2O (r= 0,86- 1,00). La plupart des coefficients de corrélation obtenus pour la CE et le pH-KCl puis le pH-H_2O étaient > 0,81. Des coefficients de corrélation élevés (0,80 - 1,00) ont été obtenus pour le pourcentage d'argile et la CEC pour la plupart des sols étudiés. Les régressions obtenues constituent d'utiles indices permettant l'estimation des qualités agronomiques des sols à partir de leurs caractéristiques physiques et chimiques existants issues d'une prospection pédologique des sols de la montagne de Bale (Ethiopie). Cette étude a

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démontré que les corrélations peuvent être utilisées pour vérifier les qualités de données analytiques à la fois entre les horizons de différents profils du sol et même des profils individuels à partir des relations pré-établies.

Introduction

In Ethiopia, Vertisols cover 12.6 million ha, or about 10.3% of the country (4). In addition, there are 2.5 million ha of soils with vertic properties. Vertisols are important to Ethiopian agriculture. Vertisols are naturally fertile soils, but poor physical properties and limited resources of small farmers limit their cultivation (20, 23, 25).

Rainfed crops such as teff (*Eragrostis tef*), wheat (*Triticum spp.),* barley (*Hordeum vulgare*), chickpea (*Cicer arietinum*), Faba bean (*Vicia faba*), lentils (*Lens culinaris*), linseed (*Linum usitatissimum*) are generally grown on these Vertisols. Most of the Vertisols in the highlands are traditionally planted late in the rainy season allowing only partial use of the potential growing period (3). In the lowlands, irrigated crops such as cotton, sugarcane, citrus, and some vegetables are grown on these soils. Water-logging limits the cultivation of bottomlands Vertisols to mainly dry-season grazing.

The Bale mountain area where Vertisols constitute a large soil resource is rapidly undergoing degradation associated with high population pressure and the need for increased production of food and fuel to meet the increasing demand. A more sustainable use of land will require a good knowledge of the soil characteristics for more judicious agronomic and engineering management. Predictive models developed from physical and chemical soil properties enhance the understanding of a soil system. The available P, organic matter content, total nitrogen, cation exchange capacity, pH and electrical conductivity of soils are important parameters to agricultural specialists.

Physical and chemical properties of Vertisols have been reported by several investigators (1, 2, 13, 14, 22, 24). It is generally accepted that smectite is the dominant clay mineral although mixed layer clays, kaolinite (5), interstratified kaolinite/smectite (22), and chlorite, palygorskite, illite and minor amounts of smectite (12) have been reported. Correlations among soil properties have been developed by many investigators (8, 10, 25). CEC, an important parameter for predicting fertility behavior, has been correlated with organic matter (OM), and fine and coarse-clay contents among soils occurring in toposequences (25).

Despite the considerable amount of work carried out in the temperate region, a paucity of information exists for similar studies on soils in the tropical region where fewer functional laboratories exist (25). Moreover, the interrelationships that exist among soil physico-chemical properties can be used to evaluate the reliability and consistency of soil analytical data through statistical means. Unfortunately, little information exists for the use of such an approach.

The objectives of this study were to derive statistical relationships among physical and chemical properties of some Ethiopian Vertic Inceptisols and Vertisols especially total nitrogen, OC, CEC, base saturation,

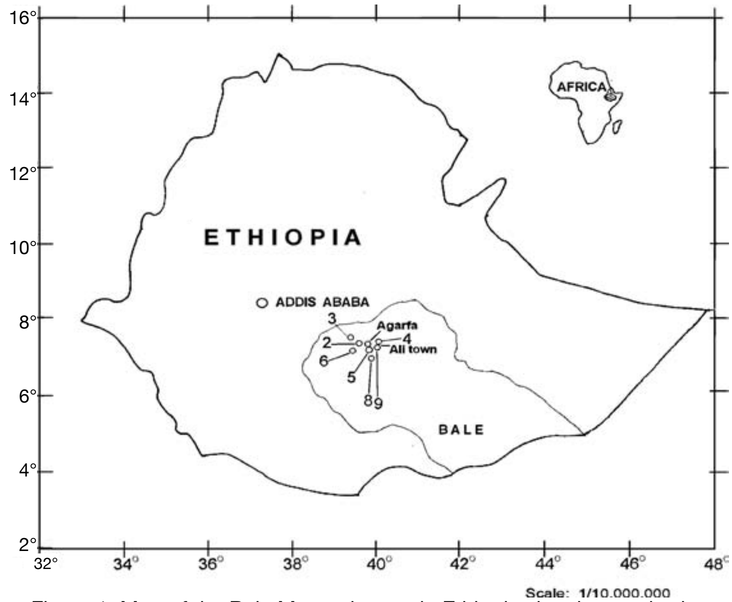

Figure 1: Map of the Bale Mountain area in Ethiopia showing study sites.

available P, $CaCO_3$, electrical conductivity and pH in order to evaluate or correct nutrient imbalances and also evaluate soil laboratory data quality.

Materials and methods

Soil samples for the study were collected from Vertic Haplustepts, and Haplusterts, which occupy undulating mountain foot slopes and flat plains and inter-mountain areas in the Bale Mountain area of Ethiopia (Figure 1). These soils have developed from basalt, alluvial, and colluvial material on 0-10% slopes under an ustic soil moisture regime (mean annual precipitation of 800-1200 mm) and a mesic soil temperature regime (mean annual soil temperatures approximately 8-14 °C). The native vegetation on the mountain slopes and plains are dominantly Juniperus woodland savanna; in the lowland along river banks various types of acasia and *Faidherbia albida* trees species abound. The dominant grass species are *Andropogon* sp., *Sporobolus* sp., and *Hyparrhenia* sp. Pedons were described using standard terminology (7, 16).

Air-dried bulk samples were crushed to pass through a 2 mm sieve; coarse fragments larger than 2 mm were removed by dry sieving. Particle-size distribution, CEC, exchangeable bases, EC, $CaCO_3$ percent, and pH were determined on the fine earth fraction by standard procedures (15). Organic carbon was determined by the wet oxidation potassium dichromate method of Walkley and Black. Total N was determined by the Kjeldahl method. Available P was determined both by the Bray and Kurtz and the 0.5 M $NaHCO_3$ Olsen methods.

Relationships among soil properties were investigated using correlation and regression analyses (9). Parameters tested and fitted to regression models were based on prior established general relationships among variables. Plots of the independent vs the dependent variables were used to determine the fit of the models (18). A linear model was used based on visual observation of the shape of the relationship. Statistical analysis was done using Microstat (6).

Results and discussion

1. Morphological properties

Munsel color values of surface horizons of these Vertisols and Vertic Inceptisols are generally around 3.1 - 3.2 qualifying them as chromic Vertisols and Vertic Inceptisols, but these values increase with depth to about 4.1 to 4.4 in the lower sola. Marked differences in color exist as a function of topographic position and drainage. The soil structure of surface horizons is dominantly angular blocky parting to fine angular blocky; coarse granular structure exists in places. Well-developed angular blocky structures and slickensides are observed in the lower sola of the Vertisols. The morphological properties of these soils are very similar to those of the Vertisols of the temperate regions (13, 14). Gilgai micro-relief reported for Vertisols in ustic moisture regimes elsewhere (11) were very poorly expressed in these soils and has been explained by both fewer and longer wet/dry cycles typical of ustic soil moisture regimes in tropical areas –"tropustic" (19, 24). The vertic Inceptisols demonstrated surficial cracking and minimal development of slickensides which do not meet the Vertisol criteria.

2. Physical and chemical properties

The studies were done on 7 profiles, but only physical and chemical properties of representative profiles are presented (Table 1). Clay contents of these soils are usually high and range from a low value of 42% in the Ap horizon of the Ali Town 1 Haplustert to a high of 86% in the Bw horizon of the Ali 2 Michael profile, with lowest values observed in surface horizons.
The A horizons of these soils have dark colors attributed to high organic matter (OM) contents (Table 1) which gradually decrease with depth. Total nitrogen is strongly associated with OM contents and decreases with depth. Similar observations have been made for Vertisols in El Salvador, North Cameroon, and India (20, 24). Available P is generally closely tied to the organic carbon content. Available P values are low and decrease with depth. The pH (2:5 soil: water) of these soils ranged from very acid (5.15) to alkaline (8.27). Calcium and magnesium dominate the exchange complex of these soils and the CEC values are generally high and range from 29.6 - 59.1 cmol (+)/kg of soil. The CEC clay of these soils ranged from 49 - 128 *cmol (+)/k*g, indicating the presence of weatherable 2:1 clay minerals. The clay contents were 56, 47, 48 and 55% for the Ap, AB, Bk and BCk horizons of the Ali Vertic Haplusterts, respectively giving corresponding CECs of 73, 128, 118, and 100 cmol (+)/kg clay.

Though the clay mineralogy was not determined, the CEC/100 g clay range from 49 - 128 cmol (+)/kg indicates a varying mineralogical suite probably dominated by 2:1 clay minerals of the smectitic or vermiculitic group. This is confirmed optically by the presence of mica in the silt and fine sand fractions. Also, the high exchangeable K contents of 0.76 - 3.99 cmol (+)/kg indicates the presence of micaceous minerals. Mica is a precursor to vermiculite.

Generally, these soils have low organic matter and total nitrogen, are near neutral to alkaline with high CEC and exchangeable bases, with Ca being the dominant cation.

3. Regression and correlation analysis

The ranges in properties of the soils used to develop the regression relationships and correlation coefficients for these soils are given in tables 2 and 3, respectively.

Table 1
Physical and Chemical Properties of Representative Profiles of Vertisols and Vertic Inceptisols of the Bale Mountain Area of Ethiopia

Horizon	Depth	Clay	OC	N	CEC		Exchangeable cations				BS	Ca-CO$_3$	EC	pH 2:5		Available P	
	(cm)	< 2 µ			Clay	Total Soil	Na^+	K^+	Ca^{++}	Mg^{++}				KCl	H_2O	Bray	Olsen
		------------%-----------			--------------------- cmol (+)/kg----------------------						---------%------		mS/cm			-------ppm------	
				Site 4 Ali town 1 vertic haplusterts													
Ap	0-30	56	2.04	0.154	73	55.78	0.76	2.74	35.42	6.24	81	2.3	0.28	4.96	6.48	14.38	2.84
AB	30-75	47	0.84	0.098	128	63.90	1.21	2.35	41.52	5.49	79	3.4	0.41	5.60	6.95	2.90	0.94
Bk	75-100	48	0.72	0.091	118	59.07	2.16	1.63	44.26	5.15	90	3.8	0.65	6.36	8.27	3.84	0.79
BCk	100-155	55	0.34	0.059	100	56.54	2.14	1.45	45.97	6.38	100	4.2	0.75	6.43	8.24	8.10	0.84
				Site 5 Ali 2 Michael haplusterts													
Ap	0-34	45	2.20	0.186	49	29.64	0.69	2.20	13.51	3.85	68	0	0.19	4.36	5.88	1.03	1.99
Bw	34-95	86	0.74	0.085	63	56.58	1.14	3.99	25.02	8.65	69	0	0.33	4.68	6.25	0.67	1.14
Bk	95-170	85	0.42	0.051	60	52.77	1.71	1.71	28.92	9.32	79	5.9	0.36	5.43	7.26	0.86	0.72
				Site 6 Agarfa haplusterts													
Ap	0-25	45	2.23	0.250	64	36.3	0.62	2.88	14.78	4.35	62	0	0.23	4.42	5.97	3.43	2.41
B1	25-50	70	1.16	0.117	67	50.6	1.22	3.98	26.14	7.74	77	0	0.29	4.52	6.14	0.99	0.81
Bk1	50-86	83	0.78	0.093	63	55.3	1.82	3.92	27.99	9.07	77	3.8	0.42	4.92	6.98	0.81	0.58
Bk2	86-160	57	0.48	0.060	91	53.5	1.73	2.42	31.90	8.60	100	3.0	0.39	5.38	7.18	0.84	0.27
				Site 8 Amigna-haro haplusterts													
Ap	0-20	59	1.46	0.194	72	47.8	0.82	2.53	25.52	6.34	74	0.0	0.32	4.53	5.59	1.40	1.48
Bk1	20-85	83	1.00	0.101	64	56.6	1.52	2.07	34.14	8.12	81	2.8	0.45	5.07	7.01	0.95	0.82
Bk2	85-165	66	0.32	0.034	75	50.8	2.30	1.51	36.28	8.78	96	3.6	0.30	5.96	7.77	2.59	0.29
				Site 9 Ali town 2 haplusterts													
Ap	0-30	42	2.02	0.168	70	36.5	0.57	2.31	13.18	3.36	52	0.0	0.18	4.56	5.94	1.68	1.62
Bw	30-95	72	0.70	0.083	70	52.9	1.50	2.94	21.44	7.63	63	0.0	0.32	4.58	6.36	1.16	0.68
Bk	95-165	73	0.12	0.014	66	48.8	1.80	2.40	25.62	9.11	80	4.2	0.40	5.11	6.97	1.76	0.51

Table 2
Ranges in soil properties used to develop the regression models

Properties (Units)	Range
Total nitrogen (%)	0.014 – 0.25
Organic carbon (%)	0.120 – 2.23
Available P-Olsen (ppm)	0.140 – 2.84
Available P-Bray (ppm)	0.080 – 14. 38
CEC, cmol, NH_4 (+)/kg	29.64 – 63.90
Base saturation (%)	52.0 – 100
Total clay (%)	42.0 – 86.0
pH (2:5) water	5.27 – 8.27
pH (2:5) KCl	4.04 – 6.43
Electrical Conductivity (EC), mS/cm	0.05 – 0.75
$CaCO_3$ (%)	0.00 – 5.00

Table 3
Correlation relationships among selected soil properties

Variable	(n)*	CEC	EC	pH-H_2O	pH-KCl	$CaCO_3$	OC	TN	P-Bray	P-Olsen
Clay	(25)	-0.015	-0.097	-0.160	-0.166	-0.0003	-0.440*	-0.416*	-0.498**	-0.406*
CEC	(25)		0.562**	0.485*	0.473*	0.416	-0.194	-0.150	0.322	0.014
EC	(25)			0.868**	0.843**	0.660**	-0.413*	-0.365	0.301	-0.131
pH-H_2O	(25)				0.961**	0.843**	-0.513**	-0.529**	0.287	-0.260
pH-KCl	(25)					0.812**	-0.567**	-0.569**	0.315	-0.309
$CaCO_3$	(25)						-0.574**	-0.606**	0.235	-0.344
OC	(25)							0.948**	0.264	0.864**
TN	(25)								0.153	0.807**
P-Bray	(25)									0.548**

**, * Significant at the 0.01 and 0.05 levels, respectively.
+ CEC= Cation Exchange Capacity, EC= Electrical Conductivity, $CaCO_3$= Percent calcium Carbonate, OC= Organic carbon (%), TN= Total Nitrogen (%), P-Bray= Available Phosphorus Bray, P-Olsen= Available Phosphorus Olsen.

Linear regression relation between nitrogen and OC (Table 4) indicates a high correlation. From the r^2 of the equation, nitrogen vs OC accounted for 88% of the variance. This relationship appears linear (Figure 2).

Table 4
Simple and multiple linear regression equations between P-Olsen, P-Bray, Total Nitrogen (TN), Base saturation (BS) and $CaCO_3$ and selected independent soil properties of the Bale Mountain area of Ethiopia

Linear (a)

Dependent Variable	Intercept	Coefficient	Variable	n	r^2
P-Olsen	= 0.133	0.936	OC	17	0.805**
	= -0.059	9.643	TN	17	0.687**
P-Bray	= -0.281	3.058	P-Olsen	24	0.423**
	= 8.789	-0.097	Clay	24	0.317**
pH-KCl	= -0.0887	0.7738	pH-H_2O	24	0.921**
	= 3.9287	0.3234	EC	24	0.698**
TN	= 0.021	0.084	OC	24	0.882**
BS	= -34.5148	21.5364	pH-KCl	17	0.623**
	= -11.30	13.19	pH-H_2O	17	0.644**
$CaCO_3$	= -11.81	2.064	pH-H_2O	17	0.682**
	= - 9.906	2.364	pH-KCl	17	0.600**

Multiple Linear (b).

Dependent Variable	n	R^2	Intercept	Coeff. (X1)	Var. (X1)	Coeff. (X2)	Var. (X2)
P-Olsen	24	0.575**	= 7.802	-0.028	Clay	-0.753	pH-H2O
	24	0.845**	= -1.590	0.019	BS	1.216	OC

OC = Organic carbon; EC = Electrical conductivity; BS = Base Saturation.
* * = Significant at the 0.01 Level; n = number of observations.

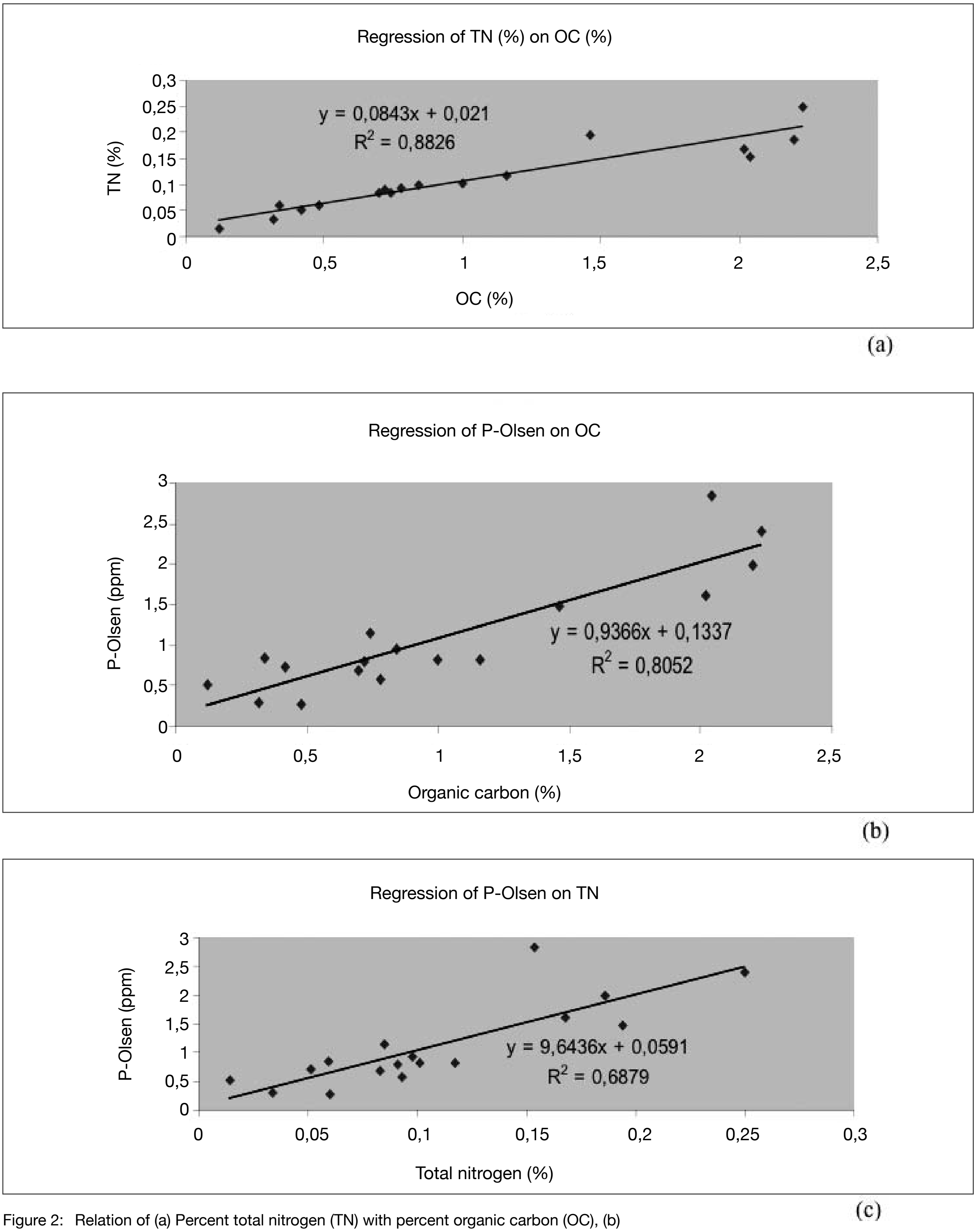

Figure 2: Relation of (a) Percent total nitrogen (TN) with percent organic carbon (OC), (b) P-Olsen with OC, and (c) P-Olsen with TN.

Regression equations between P-Olsen and selected physical and chemical properties of these soils (Table 4) indicate that the relationship of P-Olsen vs OC and P-Olsen vs Total Nitrogen (TN) account for 81 and 69% of the variance, respectively. The above relationships appear linear (Figure 2). This indicates available P-Olsen is associated with OC content as indicated by the depth function distribution of these parameters. P-Olsen has an indirect correlation with TN due to the correlation of TN with OC. The correlation of P-Bray vs OC and P-Bray

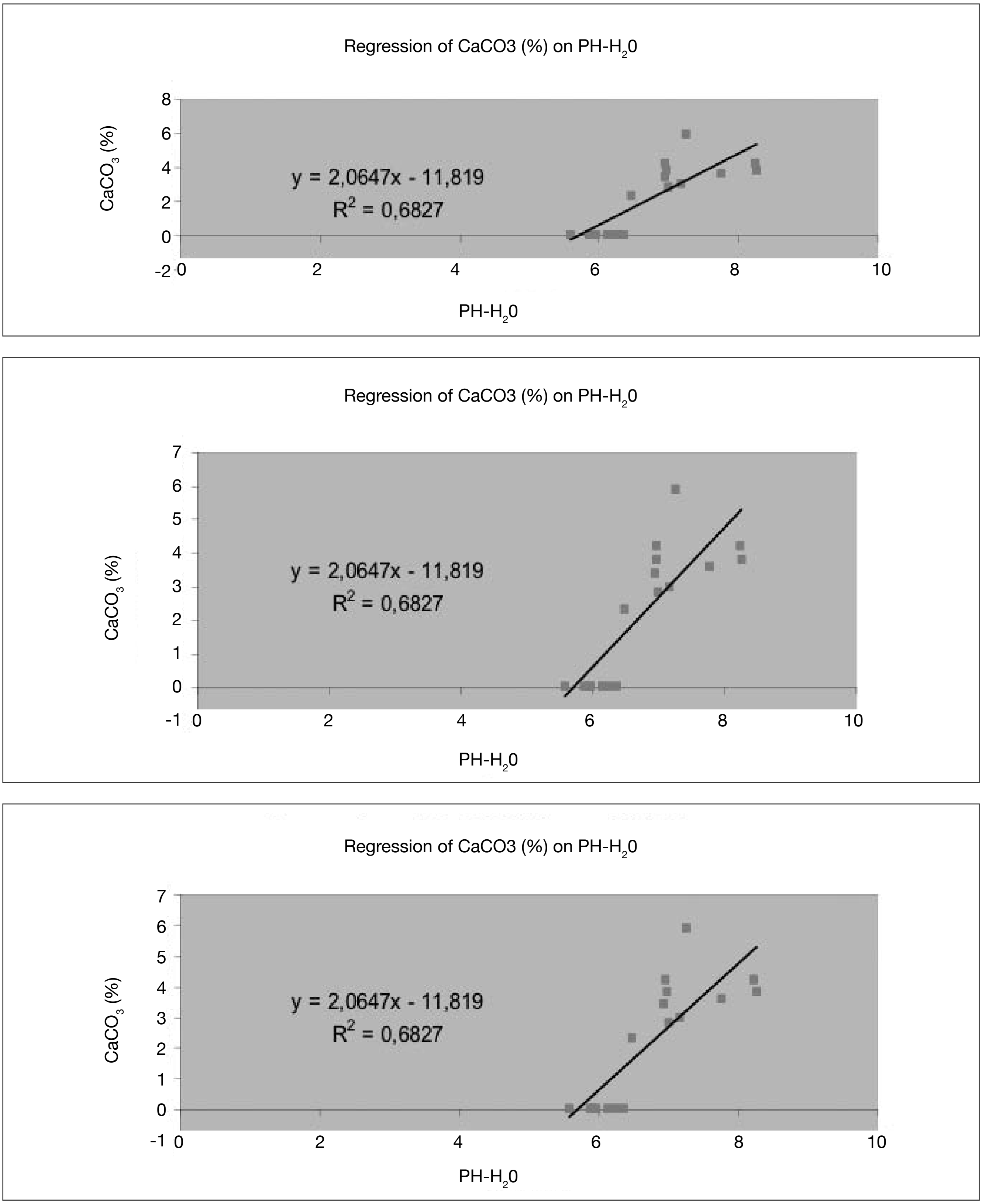

Figure 3: Relation of (a) Base Saturation % (BS) with pH-H_2O, (b) $CaCO_3$ % with pH-H_2O, and (c) $CaCO_3$ % with pH-KCl

vs TN was very low (Table 3, r= 0.264 and r= 0.153, respectively). This confirms observations (17) that the Ammonium Bicarbonate extractant is more suitable for use in neutral to alkaline soils than the Bray II extractant. Table 1 indicates that as pH increases towards the lower sola, P-Bray (except for surface horizons) also tends to increase. This is confounding and may explain the poor correlation of the organic carbon vs P-Bray. More P was extracted with increasing alkalinity. It is also possible that as carbonates increase with depth they may constitute sinks for P, which are released, when an acid extractant like P-Bray is used (17).

When multiple linear regressions was used by regressing P-Olsen vs Base saturation (BS) + OC, a greater percent of the variance could be accounted for (84.5%) (Table 4).

Base saturation, $CaCO_3$% and pH-KCl are also very important parameters for agronomic practice. Regression equations between selected physical and chemical properties indicate that the relationship of pH-KCl vs pH-H_2O, pH-KCl vs EC and pH-KCl vs $CaCO_3$ accounted for 92, 70, and 60% of the variance, respectively (Table 4) and thus give linear functions (Figure 3). Also regression equations of BS vs pH-KCl and BS vs pH-H_2O accounted for 62 and 64% of the variance, respectively, while that for $CaCO_3$ vs pH-H_2O and $CaCO_3$ vs pH-KCl accounted for 69 and 60% of the variance, respectively.

The above relationships appear linear and indicate that the parameters, pH-KCl, pH-H_2O, BS and $CaCO_3$% are interrelated, and further that soil properties can easily be predicted from parameters such as pH-H_2O, EC, OC, and pH-KCl, which can be determined at minimal cost.

CEC was not highly correlated with clay or organic carbon (Table 3), r= - 0.051 and r= -0.194, respectively which is strange. This may be due to the variable mineralogical suite of these soils as well as the fact that CEC in these soils is little associated with organic matter since the organic carbon exists in very small amounts.

4. Evaluation of analytical data quality

A quality control program is concerned with establishing and maintaining a fair level of accuracy and precision within the laboratory. Methods used may include recovery techniques, participation in exchange programs and use of reference samples among others.

Crosschecking of soil chemical and physical analysis is one of the most effective ways of deciphering the inconsistencies that exist within a set of analytical data; it can be carried out in three ways (21, 23). First, if we have already established an expected range for each of the analysis for a specific region or country we could pay attention to outlying data.

A second way is by crosschecking of data by soil horizon (in one sample). A means of locating gross errors in the chemical and physical analysis of soils is provided by the considerable number of interrelations that exist among values obtained for various parameters.

A third step is to crosscheck results within the profile. This nearly always requires a soil profile description to evaluate the course of chemical and physical characteristics with depth.

In this study, the use of regression and correlation was applied to the 2nd and 3rd methods of crosschecking analytical data. A linear relationship was observed for OC vs TN, OC vs P-Olsen, pH-KCl vs pH-H_2O, pH-KCl vs EC, pH-KCl vs $CaCO_3$, BS vs pH-KCl, BS vs pH-H_2O, and $CaCO_3$ vs pH-H_2O (Table 3) consistent with previous investigations (21, 24). The lack of correlation of CEC vs % clay and CEC vs % OC is inconsistent with other studies (21, 24) that all reported a high correlation between the above stated parameters. Though in this study the varying clay mineralogical suite as suggested by CEC/100 grams clay and the very low OC contents compared to the amount of clay may be responsible for the apparent lack of correlation; this anomaly merits further investigation. Additionally, while there is a depth function in OC distribution, the pedoturbation process, which obtains in Vertisols may have influenced the OC distribution sufficiently to result in a lack of correlation with the CEC.

Regression analysis were performed within individual soil profiles for OC vs TN, OC vs P-Bray, OC vs P-Olsen, BS vs pH-KCl, BS vs pH-H_2O, $CaCO_3$ vs pH-KCl, $CaCO_3$ vs pH-H_2O, % clay vs Total CEC, EC vs pH-KCl and EC vs pH-H_2O.

The correlation coefficients obtained for the different parameters of each of the soils are presented on table 5. Except for OC vs P-Bray site 9, P-Bray vs P-Olsen site 9, P-Bray vs pH-H_2O sites 4, 5, 6, 8, and 9, confirming reports (17) that the Ammonium Bicarbonate extractant rather than the P-Bray extractant is the extractant suitable for alkaline soils**,** and EC vs pH-KCl and EC vs pH-H_2O site 8, which had very low correlation coefficients, all the other parameters had r values which ranged from 0.74-1.00, indicating a great similarity in parent material. High correlations between OC vs TN, OC vs P-Bray, BS vs pH-KCl, BS vs pH-H_2O, and % clay vs Total CEC, within each soil profile have been observed for Central African Oxisols (21).

The correlation of % clay with soil CEC value for site 4 when the binding agent was not destroyed gave an r value of - 0.23. When the binding agent was destroyed a negative but significant correlation (r value of - 0.89) was obtained. The CEC/100 g clay values for this Vertic Haplustepts ranged from 73-128 cmol (+)/kg clay after destruction of the binding agent. This indicates that the soil is dominated by both smectite and vermiculite. The high exchangeable potassium contents for this soil (1.45-2.74 cmol (+)/kg clay) indicate release of K^+ from a micaceous mineral, probably biotite that will favor vermiculite formation. It also indicates that smectite would be forming

Table 5
Correlation relationships among soil properties within each profile

Regression Relationship	Correlation coefficients (r) for the different soils on table 1.				
	Site 4 (n= 3)	Site 5 (n= 4)	Site 6 (n= 4)	Site 8 (n= 3)	Site 9 (n= 3)
OC Vs TN	0.99**	1.00**	0.99**	0.98**	0.99*
OC vs P-Bray	0.74	0.75	0.99**	-0.78	0.10
OC vs P-Olsen	0.96**	0.99**	0.99**	0.98**	0.99**
P-Bray vs P-Olsen	0.89*	0.63	0.98**	-0.66	0.26
P-Bray vs pH-H_2O	-0.48	-0.23	-0.70	0.57	0.23
BS vs pH-KCl	0.82*	0.98**	0.92*	1.00*	0.98**
BS vs pH-H_2O	0.86*	0.98**	0.81	0.93*	1.00**
$CaCO_3$ vs pH-KCl	-	-	-	-	0.97**
$CaCO_3$ vs pH-H_2O	-	-	-	-	0.91*
% Clay vs Total CEC	-0.89*	0.99**	0.80	1.00**	0.98**
EC vs pH-KCl	0.84*	0.83*	0.82*	-0.26	0.89*
EC vs pH-H_2O	0.86*	0.81*	0.95*	0.05	0.97**

**Significant at the 1% level; *Significant at the 5% level; n=number of observations.

largely through transformation from vermiculite. With increasing weathering from vermiculite (CEC is about 150 cmol (+)/kg) to smectite (CEC is about 100 cmol (+)/kg), the charge density is being reduced while particle size reduces (% clay increases). This may account for the negative correlation of % clay with CEC within the Ali Town 1 Vertic Haplustepts profile.

The high r-value obtained for most parameters within a given profile indicates uniformity in the factors of soil formation (parent material, vegetation and relief) for a given site. This also indicates that the lower r values obtained for the same correlation relationships when all the soils are put together (Table 3) indicates variability in one or more of the factors of soil formation. Similar observations have been reported for Central African Oxisols (21). In this regard it is necessary that before regression models are developed consideration should be given to the types of vegetation, physiographic position and parent materials for each soil.

Summary and conclusions

This study represents statistical relationships among selected properties of Ethiopian Vertisols and Vertic Inceptisols. Though the data base used to develop the regression models is small, nevertheless the limitations observed in this study will set a pace for future investigations.

Nitrogen and available P can be relatively accurately predicted from percent organic carbon. pH-KCl can be relatively accurately predicted from pH-H_2O and EC. Similarly, Base Saturation and percent $CaCO_3$ can be relatively accurately predicted from pH-KCl and pH-H_2O.

Multiple regression models appreciably increased the accuracy of prediction of P-Olsen with BS + OC as dependent variables.Very high correlation coefficients were observed within individual soil profiles for the relationships of OC vs TN, OC vs available P Olsen, BS vs pH-KCl, BS vs pH-H_2O, % clay vs Total CEC, $CaCO_3$ % vs pH-H_2O, $CaCO_3$ % vs pH-KCl, EC vs pH-KCl and EC vs pH-H_2O. Lower correlation coefficients were observed for similar relations when the correlation coefficients were established across different soil profiles.

This study demonstrates that given the well established relationships that exist among soil physico-chemical properties and the distribution of some with depth, correlation relationships can be used as a tool to cross-check the reliability and consistency of laboratory analytical data.

Development of predictive models illustrated in this paper provides a useful means to estimate agronomic properties of soils from existing and often sparse physical and chemical data. This can serve as a means for technology transfer for established characterization of databases in developing countries with limited resources.

In the Vertisols, parameters like CEC, exchangeable bases, and percent clay are very similar in concentrations in horizons of the lower sola suggesting possible pedoturbation. This study also indicates that for Vertisols, OC, TN and available P generally decrease with depth, while BS, EC, pH and $CaCO_3$ % tend to increase with depth. These observations can be used for crosschecking purposes to check the reliability of analytical data within Vertisol profiles.

Soils of the Bale Mountain area have near adequate nutrient contents to support plant growth, except phosphorus, which is low. Additionally, $CaCO_3$ can act as potential sinks for soil micronutrients when they occur in high concentrations, resulting in micronutrient deficiencies.

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