Pedotransfer Functions for Cation Exchange Capacity, Available Water Holding Capacity and Soil Organic Carbon for Representative Soils of Southern Highland Zone of Tanzania

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***ABSTRACT*:**
Pedotransfer functions are useful tools in estimating the not easily measured and expensive soil properties. They are especially valuable in settings such as the SHZT where limited direct soil measurements are available. The objective of this study was to develop a series of pedotransfer functions and then evaluate which ones best estimate cation exchange capacity (CEC), available water holding capacity (AWHC) and soil organic carbon (SOC). Data from 20 horizons of four representative pedons was used to evaluate the most predictive properties. Best fit multiple linear regressions were used to obtain relationships and identify property coefficients. Examples of pedotransfer functions developed for the SHZT are ***%SOC = 0.1*hue-0.03*value-0.034chroma*** *(n = 20,* r^2 *= 0.74),* ***CEC*** *(meq/100g) =* ***0.44*%clay + 9.6%SOC*** *(n=20,* r^2 *= 0.93), and,* ***AWHC (mm/m) = 14.7%SOC + 0.82%clay + 0.35%silt + 0.51%sand*** *(n=12;* r^2 *= 0.96). All color attributes are for moist samples. The results of predicted CEC, AWHC, and SOC were compared to those measured in the laboratory using the t-test, and the two methods did not differ significantly; two-sided p-value=0.93. These results indicate the promising potential of using the easily measured soil properties and cheap in fiscal terms to estimate the not easily measured soil properties.*
***Keywords:* Pedotransfer function, CEC, AWHC, and SOC.**

INTRODUCTION

Pedometry is increasingly important as the cost of field and laboratory measurements of different soil parameters are tremendously expensive in terms of financial and time resources (Van den Berg *et al.*, 1997). Pedotransfer functions allow the use of few easily measured soil variables to estimate the correlated variables (Obiero, 2013). Best selection of the number of explanatory variables is important in developing the powerful pedotransfer function. The size of the data set overlies the number of explanatory variables in evaluating the power of the pedotransfer functions (Pollacco, 2008).

According to the soil survey reports the predominant soils across Tanzania to include Ferric, Chromic and Eurtric Cambisols (39.7%), Rhodic and Haplic Ferralsols (13.4%), and Humic Ferric Acrisols (9.6%) (Msanya, 2002). Most of the soils in Tanzania are highly weathered, and their capacity to hold and release nutrients is compromised (Msanya, 2002 and Szilas, 2005). However, some parts of Southern Highland Zone of Tanzania have volcanic soils which are rich in SOC, P, and K.

Cation exchange capacity is the sum of the sum of exchangeable cations the soil can adsorb under a specific set of conditions (Sumner and Miller, 1996). It refers to the ability of the soil to retain the cation from fertilizers applied for the intentions of replenishing the nutrients to support the growth of the crop; two factors: organic matter and type and amount of clay mineralogy affect the CEC value (Msanya, 2016; Mbaga, 2017). The various method is used to quantify CEC; ammonium acetate method is amongst. Majority of the small scale farmers can not afford these methods because they are very expensive with respect to temporal and monetary resources.

Mapping and quantifying SOC contents and distributions is crucial for modeling global carbon cycles (Wills, 2007). The role of organic matter, in soil fertility and crop productivity, is well documented by various research findings (Reddy *et al.*, 2005; Meena *et al.*, 2007). It affects the nutrients and moisture retention capacity in soils; this property enhances the plants' nutrients uptake. Different laboratory methods can be used to determine the organic carbon; Walkley and Black wet oxidation are the common one; others are combustion and loss on ignition (Wills, 2007). However, these methods are expensive. Part of this work is suggesting the prediction of soil organic carbon using the pedotransfer function as an alternative to minimize analysis expenses in areas with enough baseline data for soil characterization.

Available water holding capacity is the soil property that defines the amount of water that can be contained in the soil matrix under given conditions. Amount of organic matter and soils texture affect the soil ability to retain the amount of water; normally soil with higher clay content holds more amount of water than sand textured soils. The optimal amount of water in the soil matrix is essential for crop optimal physiological growth and development. This property is not routinely determined by soil surveyors due to difficulties of measurements (Tietje and Henning, 1996). The proposed alternative solution to this problem is the use of pedotransfer functions to estimate the amount of available water holding solution.

Majority of works on the development of pedotransfer functions have been done in the temperate regions (Young, 1999), some evaluation of such pedotransfer functions has been done in sub-Saharan Africa (Mdemu, 2015); the evaluation in this work indicated matched results between the externally pedotransfer functions and the measured results for water retention in the soils of the Sokoine University of Agriculture Farm in Morogoro, Tanzania; this is not enough evidence to convince the adoption of such pedotransfer functions. Significant variations of key parameters, such as soil physical, chemical, and biological properties pose significant variations among the tropical and temperate region's soils (Mdemu, 2015). This poses the barrier in the applicability such pedotransfer functions in sub-Saharan Africa due to the difference of the coefficients of inherent soils (Seilsepour, 2008). Therefore, the objective of this study is to develop pedotransfer functions using the multiple linear regressions that can predict soil variables such as CEC, AWHC, and SOC using the easily measurable soil properties like soil color, texture, and bulk density as an alternative to the conventional laboratory methods.

MATERIALS AND METHODS

Site description

This study was conducted across three specific administrative units (Mbozi and Mbeya districts, and Iringa Municipal) of SHZT. The fields' sites were located at the villages of Mbimba, Uyole, Inyala, and Seatondale whose GPS coordinates are 032^{o} 57.29′E,09^{o}05.31′S;033^{o}30.98′E,08^{o}55.04′S;033^{o}38.20′E,08^{o}51.1′S;035^{o}41.87′E;07^{o}47.502′S respectively. Site information such as weather, elevation, parent materials, landforms, land use, soil temperature, and moisture regimes, geographical locations coordinates were determined using topographic, geological maps; Schoeneberger *et al.* (2012) field description guidebook and *etrec10* GPS.

Fieldwork

The sites were initially surveyed using transect as well as field validation and auger observations. Rough soil mapping units were then established to provide the general view of soil representative distribution at each site. From this major representative soils and landscapes, one pedon was opened at each site for descriptions and characterization using Schoeneberger *et al.* (2012), and Munsell Soil Color Charts 1994 revised edition. Twelve samples (three for each pedon) were collected for soil water characterization. Depths of collections were 0-5 cm, 45-50 cm, and 95-100 cm. Twenty characterization samples (one sample from each horizon) were collected from the four pedons.

Laboratory work

Soil samples from each horizon were air-dried and ground to pass through a 2-mm sieve for laboratory analyses at the Sokoine University of Agriculture Laboratory. Particle size analysis was determined by the hydrometer method after dispersion with sodium hexametaphosphate 5% (NSS, 1990). Textural classes were determined using the USDA textural class triangle (Schoeneberger *et al.*, 2012). Soil pH was measured in water and 1 M KCl at a ratio of 1:2.5 soil-water and soil-KCl, (McLean, 1986), and at a ratio of 1:50 soil-1M NaF, with measurements taken after 2 min (Fieldes and Perrot, 1966; NSS, 1990). Organic carbon was determined by the Walkley and Black wet oxidation method (Nelson and Sommers, 1982). Total N was determined using the micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). Cation exchange capacity of the soil (CEC_{soil}) and exchangeable bases were determined by saturating the soil with neutral 1M NH_4OAc (ammonium acetate), and the adsorbed NH^{4+} were displaced by using 1MKCl and then determined by Kjeldahl distillation method for estimation of CEC of the soil (Chapman, 1965). The exchangeable bases (Ca^{2+}, Mg^{2+}, $Na^{+,}$ and K^{+}) were determined by atomic absorption spectrophotometer (Thomas, 1982). The total exchangeable bases (TEB) were calculated arithmetically as a sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, $Na^{+,}$ and K^{+}) for a given soil sample and the base saturation percent calculated by dividing TEB by the sample respective CEC multiplied by 100.

% SOC and % clay were used to develop a Pedotransfer function that estimated the CEC of representative soils of SHZT. Two Pedotransfer functions were developed using Microsoft excel office 2013. The prediction regression model targeted specific site and the overall sites. %SOC, %clay, %silt, %sand, structure code and bulk density variables

were used to develop multiple linear regression model for estimation of available water holding a capacity of representative soils of SHZT. The dry and moist Munsell colors were used to develop multiple linear regression models for estimation of %SOC.

The Statistical Test

The selected physico-chemical soil properties (available water holding capacity, soil organic carbon and cation exchange capacity) data measured in the laboratory and the pedotransfer predicted data were subjected to JMP software to test the level of significant difference among the two methods of soil properties determinations. The results of this test were used to determine whether the two methods have a significant difference.

RESULTS

The statistical test outputs indicated that the physico-chemical properties measured in the laboratory and those estimated by the pedotransfer functions did not differ significantly. The results indicated that the CEC values are the same two sided p-value = 0.46, AWHC values are the same; two sided p-value = 0.9323, and SOC values are the same; two sided p-value=0.9694. This suggests that the pedotransfer functions can be used in instances where the use of soil laboratory facilities is not accessible.

The results from the four representative soils of SHZT indicate the great potential for the use of available data set to develop pedotransfer functions that can be used in the estimation of the not easily measured and expensive soil parameters like %SOC, CEC and AWHC (Tables 1 to 10 and Figures 1 to 3). Using the available data sets, it was possible to develop the pedotransfer functions. The key observation is the potential to estimate the not easily measured expensive soil properties from the cheap and easily measured soil properties using the appropriate pedotransfer functions as shown in the results.

Table 1: Physical properties of representative soils of SHZT

Pedon Id	Horizon	Depth (cm)	[1]Texture	Dry color	Moist color	[2]Consistence	[3]Structure	[4]Horizon. boundary
Seatondale	Ap	0-12	S	10YR5/1	10YR3/3	fr,vfr	Sbk	as
	AB	12-19	LS	10YR4/1	10YR3/4	fr,vfr	Sbk	as
	Bt1	19-30	SCL	5YR4/2	5YR3/4	vh,vfi	Sbk	cw

Pedon Id	Horizon	Depth (cm)	[1]Texture	Dry color	Moist color	[2]Consistence	[3]Structure	[4]Horizon. boundary
	Bt2	30-54	SC	7.5YR4/6	5YR4/6	vh,vfi	Sbk	gw
	Bt3	54-84	SCL	7.5YR4/6	7.5YR4/6	vh,vfi	Sbk	gw
	Bt4	84+	SC	7.5YR4/6	7.5YR4/6	vh,vfi	Sbk	-
Mbimba	Ap	0-12	C	10YR4/3	10YR3/1	h,fr	Sbk	as
	BA	12-50	C	7.5YR3/3	10YR4/4	h,fr	Sbk	cs
	Bt1	50-84	C	7.5YR4/6	10YR3/4	h,fr	Sbk	cs
	Bt2	84-117	C	7.5YR4/4	10YR4/4	h,fr	Sbk	cs
	Bt3	117+	C	7.5YR3/3	7.5YR ¾	h,fr	Sbk	-
Inyala	Ap	0-12	SCL	7.5YR4/3	7.5YR 3/3	h,fr	Sbk	as
	BA	12-47	C	7.5YR4/4	7.5YR ¾	h,fi	Sbk	cs
	Bt1	47-78	C	7.5YR5/4	7.5YR 3/6	h,fi	Sbk	cs
	Bt2	78-120	C	7.5YR5/4	7.5YR 3/3	h,fi	Sbk	cs
	Bt3	120+	C	7.5YR4/6	7.5YR 4/6	h,fi	Sbk	-
Uyole	Ap	0-20	SCL	7.5YR4/3	7.5YR 3/1	h,vfr	Sbk	as
	BA	20-30	SCL	7.5YR3/4	7.5YR 3/2	h,vfr	Sbk	gi
	CB	30-130	SCL	7.5YR8/1	7.5YR 8/1	L	-	gs
	2Bt	130+	SCL	7.5YR3/3	7.5YR 4/3	h,vfr	Sbk	-

[1]Texture: C=clay; S=sand; LS = loamy sand; SC= sandy clay; SCL = sandy clay loam
[2]Consistence: fr = friable; vfr = very friable; vh = very hard; h=hard; vfi = very firm; l = loose;
[3]Structure: sbk = subangular blocky;
[4]Horizon boundary: as = abrupt smooth; cs = clear smooth ; gi = gradual irregular; gs = gradual smooth; gw = gradual wavy; aw = abrupt wavy; cw = clear wavy

Table 2: Particle size distribution of the representative pedons of SHZT

Pedon Id	Horizon	Depth (cm)	% clay	% silt	% sand
Seatondale	Ap	0-12	7.8	3.3	88.9
	AB	12-19	9.8	3.3	86.9
	Bt1	19-30	39.8	1.3	58.9
	Bt2	30-54	33.8	5.3	60.9
	Bt3	54-84	35.8	3.3	60.9
	Bt4	84+	29.8	1.3	68.9
Mbimba	Ap	0-12	41.8	17.3	40.9
	BA	12-50	55.8	13.3	30.9
	Bt1	50-84	41.8	17.3	40.9
	Bt2	84-117	51.8	13.3	34.9
	Bt3	117+	53.8	13.3	32.9
Inyala	Ap	0-12	29.8	17.3	52.9
	BA	12-47	43.8	15.3	40.9
	Bt1	47-78	45.8	17.3	36.9
	Bt2	78-120	41.8	19.3	38.9
	Bt3	120+	55.8	13.3	30.9
Uyole	Ap	0-20	25.8	23.3	50.9
	BA	20-30	33.8	17.3	48.9
	CB	30-130	29.8	19.3	50.9
	2Bt	130+	25.8	21.3	52.9

Table 3: Horizons, depths, textural class, bulk density and available water holding capacities of representative soils of SHZT

Pedon Id	Horizon	Depth (cm)	Textural Class	Bulk density g/cm^3	Available water capacity	
					%vol/vol	mm/m
Seatondale	Ap	0-12	S	1.34	4.0	40
	AB	12-19	LS	nd	Nd	nd
	Bt1	19-30	SCL	nd	Nd	nd
	Bt2	30-54	SC	1.48	3.1	31

Pedon Id	Horizon	Depth (cm)	Textural Class	Bulk density g/cm^3	Available water capacity	
					%vol/vol	mm/m
	Bt3	54-84	SCL	nd	Nd	nd
	Bt4	84+	SC	1.58	2.9	29
Mbimba	Ap	0-12	C	1.15	6.6	66
	BA	12-50	C	0.88	5.0	50
	Bt1	50-84	C	nd	Nd	nd
	Bt2	84-117	C	0.79	5.2	52
	Bt3	117+	C	nd	Nd	nd
Inyala	Ap	0-12	SCL	1.46	4.0	40
	BA	12-47	C	1.51	Nd	nd
	Bt1	47-78	C	nd	4.0	40
	Bt2	78-120	C	1.43	4.3	43
	Bt3	120+	C	nd	Nd	nd
Uyole	Ap	0-20	SCL	0.99	5.0	50
	BA	20-30	SCL	nd	Nd	nd
	CB	30-130	SCL	0.80	7.0	70
	2Bt	130+	SCL	0.79	Nd	nd

nd= not determined

Table 4: Exchangeable cations and cation exchange capacity and base saturation percent of the representative soils of SHZT

Pedon Id	Horizon	Exchangeable bases (cmol(+)/kg)				CEC	BS
		Ca	**Mg**	**K**	**Na**	**(meq/100g)**	**%**
Seatondale	Ap	4.01	0.66	0.61	0.08	17.20	31.2
	AB	3.46	0.50	0.19	0.07	20.80	20.3
	Bt1	8.47	1.56	0.37	0.09	16.00	65.6
	Bt2	6.80	2.02	0.48	0.11	18.40	51.2
	Bt3	6.80	1.87	0.99	0.06	20.60	47.1
	Bt4	4.57	1.67	0.99	0.29	28.60	26.3
Mbimba	Ap	7.36	1.87	2.03	0.07	36.40	31.1
	BA	10.14	1.39	2.41	0.16	33.00	42.7
	Bt1	6.80	3.86	6.09	0.27	31.40	54.2
	Bt2	6.24	2.49	7.30	0.28	21.60	75.5
	Bt3	6.24	3.23	8.12	0.32	26.00	68.9
Inyala	Ap	12.93	3.41	1.14	0.11	19.60	89.7
	BA	11.26	2.55	0.71	0.20	18.40	80.0
	Bt1	9.03	2.46	1.50	0.42	22.00	61.0
	Bt2	6.24	2.20	1.50	0.21	23.80	42.7

Pedon Id	Horizon	Exchangeable bases (cmol(+)/kg)				CEC	BS
		Ca	**Mg**	**K**	**Na**	**(meq/100g)**	**%**
	Bt3	8.47	2.67	1.66	0.22	20.40	63.9
Uyole	Ap	16.83	3.37	0.62	0.27	22.80	92.5
	BA	12.93	2.88	5.42	0.45	24.20	89.6
	CB	8.47	2.67	10.83	1.41	21.60	108.3
	2Bt	10.70	3.07	13.84	2.06	24.40	121.6

Table 5: % SOC, %N, C/N and available phosphorus values for the representative soils of SHZT

Pedon Id	Horizon	pH			% OC	% OM	% N	C/N	Avail. P (Bray 1)
		H_2O	KCl	NaF				Ratio	mg P/kg
Seatondale	Ap	6.16	4.75	8.20	0.65	1.12	0.05	13	10.67
	AB	5.98	4.64	8.13	0.40	0.70	0.05	8	10.42
	Bt1	6.15	4.54	7.87	0.41	0.71	0.04	10	2.42
	Bt2	6.24	4.92	7.75	0.25	0.43	0.02	12	1.92
	Bt3	6.21	4.86	7.66	0.28	0.49	0.05	6	1.83
	Bt4	6.16	5.16	7.43	0.99	1.72	0.06	17	2.87
Mbimba	Ap	5.50	4.08	8.50	0.84	1.45	0.07	13	5.17
	BA	5.88	4.38	8.89	0.90	1.56	0.05	18	1.04
	Bt1	6.34	4.74	9.38	0.35	0.62	0.03	13	0.71
	Bt2	6.20	4.72	9.10	0.35	0.61	0.04	10	0.92
	Bt3	6.40	4.66	8.80	0.44	0.77	0.04	10	1.04
Inyala	Ap	6.00	4.60	8.24	1.07	1.86	0.09	13	12.50
	BA	5.92	4.38	7.96	0.62	1.08	0.06	11	2.29
	Bt1	5.96	4.34	7.74	0.29	0.50	0.03	10	1.42
	Bt2	6.26	4.52	7.71	0.12	0.22	0.01	9	1.58
	Bt3	5.46	4.50	7.74	0.50	0.87	0.04	12	1.04
Uyole	Ap	6.78	5.02	7.82	1.52	2.64	0.11	14	11.17
	BA	7.20	5.00	7.76	0.89	1.54	0.06	16	1.37
	CB	7.02	5.12	7.93	0.34	0.22	0.02	6	1.46
	2Bt	7.40	4.92	7.99	0.13	0.59	0.02	16	1.54

Table 6: %clay and %SOC as Predictors of CEC of four representative pedons of SHZT

Pedon Id	Horizon	CEC (cmol(+)/kg)	% clay	%SOC	CEC predicted (meq/100g)
Seatondale	Ap	17.2	8	0.65	9.8

	AB	20.8	10	0.40	8.2
	Bt1	16.0	40	0.41	21.5
	Bt2	18.4	34	0.25	17.4
	Bt3	20.6	36	0.28	18.5
	Bt4	28.6	30	0.99	22.7
Mbimba	Ap	36.4	42	0.84	26.5
	BA	33.0	56	0.90	33.3
	Bt1	31.4	42	0.35	21.8
	Bt2	21.6	52	0.35	26.2
	Bt3	26.0	54	0.44	28.0
Inyala	Ap	19.6	44	1.07	29.6
	BA	18.4	46	0.62	26.2
	Bt1	22.0	42	0.29	21.3
	Bt2	23.8	56	0.12	25.8
	Bt3	20.4	44	0.50	24.2
Uyole	Ap	22.8	26	1.52	26.0
	BA	24.2	34	0.89	23.5
	CB	21.6	26	0.34	14.7
	2Bt	24.4	30	0.13	14.4

Table 7: %Clay and %SOC as Predictors of CEC for the representative pedons of SHZT, done on individual site bases

Pedon Id	Horizon	CEC (cmol(+)/kg)	% clay	%SOC	Predicted CEC (cmol(+)/kg)
Seatondale	Ap	17.2	8	0.65	17.3
	AB	20.8	10	0.40	12.2
	Bt1	16.0	40	0.41	21.4
	Bt2	18.4	34	0.25	15.9
	Bt3	20.6	36	0.28	17.2
	Bt4	28.6	30	0.99	31.7
Mbimba	Ap	36.4	42	0.84	27.0
	BA	33.0	56	0.90	33.6
	Bt1	31.4	42	0.35	21.8
	Bt2	21.6	52	0.35	26.1
	Bt3	26.0	54	0.44	27.9
Inyala	Ap	19.6	44	1.07	18.8
	BA	18.4	46	0.62	20.1
	Bt1	22.0	42	0.29	18.6
	Bt2	23.8	56	0.12	25.1
	Bt3	20.4	44	0.50	19.3
Uyole	Ap	22.8	26	1.52	21.3
	BA	24.2	34	0.89	28.4
	CB	21.6	26	0.34	21.9
	2Bt	24.4	30	0.13	25.4

Table 8: %SOC, %clay, %silt, %sand and bulk density as predictors of AWHC of the representative soils of SHZT

	Depth (cm)	Water retention	% SOC	% Clay	% Silt	% Sand	Bulk density	Predicted water retention mm/m
Seatondale	0-12	40	0.65	7.76	3.28	88.96	1.34	35
	30-54	31	0.41	33.76	5.28	60.96	1.48	37
	54-84+	29	0.28	29.76	1.28	68.96	1.58	32
Mbimba	0-12	66	0.83	41.76	17.28	40.96	1.15	50
	12-50	50	0.90	55.76	13.28	30.96	0.88	62
	50-84	52	0.44	41.76	17.28	40.96	0.79	52

	Depth (cm)	Water retention	% SOC	% Clay	% Silt	% Sand	Bulk density	Predicted water retention mm/m
Inyala	0-12	40	1.07	29.76	17.28	52.96	1.46	44
	12-47	40	0.62	43.76	15.28	40.96	1.51	41
	78-120	43	0.29	41.76	19.28	38.96	1.43	36
Uyole	0-20	50	1.52	25.76	23.28	50.96	0.99	58
	20-30	70	0.89	33.76	17.28	48.96	0.80	55
	30-130+	27	0.34	25.76	21.28	52.96	0.97	41

Table 9: Epipedon’s moist color as a predictor of %SOC for representative soils of SHZT

Pedon Id	%SOC	Hue	Value	Chroma	Predicted %SOC
Seatondale	0.65	10	3	2	0.62
	0.41	10	3	2	0.62
Mbimba	0.83	10	3	1	0.90
	0.90	7.5	4	4	1.10
Inyala	1.07	7.5	3	1	1.18
	0.62	7.5	3	4	0.34
Uyole	1.52	7.5	3	1	1.18
	0.89	7.5	3	2	0.90

Table 10: Soil’s moist color as a predictor of %SOC for the representative pedons in SHZT

Pedon Id	%SOC	Hue	Value	Chroma	predicted %SOC
Seatondale	0.65	10	3	2	0.85
	0.4	10	3	2	0.85
	0.41	5	3	2	0.35
	0.25	5	4	6	0.2
	0.28	7.5	4	6	0.45
	0.99	7.5	4	6	0.45
Mbimba	0.84	10	3	1	0.88
	0.9	7.5	4	4	0.51
	0.35	7.5	3	4	0.54
	0.35	7.5	4	4	0.51
	0.44	7.5	3	4	0.54
Inyala	1.07	7.5	3	1	0.63
	0.62	7.5	3	4	0.54
	0.29	7.5	3	6	0.48
	0.12	7.5	4	3	0.54
	0.5	7.5	4	6	0.45
Uyole	1.52	7.5	3	1	0.63
	0.89	7.5	3	2	0.6

Pedon Id	%SOC	Hue	Value	Chroma	predicted %SOC
	0.34	7.5	8	1	0.48
	0.13	7.5	4	3	0.54

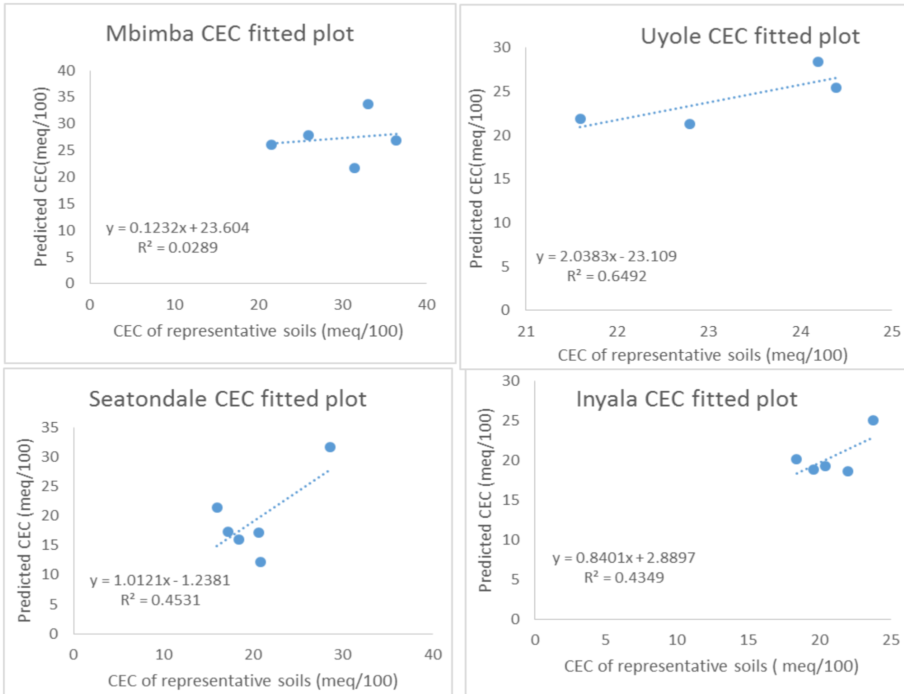

Figure 1: Individual site CEC fitted plots of the representative soils of SHZT

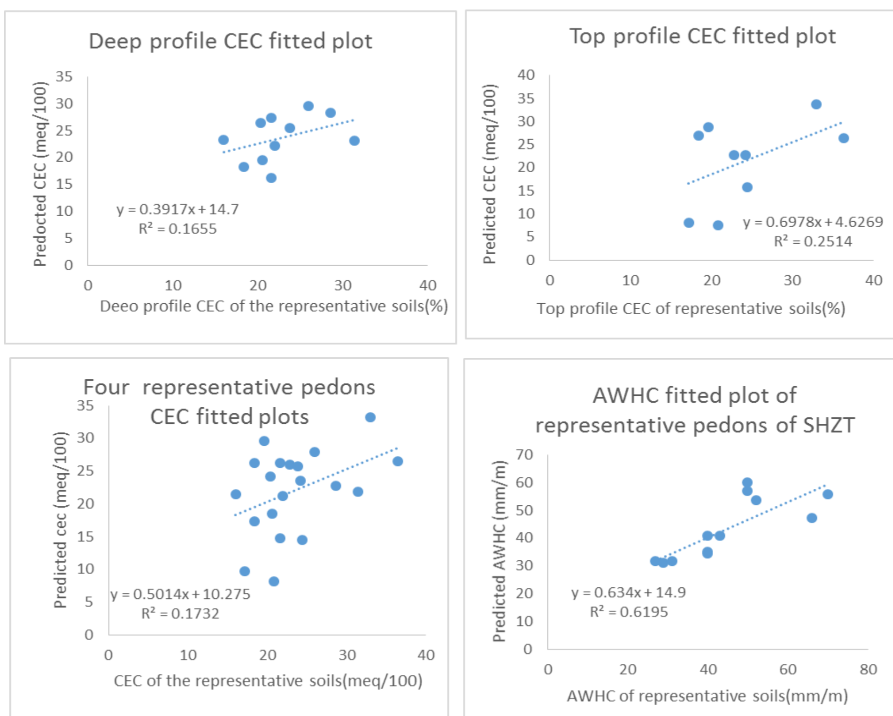

Figure 2: CEC and AWHC fitted plots of the representative soils of SHZT

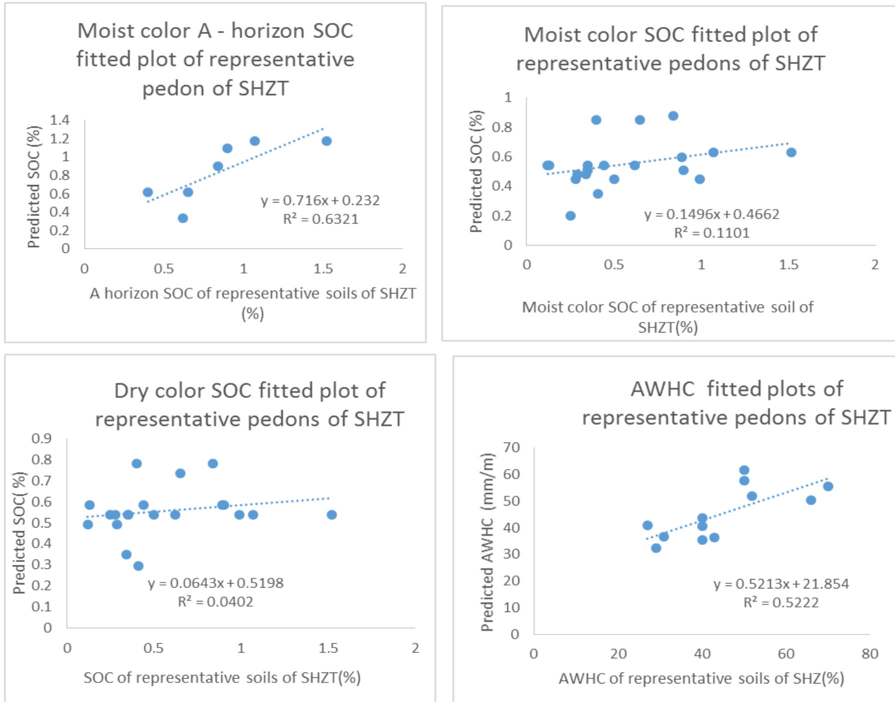

Figure 3: SOC and AWHC fitted plots of the representative soils of SHZT

Table 11: Pedotransfer functions for CEC, SOC, and AWHC of the representative soil of SHZT

Pedon Id	**Prediction Model**	**P-value**	**R2**	**adjusted R2**	**n**
All sites	CEC(meq/100g)= 0.44*%clay+9.6*%soc	<0.0001	0.93	0.86	20
Seatondale	CEC(meq/100g)=0.3*%clay+22.86*%soc	0.039	0.94	0.59	6
Mbimba	CEC (meq/100g)= 0.43*%clay+10.96*%soc	0.13	0.96	0.44	5
Inyala	CEC (meq/100g)=0.45*%clay-0.93*%soc	0.0687	0.99	0.49	5
Uyole	CEC (meq/100g)=0.85*%clay-5.2*%soc	NA	0.91	-0.002	4
A horizons	CEC meq/100g)=0.5*%clay+6.4*%soc	0.0019	0.90	0.72	9
B horizons	CEC (meq/100g)=0.42*%clay +15.8*%soc	<0.0001	0.96	0.84	20
AWHC1	AWHC= 9.4*%soc +0.66*%clay + 0.25*%silt +88.9*%sand+ 2.57*structure - 20.77*BD		0.97	0.78	20
AWHC2	AWHC= 14.66*%soc +0.82*%clay + 0.35*%silt +0.51*%sand - 20.17*BD	0.0002	0.96	0.79	13
SOC A	SOC = 0.76*Value -0.11*Hue- 0.27*Chroma	0.0024	0.96	0.74	8
SOC G	SOC = 0.1*Hue - 0.03*Value - 0.034* Chroma	<0.0001	0.74	0.66	20

DISCUSSION

Prediction of cation exchange capacity of the representative soils of SHZT was made four times. The overall results indicate the potential of using two easily measurable soil properties, %clay, and %SOC to estimate cation exchange capacity of soil (Table 11). Three pedotransfer functions have been developed, the overall sites, individual sites, and the epipedon CEC estimation regression equations. Larger than the user dataset would result in the best pedotransfer functions. Multiple regression pedotransfer functions produced differ in their strength to estimate the CEC. The best fits don't provide a very good trend; however, with increased data set size, the fitted plot would provide convincing distribution (Figure 2). These findings are in line with the works of MacDolald (1998) who suggested determination of CEC using OC and %clay for the soils of Quebec and Alberta State in Canada; Rashid and Seilsepour (2008) also proposed the model to predict CEC of soils of Varamin in Iran using OC and pH with R^2=0.77.

Prediction of available water holding capacity can be made using the easily measured soil properties such as %soil organic carbon, %clay, %silt,% sand, soil structure and bulk density $p<0.0002$ (Table 11). It can also be easily estimated without including soil structure in the pedotransfer function (Table 11). Not including structure provides better statistical power, considering adjusted r square and the fitted plots (Figure 3). However, both multiple regression models indicate the potential of estimating the available water holding capacity. The endeavor that can result in serving resource in soil science application aspect. These findings are in line with the works of Schaap *et al.* (1999) and Young *et al.* (1999) who proposed the estimation of available water holding capacity using organic carbon, bulk density and porosity.

The prediction of soil organic carbon can be made using soil properties such as Hue, Value and Chroma. Taking account of dry and moist colors (Tables 9 and 10). The two pedotransfer functions indicate the potential for predicting soil organic matter. However, the epipedon's moist soil colors are observed to be the best predictors of soil organic carbon (Table 11). Using the epipedons (A-horizons) provides a better statistical power, considering adjusted r square and the fitted plot (Figure 3). There is minimal statistical potential for estimating soil organic carbon using the dry color. This finding is in line with the work of Wills *et al.* (2007) on the prediction of soil organic content in northeastern Iowa-USA using field and laboratory measurements, whose results showed that the soil colors could be used to predict the SOC across the landscapes. The results of the work of Mwango and others in the maize cropland ecosystem of Coastal plains of Tanzania proposed the estimation of soil organic carbon using the soil texture; the soil with more clay and silt contents correlated with higher contents of soil organic carbon (Mwango *et al.*, 2018)

CONCLUSION

The easily measured field and laboratory soil properties can be used to estimate the not easily measured and expensive soil properties using the accurately developed pedotransfer functions. Large data set is crucial to make the pedotransfer functions powerful. The soil organic carbon can best be predicted by the pedotransfer function of the epipedons' measured soil properties, while available water holding capacity is best estimated with the pedotransfer function not containing soil structure as one of the independent variables. In the case of CEC, the best estimation is made by a pedotransfer function that involves the independent variables from all the involved pedons.

RECOMMENDATION

The coefficients of the pedotransfer functions depend on the types of soils that have been used to develop the equations. Therefore the models are not constant and should be determined directly for the soils of interest. The use of large data sets is recommended to be used in developing powerful pedotransfer functions.

REFERENCE

i. *Bremmer, J.M and C.S Mulvaney. 1982. Total nitrogen. In: L.A. Page, R.H. Miller, and D.R. Keeney (Eds.) Methods of soil analysis, Part 2 (2nd Ed.) Agronomy Monograph No. 9. American Society of Agronomy and Soil Science Society of America, Madison, WI. pp 595-624.*

ii. *Chapman, H. D. 1965. Cation Exchange Capacity. In: C.A. Black (Ed.) Methods of soil analysis. Agronomy Monograph No. 9. American Society of Agronomy and Soil Science Society of America, Madison, WI.891-901pp.*

iii. *Cornelis, W.M., Ronsyn, J., Van Meirvenne, M. and Hartmann, R., 2001. Evaluation of pedotransfer functions for predicting the soil moisture retention curve. Soil Science Society of America Journal, 65(3), pp.63*

iv. *Cosby, B.J., Hornberger, G.M., Clapp, R.B., Ginn, T.R., 1984. A statistical exploration of the relationship of soil moisture characteristics to the physical properties of soils. Water Resource. Research. 20 (6), 682–690.*

v. *Eswaran, H., E. Van Den Berg, and P. Reich. 1993. Organic carbon in soils of the world. Soil Science Society of America Journal 57:192-194.*

vi. *Fieldes, M., and K. W. Perrot. 1966. The nature of allophane in soils. I. Significance of randomness in pedogenesis. New Zeland Journal of Science 9: 622-632.*

vii. *Gupta, S. and Larson, W.E., 1979. Estimating soil water retention characteristics from particle size distribution, organic matter percent, and bulk density. Water resources research, 15(6), pp.1633-1635.*

viii. *Hubert, Leirs, Herwig, 2014. Landform and surface attributes for prediction of rodent burrows in the Western Usambara Mountains, Tanzania. Tanzan. J. Health Res. 16 (3). https://doi.org/10.4314/thrb.v16i3.5.*

ix. *Jones, R. J., R. Hiederer, E. Rusco, and L. Montanarella. 2005. Estimating organic carbon in the soils of Europe for policy support. European Journal of Soil Science 56: 655-671.*

x. *Keshavarzi, A., Sarmadian, F., Omran, E.W., Iqbal, M., 2015. A neural network model for estimating soil phosphorus using terrain analysis, Egypt. J. Remote Sens. Space. Sci.https://doi.org/10.1016/j.ejrs.2015.06.004.*

xi. *Lakzian, A., Sangani, M.F., Astaraei, A., Fotovat, A., 2013. Estimation and mapping soil organic carbon content using terrain analysis (case study: Mashhad, Iran). J. Water Soil 27 (1), 180–192.*

xii. *Lal, R., 2012. World Soils and the Carbon Cycle in Relation to Climate Change and Food Security. Carbon Management and Sequestration Center. The Ohio State University, Columbus (52pp).*

xiii. *MacDonald K.B. 1998. Development of pedotransfer functions of southern Ontario soils. Report from greenhouse and processing crops research center, Harrow Ontario. No. 01686-8-0436*

xiv. *Mbaga, H.R., Msanya, B.M. and Mrema, J.P. 2017. Pedological characterization of typical soil of Dakawa Irrigation Scheme, Mvomero District, Morogoro Region, Tanzania. International Journal of Current Research Biosciences and Plant Biology 4 (6):77-86.*

xv. *Mclean, E.O. 1986. Soil pH and lime requirement. In: L.A. Page, R.H. Miller, and D.R. Keeney (Eds.) Methods of soil analysis, Part 2 (2nd Ed.) Agronomy Monograph No. vii. American Society of Agronomy and Soil Science Society of America, Madison, WI. p. 199-223*

xvi. *Mdemu, M.V., 2015. Evaluation and Development of Pedotransfer Functions for Estimating Soil Water Holding Capacity in the Tropics: The Case Of Sokoine University of Agriculture Farm in Morogoro, Tanzania. Journal of Geography and Geology, 7(1), p.1.*

xvii. *Meliyo, Joel L., Massawe, Boniface H.J., Msanya, Balthazar M., Kimaro, Didas N., Hieronimo, Proches, Mulungu, Loth S., Kihupi, Nganga I., Deckers, Jozef A., Gulinck,*

xviii. *Msanya, B.M., Magoggo, J.P. and Otsuka, H. (2002). Development of soil surveys in Tanzania. Pedologist 46:79-88.*

xix. *Msanya, B.M., Munishi, J., Amuri, N., Semu, E., Mhoro, L. and Malley, Z., 2016. Morphology, genesis, physico-chemical properties, classification and potential of soils derived from volcanic parent materials in selected Districts of Mbeya Region, Tanzania.*

xx. *Mwango, S.B., Wickama, J., Msanya, B.M., Kimaro, D.N., Mbogoni, J.D. and Meliyo, J.L., 2019. The use of pedo-transfer functions for estimating soil organic carbon contents in maize cropland ecosystem in the Coastal Plains of Tanzania. CATENA, 172, pp.163-169.*

xxi. *National Soil Service. 1990. Laboratory procedures for routine analysis, 3rd edition. Agricultural Research Institue. Mlingano Tanga, Tanzania. pp. 212*

xxii. *Nelson, D.W., and L.E. Sommers. 1982. Total organic carbon. In: L.A. Page, R.H. Miller, and D.R. Keeney (Eds.) Methods of soil analysis, Part 2 (2nd Ed.) Agronomy Monograph No. 9. American Society of Agronomy and Soil Science Society of America, Madison, WI. pp. 539-579.*

xxiii. *Obiero, J.P., Gumbe, L.O., Omuto, C.T., Hassan, M.A. and Agullo, J.O., 2013. Development of Pedotransfer Functions for Saturated Hydraulic Conductivity. Open Journal of Modern Hydrology, 3(03), p.154.*

xxiv. *Obiero, J.P., Gumbe, L.O., Omuto, C.T., Hassan, M.A. and Agullo, J.O., 2013. Development of Pedotransfer Functions for Saturated Hydraulic Conductivity. Open Journal of Modern Hydrology, 3(03), p.154.*

xxv. *Pachepsky, Y.A. and Rawls, W.J., 1999. Accuracy and reliability of pedotransfer functions as affected by grouping soils. Soil Science Society of America Journal, 63(6), pp.1748-1757.*

xxvi. *Pidgeon, J.D., 1972. The measurement and prediction of available water capacity of ferrallitic soils in Uganda. Journal of Soil Science, 23(4), pp.431-441.*

xxvii. *Pollacco, J. A. P. 2008. A generally applicable pedotransfer function that estimates field capacity and permanent wilting point from soil texture and bulk density. Canadian Journal of Soil Science 88: 761-774.*

xxviii. *Rasoulzadeh, A., 2011. Estimating hydraulic conductivity using pedotransfer functions.In: Elango, Lakshmanan (Ed.), Hydraulic Conductivity - Issues, Determination and Applications. InTech978-953-307-288-3, Available from: http://www.intechopen.com/books/hydraulic-conductivity-issues-determination-and-applications/ estimating-hydraulic-conductivity-using-pedotransfer-functions.*

xxix. *Saxton, K. E., W. Rawls, J. S. Romberger, and V. Papendick. 1986. Estimating generalized soil-water characteristics from texture. Soil Science Society of America Journal 50:1031-1036.*

xxx. *Schaap, M. G., Leij, F. J., & Genuchten, M. Th. 1999. Development of pedotransfer functions and related computer programs. U.S. Salinity Laboratory, Riverside, CA, pp 7.*

xxxi. *Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and Soil Survey Staff. 2012. Field book of describing and sampling soils, Version 3.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.*

xxxii. *Seilsepour, M. and Rashidi, M., 2008. Modeling of soil available phosphorus based on soil organic carbon. ARPN Journal of Agricultural Biological Science , 3, pp.1-5.*

xxxiii. *Seilsepour, M., Rashidi, M., 2008. Prediction of soil cation exchange capacity based on some soil physical and chemical properties. World Applied Science. Journal 3, 200–205.*

xxxiv. *Shelukindo, H.B., Semu, E., Msanya, B.M., Singh, B.R., Munishi, P.K.T., 2014b. Predictor variables for soil organic carbon contents in the Miombo woodlands ecosystem of Kitonga forest reserve, Tanzania. International Journal of Agricultural Science 4 (7), 222–231 (ISSN: 2167-0447).*

xxxv. *Sumner, M.E. and Miller, W.P., 1996. Cation exchange capacity and exchange coefficients. Methods of Soil Analysis Part 3—Chemical Methods, (methodsofsoilan3), pp.1201-1229.*

xxxvi. *Szilas, C., Møberg, J.P., Borggaard, O.K. and Semoka J.M. (2005). Mineralogy of characteristic well-drained soils of sub-humid to humid Tanzania. Acta Agriculturae Scandinavica, Section B-Soil and Plant Science 55: 241-251*

xxxvii. *Thomas, G.W. 1982. Exchangeable cations. In: L.A. Page, R.H. Miller, and D.R. Keeney (Eds.) Methods of soil analysis, Part 2 (2nd Ed.) Agronomy Monograph No. 9. American Society of Agronomy and Soil Science Society of America, Madison, WI. pp 595-624*

xxxviii. *Tietje, O., and Hennings, V. 1996. Accuracy of the saturated hydraulic conductivity prediction by pedo-transfer functions compared to variability within FAO textural classes. Geoderma, 69, 71-84.*

xxxix. *Van den Berg, M., E. Klamt, L. P. Van Reeuwijk, and W. G. Sombroek. 1997. Pedotransfer functions for the estimation of moisture retention characteristics of Ferralsols and related soils. Geoderma 78:161-180.*

xl. *Vareecken, H., Maes, J., Feyen, J., Darius, P., 1989. Estimating the soil moisture retention characteristics from texture, bulk density and carbon content. Soil Science. 148, 389–403.*

xli. *Vereecken, H. and Herbst, M., 2004. Statistical regression. Developments in soil science, 30, pp.3-19.*

xlii. *Wills, S.A., Burras, C.L. and Sandor, J.A., 2007. Prediction of soil organic carbon content using field and laboratory measurements of soil color. Soil Science Society of America Journal, 71(2), pp.380-388.*

xliii. *Wösten, J.H.M., Pachepsky, Y.A. and Rawls, W.J., 2001. Pedotransfer functions: bridging the gap between available basic soil data and missing soil hydraulic characteristics. Journal of hydrology, 251(3-4), pp.123-150.*

xliv. *Wösten, J.H.M., van Genuchten, M.T., 1988. Using texture and other soil properties to predict the unsaturated hydraulic conductivity. Soil Science Society of America Journal. 52, 1762–1770.*

xlv. *Young, M. D. B., Gowing, J. W., Hatibu, N., Mahoo, H. M. F., & Payton, R. W. 1999. Assessment and development of pedotransfer functions for Semi-Arid Sub-Saharan Africa. Physics and Chemistry of the Earth –European Geophysical Society (B), Elsevier Science Ltd. 24, 845–849.*