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Modelling the relationship between soil color and particle size for soil survey in Ferralsol environments

B. Kone[1, 2,*], A. Yao-Kouame[2], J.B. Ettien[2], S. Oikeh[1], G. Yoro[3] and S. Diatta[1]
[1]Africa Rice Center (WARDA) Cotonou, 01 BP 2031 Cotonou
[2]Université de Cocody-Abidjan, UFR des Sciences de la Terre et des Ressources Minière, Côte d'Ivoire.
[3]Centre National de Recherche Agronomique (CNRA), Gagnoa, Côte d'Ivoire

Abstract

Soil texture is an important property for evaluating its inherent fertility especially by using pedo-transfers functions requiring particle size data. However, there is no existing quantitative method for in situ estimation of soil particle size, delaying judgement of soil chemical properties in the field. For this purpose, laboratory particle size analyses of 1028 samples from 281 Ferralsol profiles, located between latitudes 7º N and 10º N in Côte d'Ivoire and their respective colour notation by Munsell chart were used to generate prediction models. Multiple Linear Regression Analysis by Group was processed to identify clay, sand and silt contents in the soil based on color hue (2.5YR, 5YR, 7.5YR, and 10YR) and Chroma (1, 2, 3, 4, 5, 6, 7, 8). The evaluation was conducted for each horizon coded as H1 (0-20 cm), H2 (20-60 cm), H3 (60-80 cm) and H4 (80-150 cm) and used as grouping variables. Highly significant (P< 0.001) models were identified for clay and sand. These models were used to estimate successfully clay and sand contents for other Ferralsol samples by comparing calculated and measured mean using the null hypothesis of difference and Tukey's tests. They were accurate for at all depths, except 80 - 150 cm, for sand in 10YR soils. The method was deemed appropriate for in situ estimation of soil particle size contents in Ferralsol environment for improving reconnaissance agricultural soil surveys.

Key words: Ferralsols, models, particle size, soil color, soil survey

Introduction

Physical properties of soils with low cation exchange capacity (CEC), such as Ferralsols in West Africa, are important for sustaining high farm productivity and prevention of soil degradation that can be induced by intensive and continuous farming (Lal, 1987). Soil texture is a major physical property controlling the variability of other quality components, specifically those parts below the organic horizon (Pardini *et al.,* 2004). Therefore, it has been used for pedo-transfer functions (Bouma, 1989), helping for example, to predict soil hydrodynamic characteristics (FAO, 2007) and to ascertain the soil structural instability index (Henin *et al.,* 1960; Briones and Veraciones, 1965). It also accounts for geochemical processes variability along the toposequence (Hook and Ingrid, 2000) and is highly correlated with crop yield (Avendaňo *et al.,* 2004). Together with other criteria, texture is, therefore, extremely relevant in soil survey for agricultural evaluation.

To access the potential of soil texture for agriculture, it is important to know soil particle size (PS) distribution, at least in terms of the proportion of sand, silt and clay. This information has been used in most of the existing models (SOILPARA) of soil parameters (Scientific Software Group, 1998). Thus, knowledge of soil PS distribution is a prerequisite in soil survey for agriculture.

We are not aware of any quantitative field method for in-situ estimation of soil particle sizes. This is a hindrance to the quantitative evaluation of the other parameters. Currently, soil samples must be analyzed in a laboratory (Gee and Bauder, 1986). This is costly and time consuming, thus, slows down decision-making process, despite the use of the tactile method (Clark, 1936) which refers only to texture with limited inference to laboratory test results (Rice, 2002).

The simplified method of particle size analysis developed by Kettler *et al*. (2001) is also for use in the laboratory and cannot be used in the field during soil surveys. A quicker and cheaper method for predicting soil particle size in the field is therefore necessary as a method of soil judgment (Getty *et al*. 2003).

A number of water-shed studies are being conducted outside Africa on predicting spatial variation of soil particle sizes through various remote sensing methods (Hwang, 2004; Zhai *et al*. 2006). However, this is not yet the case in

*Email: b.kone@cgiar.org

Africa, where studies conducted so far have been merely descriptive (Levèque, 1977; Greenland, 1981) and not suitable for quantitative prediction of soil particle sizes.

It is well known that soil color has lateral and vertical gradients, which are parallels to soil texture gradient along the toposequence and across soil depth, respectively (Blavet, 2000; Cornus *et al.,* 2005). Furthermore, soil color can provide information about soil organic matter, drainage and biotic activities in Ferralsol environments (Poss and Valentin, 1983). It was reported good relationships between landscape, soil texture and fertility and soil color (Koné *et al.,* 2009). Therefore, we hypothesize that soil color can be used to determine soil particle size contents. Linear models, previously used successfully by Soybold *et al.* (2005) for CEC prediction in the USA, and recommended for Alfisols that are a predominant soil type in the West African savannah (Lal, 1987), can meet this requirement.

The color of Ferralsols is due to its iron content (Mauricio and Ildeu, 2005) which is also related to soil color hue (Segalen, 1969) and chroma (Scheinot and Schwertmann, 1999). Although variable according to some observers, color notation by Munsell chart is still the current reliable method of soil color determination, especially in the field (Barrett, 2002; Islam *et al*., 2004). Therefore, dominant hues (2.5YR, 5YR, 7.5YR and 10YR) and their chroma in ferralsol environment (Segalen, 1969; Shulte and Ruhiyat, 1998) as described by Munsell chart can be used as explanatory variables in the linear model.

The objective of this study was to identify an innovative tool for in-situ estimation of particle size of Ferralsols. The study concerned the savannah and transitional zones of West Africa (Côte d'Ivoire) and Multiple Linear Regression Analysis of soil color hue (T) and chroma (C) will be used.

Materials and Methods

Study zone location

The study was carried out at 19 sites on Ferralsols (FAO *et al*., 1998) located between latitude 7° N and 10° N in Côte d'Ivoire (Figure 1). This area covers the four major agro-ecological zones described by Eldin (1971) - Sudan savannah with grassland, Guinea savannah with woodland, derived savannah (a transition between savannah and forest agro ecologies), and a zone located in the far western mountainous area of the country. Annual average rainfall ranges from 1200 to 2000 mm.

Landscapes and soils

The area surveyed abounds in landscapes with dismantled or unaffected summit ferruginous cuirass plateau landscapes with concave-convex or convex-concave sides, as well as variable rocky outcroppings. A few Inselbergs were also observed. Upland soils concerned by the study were essentially Epidystric, Hyperdystric and Dystric Ferralsols. The world reference base for soil resources-WBSR (FAO *et al.,* 1998) was used for soil classification.

Soil sampling and particle size analysis

A total of 1028 samples (2 kg each) were taken from horizons up to a maximum depth of 1.5 m. Two hundred and eighty-nine (289) soil profiles were surveyed along representative catena of various landscapes at 19 sites, which were unequally distributed on three groups of Ferralsol in the study area (Figure 1). A randomized unequal sampling (Webster and Oliver, 1990) stratified by groups of Ferralsol was applied to the studied area. Along the catena of representative landscapes, the soil profiles were done at equidistance of 100 m from the summit to the foot slope. Lowland soils were not concerned.

The identified horizons in the soil profiles were coded according to depth classes - H1 (0–20 cm), H2 (20–60 cm), H3 (60–80) cm and H4 (80–150 cm). The soil profiles were divided into organic horizons (Diatta, 1996), minimum, medium and maximum crop rooting depths (Weaver, 1926; Böhn, 1976; Chopart, 1985), consistent with soil profiles A, B, B/C, and C horizons described earlier for the study area by Berger (1964).

Soil color was identified using the Munsell chart. Soil particle sizes (sand, clay and silt contents) were determined with the Robinson pipette method (Gee and Bauder, 1986) and labelled as measured values (MV).

Regression Analysis

Statistical Analysis Software-SAS (1989) was used to perform a Pearson correlation (R) of the soil color (numerical part of hue-T and chroma-C) with the weighted mean values of soil PS (clay, sand and silt) was analyzed by depth class to test how well they correlate with each other considering the values of R and its probability. The described horizon thickness was used as the weighted variable. Regression curves were drawn using Excel software (Microsoft, 2003) to generate regression coefficients (R^2) for each PS in the 0-20 cm horizon according to hue (T). The stepwise method was used to evaluate the model fitness considering the highest value of R^2.

Multiple Linear Regression Analysis Grouped (MLRAG) of soil PS (clay, sand and silt) was done by the soil color hue (T) and chroma (C) as explanatory variables for the different depth classes (H1, H2, H3 and H4) as group variables. MLRAG parameters were therefore T, C, H1, H2, H3, H4, and their respective interactions (T × H, C × H) as well as the regression constant (Cte). GenStat released 7.2 DE (GenStat, 2007) was used for these analysis.

Step 3: Cte + β1.T+ β2.C + β3.H2 + β4.H3 + β5.H4 + β6.T×H2 + β7.T×H3 + β8.T×H4 + β9.C×H2 + β10.C × H3 + β11.C × H4 **[3]**

H1 was used as the reference factor in the analysis.

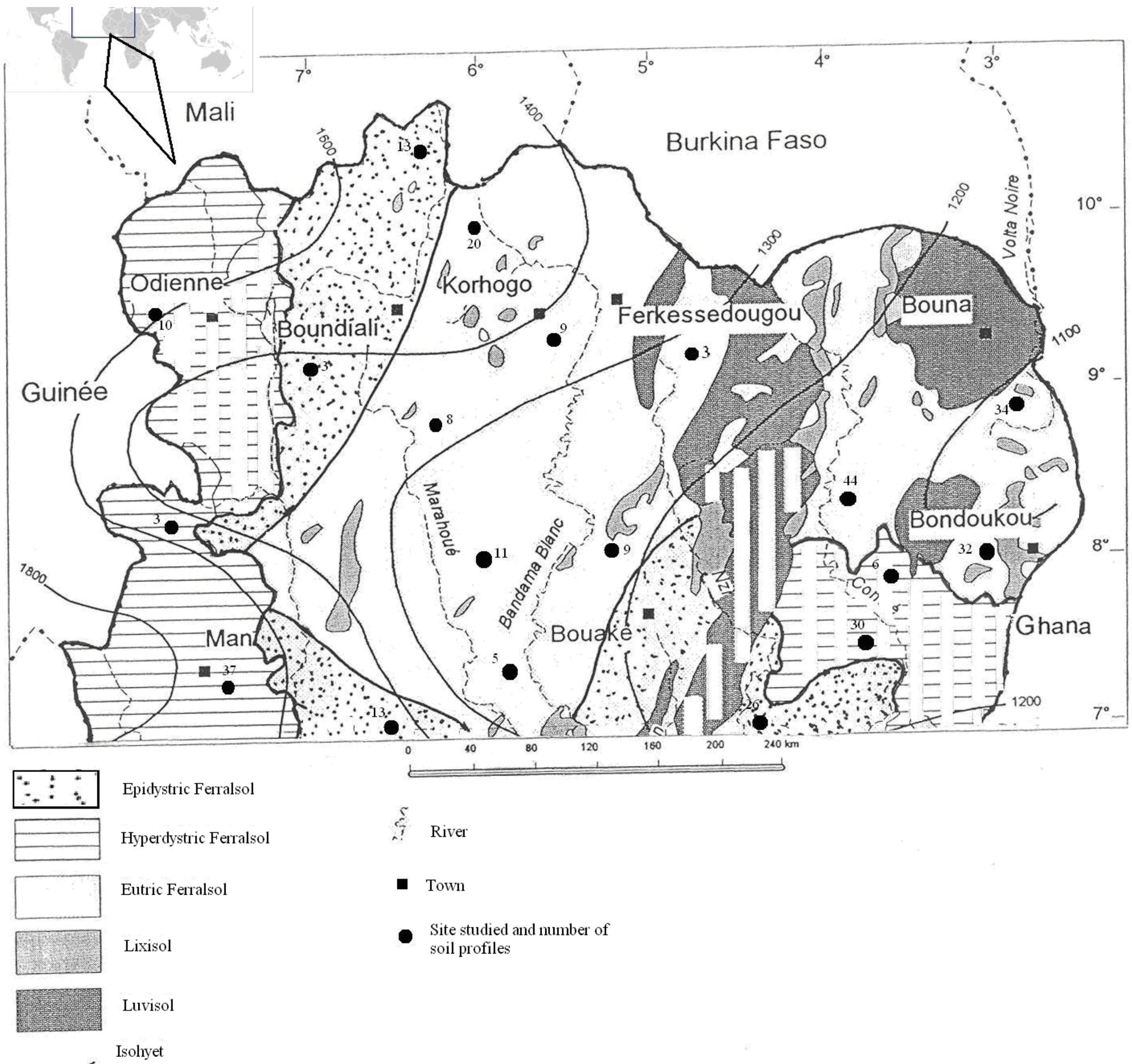

Figure 1. Number and location of soil profiles according different groups of Ferralsol of the zone studied

Model structure

The model of calculated value 1 (CV1) was generated by stepwise analysis (Hocking, 1976) as shown below:

Step 1: Cte + β1.T + β2.C **[1]**

Step 2: Cte + β1.T+ β2.C + β3.H2 + β4.H3 + β5.H4 **[2]**

β represents the slope of the respective parameters (1, 2, 3, 4, 5, 6, 7 and 8).

CV1 was calculated in a given horizon by allocating a value of 1 to H and replacing T and C by their numerical values. The constant (Cte) was always included in the model structure. CV1 structure in H1 was Cte + β1.T + β2.C.

Fitting models

The F-test probability (*P*) was used to assess the relevance of the regression for any expected prediction. The use of the parameters for model terms was also confirmed by the t-statistical probability. The various probabilities were evaluated for significance at $\alpha = 0.05$ using SAS (1989). Significant parameters from significant regressions were considered as fit models for specific PS.

Model accuracy and validation

The model terms generated by regression were used to calculate CV1 while model standard deviation (SD), also generated by the analysis, helped to calculate CV2 and CV3 as shown below:

$$CV2 = CV1 + SD \quad \textbf{[5]}$$

$$CV3 = CV1 - SD \quad \textbf{[6]}$$

Therefore, each explained variable had three calculated values (CV1, CV2 and CV3) and a measured value (MV).

Model accuracy and validation were studied by comparing the calculated values with the corresponding measured values (MV). For this purpose, 608 new samples from 40 soil profiles in the study area were used. They were analyzed in the laboratory to generate new measured values (MV) of PS. These MV were compared to their corresponding calculated values (CV1, CV2 and CV3) based on the appropriate fitted models in a particular depth class. Using GLM analysis, the four values of a PS were compared one by one (1:1) using the null hypothesis of difference. The difference in the values and its probability were generated by SAS (1989) for H, T, C and the interaction-C × T.

The Least Square Mean (LSM) values were also compared graphically according to color hue in every depth class. The significance of differences between LSM of calculated and MV was evaluated by Root Mean Square Error (MSE) for accurate model validation for other samples.

Results

Fitting models

There was a higher fit of polynomial ($R^2 > 0.90$) trends of soil PS than the linear ($0.4 < R^2 < 0.69$) trend (Figure 2). The results mean a complex relationship between soil color hue (T) and its PS content, according to the lateral gradient of soil color, while changing from 2.5YR to 10YR progressively through 5YR and 7.5YR. However, each trend showed a decrease in clay and silt contents, while enrichment was observed in sand content in the 0–20 cm horizon concomitantly with T increasing in yellowness. Therefore, redder (2.5YR and 5YR) Ferralsols are richer in fine PS (clay and silt) than the yellowish Ferralsols (7.5YR and 10YR), which had the highest content of sand.

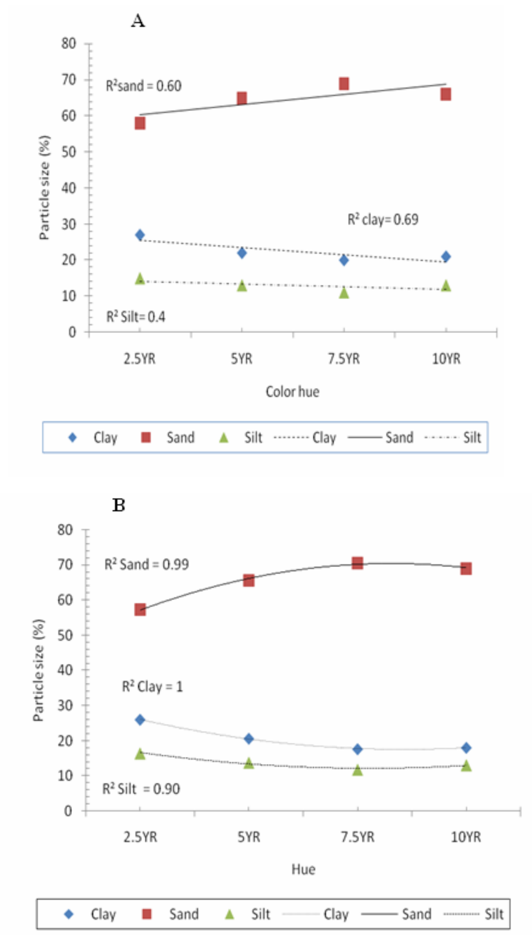

Figure 2. Linear-A and non-linear-B relationships evaluation between soil color (2.5YR, 5YR, 7.5YR and 10YR) and its' particle size in horizon 0–20 cm

For the soil profile, Table 1 shows highly significant ($P<0.01$) correlations (R) between T and C with clay and sand from H1 to H4; the lowest values of R were observed for silt, which was significantly correlated ($P<0.05$) only in H1 and H2. These results indicate a stronger and more consistent relationship of soil color parameters (T and C) with clay and sand than with silt.

In fact, the results of MLRAG for clay, sand and silt contents using T and C by depth class (H1, H2, H3 and H4), showed a significant ($P<0.001$) probability for regression and most of the parameters for clay and sand (Table 2). Except for T and the constant (Cte), other parameters were not significant for silt estimation. Therefore, no linear model was obtained for silt content prediction in Ferralsol profiles. Meanwhile, clay and sand can be estimated by different models using T and C according to soil depth, as presented in Table 3.

Model accuracy and validation

Accurate models for clay and sand were identified by GLM analysis comparing PS mean values (CV1, CV2, CV3, and MV) one by one (1:1) using the null hypothesis test of difference and Tukey's test. Difference between values and their probability are presented in Table 4 for clay and for sand (Table 5) in the 0–20 cm horizon. The result was presented exclusively for chroma 3 as an example of model accuracy calculation.

There were no significant (P > 0.05) differences between the predicted values (CV1) and the measured values (MV) both for clay and sand for 2.5YR, 5YR and 10YR soils (Tables 4 and 5). Despite of the significant probability (P = 0.037) of the null hypothesis test, Tukey's test can attest the accuracy of CV1 for sand in 2.5YR soils (Table 5). Lower values of differences observed for CV3 of clay (Table 4) and CV2 of sand (Table 5) in 7.5YR soils can allow their use for respective PS prediction. The accuracy of the model CV2 was also revealed for clay (2.5YR and 10YR) and sand (5YR). Thus, CV1 was more accurate model for PS prediction in the 0 – 20 cm depth.

Table 1. Pearson correlation and its' probability of PS weighted mean values with soil hue (T) and chroma (C) by soil depth (H)[1]

		Correlation coefficients and probability					
		Clay		Sand		Silt	
		R	***P***	**R**	***P***	**R**	***P***
H1	T	-0.29	<0.0001	0.31	<0.0001	-0.17	0.0008
	C	0.36	<0.0001	-0.37	<0.0001	0.14	0.0072
H2	T	-0.37	<0.0001	0.39	<0.0001	-0.18	0.0014
	C	0.31	<0.0001	-0.24	<0.0001	-0.05	0.3173
H3	T	-0.43	<0.0001	0.41	<0.0001	-0.10	0.1383
	C	0.24	0.0003	-0.21	0.0017	0.005	0.9365
H4	T	-0.50	<0.0001	0.47	<0.0001	-0.003	0.9702
	C	0.29	0.0009	-0.28	0.0017	0.009	0.9154

[1]n (population) = 319 (H1); 351 (H2); 220 (H3) and 138 (H4)

Table 2. Probability evaluation of the Multiple Linear Regressions and their parameters for soil particle sizes (Clay, Sand and Silt) grouped per soil depths (H1, H2, H3 and H4)

Parameter	slop (ß) and probability (*P*)					
	Clay		Sand		Silt	
	β	***P***	**β**	***P***	**β**	***P***
Constant	17.91	<0.001	68.1	<0.001	13.99	<0.001
T	-0.667	0.005	1.039	<0.001	-0.37	0.014
C	1.999	<0.001	-2.462	<0.001	0.463	0.087
H2	12.67	0.001	-17.38	<0.001	4.71	0.056
H3	28.26	<0.001	-26.99	<0.001	-1.27	0.685
H4	21.91	<0.001	-20.23	0.007	-1.68	0.663
T × H2	-1.073	0.003	1.346	0.002	-0.272	0.236
T × H3	-1.710	<0.001	1.599	0.001	0.111	0.667
T×H4	-1.373	0.003	0.959	0.001	0.415	0.162
C×H2	-0.096	0.871	1.095	0.093	-0.999	0.008
C×H3	-1.499	0.026	2.041	0.013	-0.542	0.205
C×H4	-0.292	0.716	0.719	0.466	-0.426	0.405
Reg.*P*.	<0.001		<0.001		<0.001	
Var. (%)	40.8		30.6		3.9	
SD (%)	10.5		12.9		6.69	

Model terms: (Clay; Sand; Silt) = Const. + T + C + H + T × H + C × H ; H1 is the reference factor

The validation tests showed the existence of highly accurate models in each horizon (H) for clay (Figure 3) and sand (Figure 4) contents according to the hue (T). The models CV1 and CV3 in that order were more accurate for clay prediction. Similar case was noticed for sand considering CV1 and CV2. However, for sand content, the model's accuracy was low in H3 and H4 for 10YR soils. Thus, any model was validated for these soil samples as shown in Table 6.

Table 3. Models selected for soil particle size prediction after the Multiple Linear Regression Analysis by color hue (T) and chroma (C) at each depth (H)

Dependent Variable	Independent Variable	Model (CV1)	Error	CV (%)
Clay (%)	T, C (H1)	17.91 – 0.667 T + 1.999 C	10.5	41.0
	T, C (H2)	30.58 – 1.745 T + 1.999 C	10.5	38.3
	T, C (H3)	46.17 – 2.377 T + 0.5 C	10.5	32.2
	T, C (H4)	39.82 – 2.04 T + 1.999 C	10.5	42.2
Sand (%)	T, C (H1)	68.1 + 1.039 T – 2.462 C	12.9	18.7
	T, C (H2)	50.72 + 2.385 T – 1.372 C	12.9	25.1
	T, C (H3)	41.11 + 2.638 T – 0.421 C	12.9	26.8
	T, C (H4)	47.87 + 1.998 T – 2.462 C	12.9	37.5
Silt (%)	T, C (H1, H2, H3, H4)			100-[Clay–Sand]

C = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11

Table 4. Comparison of clay predicted values (CV1, CV2, V3) with measured value (MV) by soil color hue and chroma 3 in H1 (0-20 cm)

Color		LSM (%)	SE	Difference	
				Effect	Pr>|T|
2.5YR/3	CV1	22.2	3.33	-0.17ns	0.869
	CV2	32.7	3.33	2.06ns	0.073
	CV3	11.7	3.33	-2.40	0.043
	MV	23.0	3.33		
5YR/3	CV1	20.6	1.16	0.62ns	0.536
	CV2	31.1	1.16	7.03	0.0001
	CV3	10.1	1.16	-5.77	0.0001
	MV	19.5	1.16		
7.5YR/3	CV1	18.9	1.49×10^{-6}	6.9	-----
	VC2	29.4	1.49×10^{-6}	17.4	-----
	CV3	08.4	1.49×10^{-6}	-3.59	-----
	MV	12.0	1.49×10^{-6}		
10YR/3	CV1	17.2	2.30	-6.26ns	0.013
	CV2	27.7	2.30	4.23ns	0.080
	CV3	06.7	2.30	-16.7	<0.0001
	MV	23.5	2.30		

ns: no significant difference with MV according to Tukey's test.
------: not defined because of low effective (1)

Discussion

Particle size spatial distribution

Based on the highest R^2 values, the second-degree polynomial trends (Figure 2b) were identified for clay, sand and silt estimations by soil color hue (T), considering its lateral gradient (Blavet *et al.*, 2000) consisting in change from red (summit) to yellow (low slop) in the 0 – 20 cm soil depth. Particle size contents in the soil of 10YR were suspected to have induced these polynomial trends. In fact, a linear trend of respective PS can be observed when the soil color was changed from 2.5YR, 5YR to 7.5YR (Figure 2a). To fit the increase in clay and silt contents in soil of 10YR the polynomial trends were more suitable. Similar effect was also induced by the decrease of sand particle content in soil of 10YR compared to the one of 7.5YR (Figure 2b). These results revealed some accumulation of fine particles in the soil (10YR) of lower slope as consequence of lateral transport of water along the toposequence. Thus, our study is supporting the warping process in the soil of the lower slope in ferralsol environment (Roose, 1979) in opposition to the concept of total evacuation of mobilized particles in the lowland (Poss, 1978). Water table fluctuation and the temporal saturated status of the soil in lower slop (10YR) could have induced this deposition slowing down hypodermic water flow. These analyses show the particularity of Ferralsol of 10YR in color hue compared to those of 2.5YR, 5YR and 7.5YR.

in the topsoil as follows: soils in the summit and upper slope are more reddish (2.5YR and 5YR), with the highest content of clay and silt, while soils in the midslope and lower slope are more yellowish, with the highest content of sand. Thus, the content of coarse particles in the soil increased from the summit to the lower slope, while soil color increased in the intensity of yellow.

Similar results were earlier reported by Fritsch (1993) in northern Côte d'Ivoire but no model was proposed to explain the trends in soil PS. Thus, our results have expounded on the knowledge of the morpho-pedology of Ferralsols. Moreover, by considering the chroma as a subunit of hue (×-axis), it may be possible to estimate soil

Table 5. Comparison of Sand predicted values (CV1, CV2, V3) with measured value (MV) by soil color hue and chroma 3 in H1 (0-20 cm)

Color		LSM (%)	SE	Differences	
				Effect	Pr>|T|
2.5YR/3	CV1	63.3	1.49	-5.35ns	0.037
	CV2	76.2	1.49	7.57	0.008
	CV3	50.4	1.49	-18.20	<0.0001
	MV	68.6	1.49		
5YR/3	CV1	65.9	4.75	-3.59ns	0.621
	CV2	78.8	4.75	9.30ns	0.238
	CV3	53.0	4.75	-16.49	0.070
	MV	69.5	4.75		
7.5YR/3	CV1	68.5	1.43×10^{-6}	-7.5	-----
	CV2	81.4	1.43×10^{-6}	5.4	-----
	CV3	55.6	1.43×10^{-6}	-20.3	-----
	MV	76	1.43×10^{-6}		
10YR/3	CV1	71.1	1.61	5.43ns	0.027
	CV2	84.0	1.61	17.80	<0.0001
	CV3	60.7	1.61	-7.15	0.003
	MV	65.6			

ns: no significant difference with MV according to Tukey's test.
------: not defined because of low effective (1)

Table 6. User guide for prediction models for ferralsol soil particle size

	Depths	Soil color hue			
		2.5YR	5YR	7.5YR	10YR
Clay	H1	CV1	CV1	CV1	CV1
	H2	CV1	CV1	CV1	CV3
	H3	CV1	CV1	CV1	CV3
	H4	CV1	CV3	CV1	CV3
Sand	H1	CV1	CV1	CV1	CV1
	H2	CV2	CV1	CV1	CV3
	H3	CV2	CV1	CV1	----
	H4	CV1	CV1	CV1	----
Silt	(H1, H2, H3, H4)				100-[Clay +Sand]

----: not validated

Moreover, based on the established relationship between Ferralsols color hue and texture gradients along a toposequence (Ray and Jamil, 1986; Koné *et al*., 2009), our results can be used to interpret the spatial distribution of PS

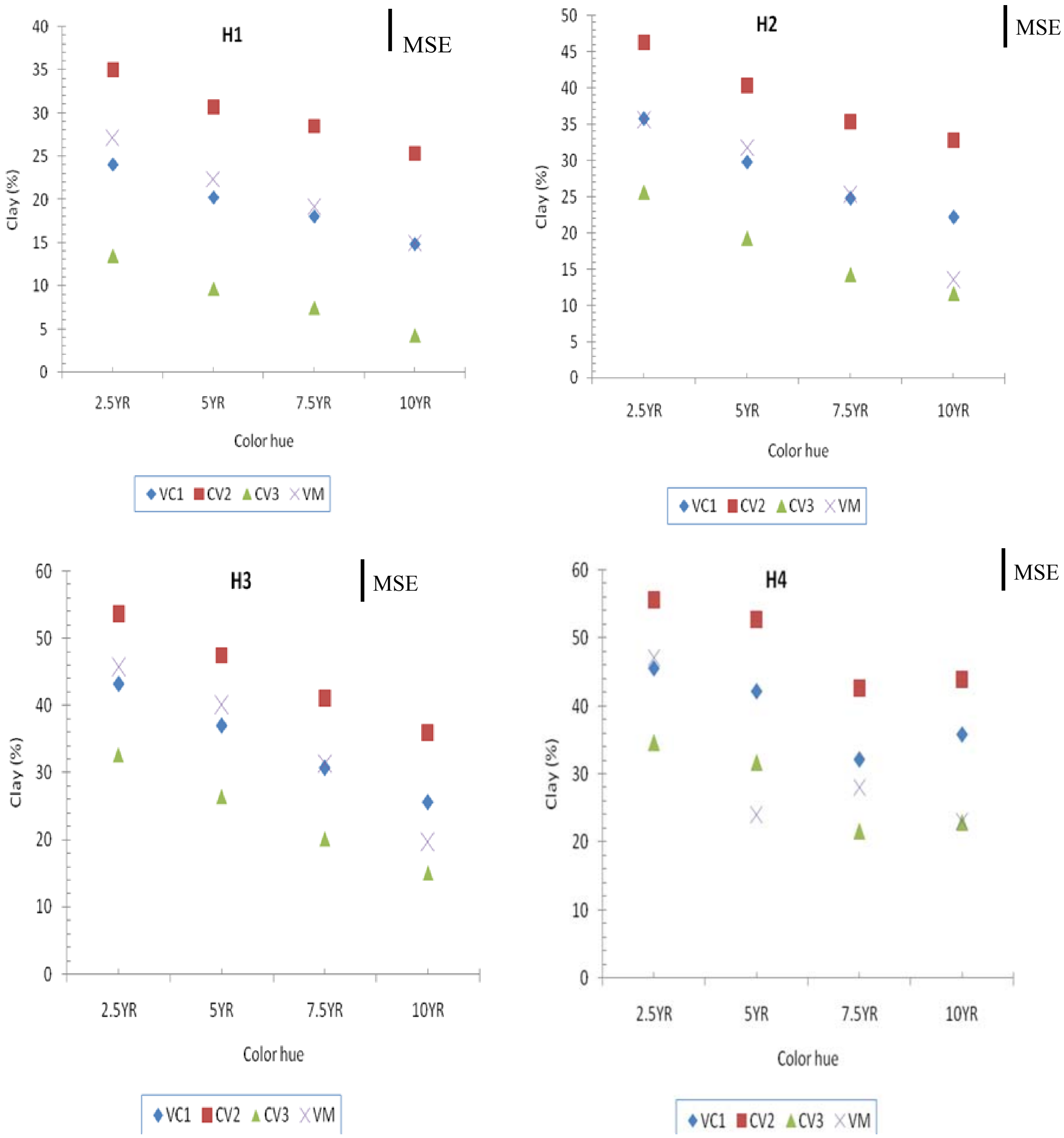

Figure 3. Comparisons of measured values (VM) with the calculated values (VC1, VC2, VC3) in each depth (H1, H2, H3, H4) by color hue for clay soil content

PS even on a smaller scale (in farmers' fields). Therefore, these polynomial models could serve as a tool for mapping soil texture with a positive implication for landscape planning and for agricultural purposes (Roche *et al.*, 1980).

Although the existing multiple linear models for PS distribution were established for Australian soils by Minasny and McBratney (2007), it has not been used in Africa. This may be due to the non-availability of the Landsat TM data required. Therefore, the findings of our study can serve as on needed alternative method for estimating spatial distribution of soil particle size in Africa and as a useful tool for resource-limited scientists in developing countries.

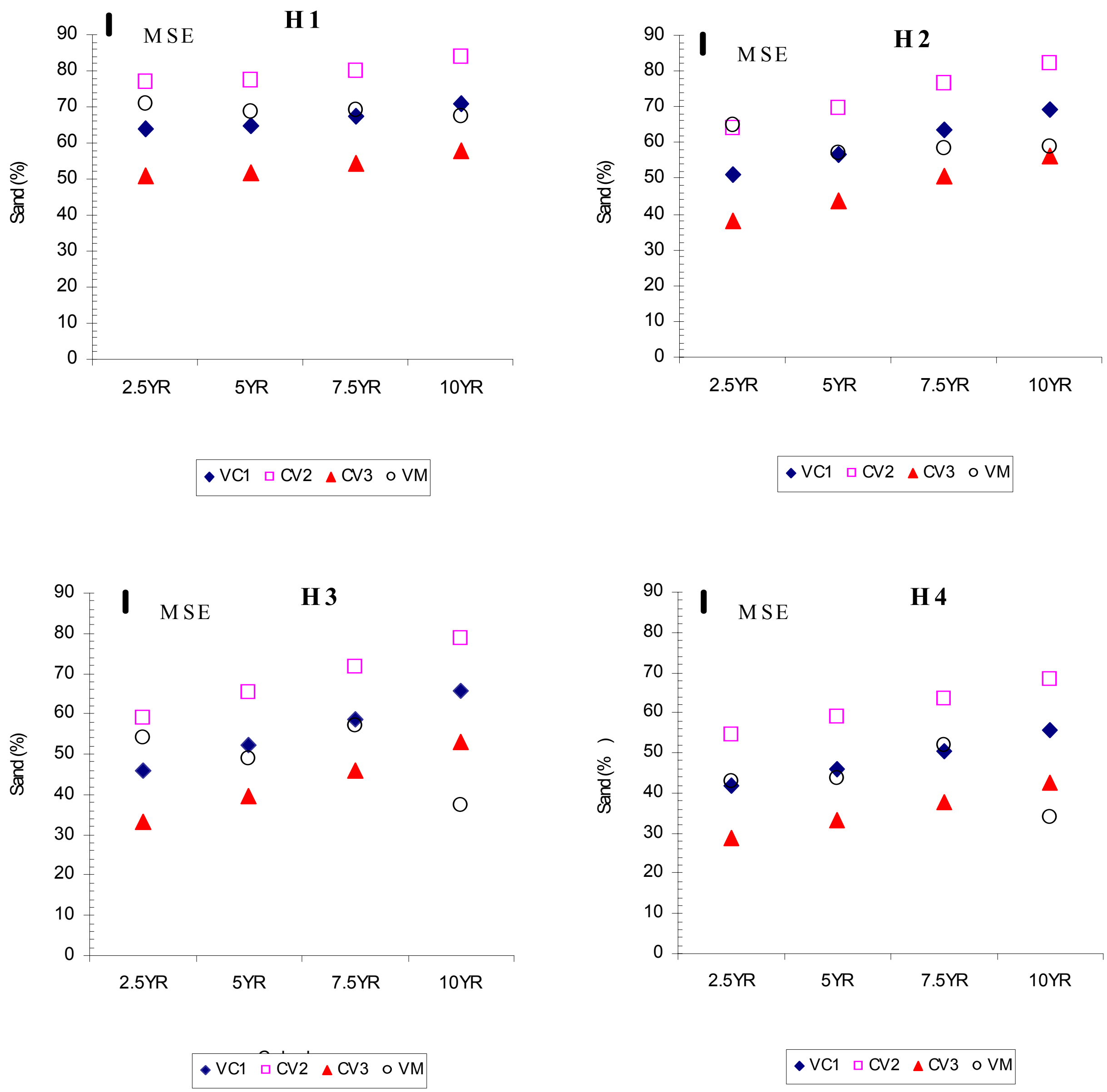

Figure 4. Comparisons of measured values (VM) with the calculated values (VC1, VC2, VC3) in each depth (H1, H2, H3, H4) by color hue for sandy soil content

Linear models accuracy

The combined uses of the color hue and chroma have reduced the effect of the characteristics attributed to soil of 10YR in the polynomial of PS trends leading to linear models of clay and sand prediction. Differences in the mineralogy of the respective soil particles, as well as in their mobilization process especially the vertical transportation (migration) by water, could account for these model fit of T and C and the lack of model fit for silt, using MLRAG grouped by depth class (H) (Table 2). In fact, vertical mobilized particle sizes were identified between 10^{-1} and 10 µm (Pilgrim and Huff, 1993; Kaplan *et al.*, 1997), indicating that a part of the silt (2 – 20 or 50 µm) was not mobilized, and therefore, not carried across the soil profile by water as was the case for clay particles (< 2 µm). This variability in the mobilization of silt particles was also different from that of sand particles, which is not transported vertically by water and thus remained as elluviated particles. Moreover, the clay mineralogy in our study (Ferralsol) is essentially composed of kaolinit, illite and smectite in different ratios according to the toposequence position and across the soil profile (Diatta, 1996). Considering the significant influence induced by clay mineralogy on hematite and goethite in the soil (Schwertmann, 1988; Marcedo and Bryant, 1989), as well as influencing soil color, soil clay content must be related to soil redness. In addition to the increasing loss of soil amorphous iron component concomitantly with the loss of clay and silt particles by weathering (Roose, 1977), there was an evidence from our study of a strong relationship between clay particle content and soil color across the soil profile and along the toposéquence (Table 1 and Figure 2). Therefore, soil color in Ferralsol is a suitable explanatory variable of PS in Ferralsol.

As principal factor of soil particle size distribution, water dynamic in Ferralsols is also linear based on the linear decrease of soil hydraulic conductibility observed by Mbagwu *et al*. (1983) in depths of 0-60 cm and 60-100 cm. This observation can explain the linear distribution of clay particles in the soil profile by water. The linear models of sand content in the soil might be essentially impaired by the linear distribution of clay particles, assuming that the effect of silt particles mobilization is minor due to their lower content in Ferralsols (Baena, 1997). Although not related to soil iron component (color), the significant linear regression of soil secondary components (synthesized material) using clay content in Ferralsols as described by Fritsch (1993) was consistent with our results.

The existence of fit model for soil content in clay and sand can help to deduct soil content in silt. Therefore, our results have generated knowledge on the use of soil color to predict soil PS for the use of pedo-transfer functions in the field. Therefore, it can be a significant contribution for reconnaissance agricultural soil survey. The use of the linear analog in the CREEP model for diffusion and mass transport simulation in soils (Rosenbloom *et al*., 2003) supports the applicability of our findings.

However, the models for sand contents were not validated at depth H3 and H4, possibly because the limited soil sample-size for 10YR resulted in model error (Wonnacott and Wonnacott, 1990). Therefore, a larger sample size (>40) would be needed in future studies for validating these models at depth 60 – 150 cm. Nevertheless, the method is suitable for predicting soil particle size in the topsoil (0 – 60 cm), which is more relevant for crop rooting profile (Ayotte, 2007) and soil degradation. Therefore, the use of soil color T and C seems to be an additional method to the use of soil redness as proposed by Hurst (1977) and Torrent *et al*. (1980; 1983) for describing soil properties especially for agriculture.

This study revealed a rapid, simple and inexpensive method for evaluating soil particle size in Ferralsols environments dominated by 2.5YR, 5YR, 7.5YR and 10YR soil color hue. It therefore provides a tool for soil mapping in agronomic reconnaissance with implications for precision agriculture and landscape planning. The observed incidence of soil color changes by weathering and land use over time by farmers in northern Côte d'Ivoire (Pieri, 1989) support the application of our results for land degradation surveillance.

Conclusion

Multiple linear regression analysis grouped by soil depth helped to identify accurate models for predicting clay and sand contents in Ferralsols, and to determine silt content by subtraction. The lack of more accurate tool (portable infrared spectrophotometer) for soil color measurement in the field (Islam, 2004) justifies the use of Munsell color chart for this purpose. More samples are required for the estimation of sand content at 60 – 150 cm depth for 10YR soils. However, the results obtained for 0 – 60 cm depth have an important application for agricultural and environmental purposes.

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