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CHARACTERIZATION AND CLASSIFICATION OF A TYPICAL IRON PAN SOIL FORMED OVER VOLTAIAN SHALE

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Abstract
Since the publication of the soil survey reports of Ghana by the Soil Research Institute, both Soil Taxonomy and the Word Reference Base (WRB) systems of soil classification have undergone many revisions. As a result, nomenclature used in these survey reports have become obsolete if not misleading. This study was carried out to characterize and classify the Kpelesawgu series using the most recent editions of Soil Taxonomy and the WRB in order to highlight the necessity for a comprehensive overhaul of Ghana's soil survey reports. The study was carried out in Lungbunga, a community in the Tolon district of the Northern Region of Ghana. Three pedons were dug to petroplinthite and a detailed morphological description of the horizons made. Disturbed soil samples were collected, air-dried, and sieved for laboratory analyses. The pH values showed the soils were generally very strongly acid in reaction. The ECEC values of all the pedons were low and ranged from 3.22cmol/kg to 5.87cmol/kg indicating the absence of primary weatherable minerals. The organic matter content of the soil was very low (< 1.30%). The argillic horizon (Bt) was the main diagnostic horizon encountered in all the three pedons. A massive ironpan was encountered at a depth 90 cm for pedon one and 60 cm for pedons two and three. Under Soil Taxonomy, the previous classifications recognized the existence of plinthite in the soil profile but not the agronomically important ironpan. We propose the creation of a "Petro" subgroup under Plinthaqualf to accommodate the classification of the Kpelesawgu series. So that the soil would be classified as a Petro Plinthaqualf at the subgroup category. Under the IUSS Working Group WRB, 2015, we propose a new name {Petric Plinthosol (Lixic)} which captures properties relevant for land use and management.

Keywords: Soil Taxonomy, WRB, Kpelesawgu series, plinthite, ironpan

Introduction

Pans are soil horizons that are strongly compacted, indurated or very high in clay content. Depending on the cementing agent or nature of compaction there are different types. Ironpan, plough pan, duripan, fragipan are examples of pans that occur in different soils across the globe.

Soils with ironpan (Petroplinthite) horizons are extensive in Ghana and cover almost 50% percent of the interior savannah zone and about 25% of the whole country (Obeng, 1970). Soils with ironpan horizons present serious challenges in their utilization for agricultural purposes especially when the ironpan horizons occur close to the surface. They restrict the development of roots and contribute to waterlogging of soils. These ironpan horizons easily get exposed on the surface if these soils are not properly managed. In extreme cases such eroded soils are eventually rendered completely barren becoming unsuitable for cultivation (Obeng, 1970).

Soils in the Kpelesawgu association are among the most common ironpan soils developed over shales within the gently undulating peneplains of the interior savanna of Ghana. The Kpelesawgu series is by far the most common member of the association (Adu, 1995a). It occurs on very gentle slopes, usually below the Wenchi-Sambu association and above the Lima-Volta association (Adu 1995a). The top soils of profiles reported by Adu (1995b) are fine sand in texture which probably have no relation with the clayey- textured parent rock.

Adu (1995b) classified the *Kpelesawgu series* differently as Eutric Plinthosol and Dystric Plinthosol based on the FAO/UNESCO (1988) classification system. He also suggested the soil could be called Gleyic Luvisol (Adu, 1995b). Under the United States Department of Agriculture (USDA) Soil Taxonomy (1975) the soil was classified as Plinthustalfs (Adu 1995a). Dedzoe *et al.* (2001)

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classified the same soil under the World Reference Base of Soil Resources (WRB) only as a Plinthosol without assigning any specific lower category name. Amatekpor (1999) also classified the same soil as a Plinthaqualf.

Since these classifications, many changes have taken place in both Soil Taxonomy and the WRB classification systems. The second edition of Soil Taxonomy was published in 1999 and a series of amendments to Soil Taxonomy have since been published as Keys to Soil Taxonomy, with the twelfth edition being Keys to Soil Taxonomy 2014 (Soil Survey Staff, 2015). Similarly, the FAO/ UNESCO classification has also undergone several changes and a new edition has been published as World Reference Base for Soil Resources 2014 update 2015 (IUSS Working Group WRB. 2015). The WRB has transformed the FAO/ UNESCO bicategorical system to a three tier classification system. Previous classifications by Adu and Dedzoe and Amatekpor, may no longer fully comply with the new systems of both Soil Taxonomy and WRB.

Because of the expanse and importance of Kpelesawgu series in the interior savanna, it is important to remove every ambiguity about its classification so as to ease scientific communication. Furthermore, globalization and the growing collaboration among scientists from different backgrounds and countries necessitate harmonization and correlation of technical languages, such as the one used in soil science (FAO, 2006).

A detail morphological description of the *Kpelesawgu series* is included in this study. Some of the selected chemical and physical properties measured include: pH; Organic matter (OM); Extractable bases, Effective cation exchange capacity (ECEC), Percentage base saturation (PBS); Exchangeable sodium percentage (ESP). Others are Particle size distribution (fine earth fraction); Texture; Bulk density (ρ_b) and Porosity. Finally, we propose an improved classification of this soil based on the latest modifications of both Soil Taxonomy and WRB.

Materials and Methods

Location, climate, and vegetation

Soil sampling for laboratory analyses was done in Lungbunga, a community in the Tolon district of the Northern Region of Ghana. The climate of the Tolon district is tropical, greatly influenced by the South – West monsoons from the South Atlantic and the harmattan winds from the Sahara Desert. The area experiences a mono-modal rainfall pattern, which starts from April/May to October with average annual rainfall of about 1043 mm. The temperature distribution is relatively uniform with mean maximum value of 38 ^{0}C. The relative humidity, however, varies greatly and is normally higher during the rainy season of about 54% (SARI, 2001). The vegetation of the area is dominated by indigenous trees such as African locust bean, known locally as dawadawa (*Parkia biglobosa),* Neem tree (*Azardirachta indica*), Shea tree (*Vitellaria parodoxa*). The predominant weeds species are *Tridax procumbens*, *Ageratum conyzoides*, *Icacina trichanta*, *Rottboellia cochinchinensis, Sporobolus pyramidalis et*c.

Soil sampling

Three pedons were dug to the ironpan horizon which was 90 cm in pedon one and 60 cm in pedons two and three. Detailed morphological description of the horizons was carried out. Core samples were collected from each pedon using a hammer-driven core sampler while disturbed samples were collected using an earth chisel. The disturbed samples were air-dried and sieved to eliminate particles bigger than 2 mm. All chemical and physical analyses in the laboratory were done in triplicate.

Morphological description

Soil colour, structure, consistency, root, concretion, and boundary characteristics were described according to the field book for describing and sampling soils (Schoeneberger *et al*., 2002).

Chemical analyses

pH

(1:1 H_2O) was measured using a glass electrode and an Orion Star A215 pH meter.

Extractable bases

They were determined by the Ammonium acetate (NH_4OAc) method using neutral 1M NH_4OAc pH 7 solution. Calcium (Ca) and magnesium (Mg) contents were determined using EDTA titration, while sodium (Na) and potassium (K) were determined by flame photometer.

The exchange acidity

This was determined by Mehlich's barium chloride-triethanolamine extraction, buffered at pH 8.2 (Mehlich, 1938). The soil was leached with an unbuffered salt solution (1M KCl solution) and Al in the leachate measured by titration (Coleman *et al*., 1959; Lin and Coleman, 1960; Mc Lean, 1965).

The Effective Cation Exchange Capacity (ECEC)

It was calculated as sum of the acidic and basic cations.

Percentage Base Saturation (PBS)

This was derived by expressing the total extractable bases (TEB) as a percentage of the ECEC, while Exchangeable Sodium Percentage (ESP) was calculated by

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expressing extractable sodium as a percentage of the ECEC.

Organic matter

Organic matter content of the soil was determined using the Walkley Black (1934) procedure. Organic carbon content was converted to organic matter content by multiplying the organic carbon values with 1.724 Van Bemmelen factor.

Physical analyses

Bulk density

It was done by oven drying core samples after which the samples were weighed, then the oven-dry weight was divided by the soil volume.

$$P_b = \frac{M_2 - M_1}{V}$$

Where: M_2 is mass of dry soil and core sampler

M_1 is mass of core sampler *and*

V is volume of core sampler

Porosity: % pore space = $\rho_b - \dfrac{\rho_b - 100}{\rho s}$

Where: ρs= Particle density of 2.65 g/cm^3

ρb = Bulk density

Particle size distribution was determined using the Bouyoucos Hydrometer method as modified by Day (1965).

Results and Discussion

General morphology of the Kpelesawgu series

A detail morphological description of all three pedons is included in the appendices. The top soil was not uniform in color. Top soil colour was dark grayish in pedon one (Appendix A), grayish yellow brown in pedon two (Appendix B) and dull yellow orange in pedon three (Appendix C). However, the subsoil was a bit uniform in colour, with the dominant colour being dull yellow orange. All horizons were sandy loam in texture except the Btv 2 horizon in pedon one which was loamy in texture.

The structure of the top soils was generally granular while the subsoil was generally angular and sub angular blocky in structure. The subsoil contains common ironstone and manganese stone concretions. The *Kpelesawgu series* is a very shallow soil with a maximum depth of 90 cm. Very hard ironpan was encountered in the bottom of all three pedons (Appendix A, B and C).

Chemical properties

Soil reaction (pH)

Generally, *Kpelesawgu series* is very strongly acid in reaction. The pH values of all the three pedons were higher in the top horizons and decreased with depth (Tables 1 to 3). The low pH is the result of increase in acidic cations (Al^{3+} and H^+) in the subsoil. The low pH of the sub soil suggests the ironpan (petroplinthite) horizon as the source of acidic cations. Martins et al. (2018) showed significant Al content of plinthic materials of the Araguaia river floodplain. Nartey et al. (1997) also showed that Plinthosols of the interior savanna of Ghana contain high amounts ammonium oxalate and CBD extractable Al. According to Olaitan and Lombin (1984), presence of hydrous oxides, like iron (Fe) and Al in soils may react with humus to form complexes which subsequently undergo hydrolysis to yield H ions, which increases soil acidity. The significant amounts Al in these soils can adversely affect plant growth. The low pH and the ironpan horizons may explain the sparse vegetation observed on these soils.

Total extractable bases (TEB) and effective cation exchange capacity (ECEC)

Total extractable bases decreased from top to bottom in all three pedons. There was a decrease in TEB from 4.44 to 2.67 cmol kg^{-1}, 3.92 to 2.32 cmol kg^{-1} and from 3.23 to 1.47 cmol kg^{-1} in pedons 1, 2 and 3 respectively (Tables 1, 2 and 3). The three pedons showed extractable Ca in the highest concentration followed by extractable Mg, K and Na (Tables 1,2 and 3).

The higher extractable bases found in the Ap 1 horizons compared to the layers underneath the Ap1 horizons of all the three Kpelesawgu pedons suggests a possibility of enrichment of the top horizons with base materials.

The annual deposition of dust carried by the harmattan weather system may be responsible for the higher base content of the top soils. Long range eolian dust have been reported to be responsible for materials contained in soils that are unlike the parent materials from which they were formed (Naruse *et al.*, 1986; Tiessen *et al.*, 1991; Adjadey and Inoue, 1999). The low ECEC values may also indicate presence of low activity clays like kaolinite and the humus poor nature of these soils. According to Buol *et al.* (2003), mineral soils with CEC of 3 – 15 cmol/kg are likely to contain significant amounts of kaolinite. The soils of the semi-arid region of West Africa are mainly kaolinitic (Obeng, 1971).

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Percentage base saturation (PBS) and Exchangeable sodium percentage (ESP)

Despite the low pH values recorded, base saturation values were generally very high (>87 %) in the top horizons but decreasing to below 50 % in the bottom horizons (Tables 1, 2 and 3). The high base saturation of top soils of the *Kpelesawgu series* confirms the findings of Tiessen *et al.* (1991) who also recorded high (>80 %) PBS values in the top soils of Northern Ghana. They postulated that the high base saturation in Northern Ghana soils is the result of the annual deposition of harmattan dust during the dry months of November to March. The ESP was lower than 15% in all the three *Kpelesawgu* pedons, indicating the absence of natric horizon (Tables 1 to 3).

Organic matter (OM) content

The soils of the three pedons contained very small amounts of organic matter. The pedons showed a gradual reduction in OM from the top to the bottom horizons. Apart from the Ap 1 horizon of pedon 1 which recorded OM content of 1.24%, OM content of all horizons of the three pedons was less than 1% (Tables 1, 2 and 3). Asiamah (2008) blamed low organic matter content of the soils interior savanna as the cause of the low levels of N, P and CEC.

Physical properties

Particle size distribution

Although the three pedons were all sandy loam in texture, accumulation of clay contents in the B horizons of the three pedons may indicate illuviation of clay into these horizons. The clay content was less than 8 % in all three pedons (Tables 1, 2 and 3). Conversely, percentage sand content generally decreased with depth and was found to be greater than 50% throughout the profile (Tables 1, 2 and 3). The clay illuviation in the B horizons implies the formation of an argillic horizon in the pedons.

Bulk density (P_b)

In all the three pedons, the bulk density values were above 1.2 g/cm^3 (Tables 1, 2 and 3). Bulk density values >1.36 g cm^{-3} show the soils are inorganic or mineral in composition. According to Weil and Brady (2017), the growth of roots into moist soils is generally limited by bulk density ranging from 1.45 g cm^{-3} in clay to 1.85 g cm^{-3} in loamy soils. The bulk density values obtained in this study were below 1.85 g/cm^3, but above 1.45g/cm^3 except a value of 1.36 g/cm^3 recorded in the Ap 1 horizon of pedon 1 (Table 1).

Classification

Classification of Kpelesawgu series under Soil Taxonomy

The soil orders of the USDA Soil Taxonomy are Gelisols, Histosols, Spodosols, Andisols, Oxisols, Vertisols, Aridisols, Ultisols, Mollisosls, Alfisols, Incepticols, and Entisols (Soil Survey Staff 2015). The "key out order" rule used in soil classification implies the elimination of all classes (Orders) that include criteria that do not fit the soil in question. The soil belongs to the first class listed for which it meets all the required criteria.

The argillic horizon (Bt) was the main diagnostic horizon encountered in all the three pedons. Also found in abundance in all three pedons is plinthite diagnostic material. The properties of all the three pedons of *Kpelesawgu series* did not satisfy the requirements of the orders above Alfisols. Alfisols are soils that have argillic, nitric or kandic horizons, are less leached and exhibit a high base saturation (Soil Survey Staff 2015). This description corresponds with the field and laboratory results obtained for the *Kpelesawgu series.* The soil is thus classified as Alfisol at the order level.

Moisture regime is used as the differentiating criterion at the Suborder level of Alfisols. *Kpelesawgu series* is usually waterlogged to the surface in the wet season and dries out rapidly early in the dry season, becoming droughty (Adu, 1995b). This condition satisfies the Aquic moisture regime. *Kpelesawgu series* is therefore an Aqualf.

At the Great Group level, the presence of the ironpan horizon qualifies this soil as a Plinthaqualf. Currently, under the USDA classification system, all Plinthaqualfs are provisionally classified at the Subgroup level as Typic Plinthaqualf (Soil Survey Staff, 2015). At the Family level, the temperature of the study area is isohyperthermic (22 ^{0}C or more). The soil is very strongly acid in reaction, with average pH value of 4.6. The amounts of clay contained in the pedons qualify the soil as coarse loamy (Tables 1, 2 and 3). It could be inferred from the low ECEC (3 – 15 cmol/kg) and Obeng (1971) that the soil probably contained 1:1 clay minerals, mainly kaolinite. *Kpelesawgu series*, therefore, should be classified as: Coarse loamy, kaolinitic, very strongly acid, isohyperthermic, Typic Plinthaqualf (Soil Survey Staff, 2015).

Proposals for improving the classification of the Kpelesawgu series at subgroup level

The current classification connotes the presence of a plinthite diagnostic material in the profile of this soil. However, the agronomically important ironpan (hardened plinthite) layer is omitted in the nomenclature of this soil and we think this could be misleading. The challenge though is that Soil Taxonomy has not included a formative element for ironpan horizons at the subgroup level. A petro subgroup reflecting the indurated nature of the plinthite material would be a more appropriate classification.

We propose the creation of a "Petro" subgroup under

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Plinthaqualf to accommodate the classification of the Kpelesawgu series and related ironpan soils of the interior savanna. So that the soil would be classified as a Petro Plinthaqualf at the subgroup category. Alternatively, a "Petroplinthite" formative element could be added to the great group category of Aqualfs so that ironpan horizon of this soil could be captured in the nomenclature. In that case the soil would be classified at the great group category as Petroplinthaqualf.

Classification of Kpelesawgu series according to the IUSS Working Group WRB, 2015

There are 32 Reference Soil Groups (RSGs) under the WRB classification system. Field and laboratory results obtained revealed the presence of two important diagnostic horizons in all the three *Kpelesawgu* pedons. The diagnostic horizons encountered are: argic horizon and plinthic horizon. The presence of an argic horizon can qualify a soil as Alisol, Acrisol, Luvisol or Lixisol (IUSS Working Group WRB. (2015)). But Alisols and Luvisols must have ECEC (by 1 M NH_4OAC) of 24 cmol/kg clay or more. Additionally, for the *Kpelesawgu series* to qualify as an Acrisol, the PBS should be less than 50 %. The *Kpelesawgu series* is rather low in ECEC and has PBS > 50 %. The *Kpelesawgu series* could therefore only be classified as Lixisols or Plinthosols . However, Plinthosols key out before Lixisols under the WRB. *Kpelesawgu series* was therefore classified as a Plinthosol. Under the WRB, a two – tier system is used as principal (prefix) and supplementary (suffix qualifiers). The recognized principal (prefix) are Petric, Pisoplinthic, Gibbsic, Stagnic, Folic/ Histic, Mollic/ Umbric, Albic, Geric and Haplic. Under the WRB, the Petric qualifier implies the presence of an indurated or cemented horizon starting ≤ 100 cm from the soil surface. The soil is therefore classified as a Petric Plinthosol.

At the supplementary qualifier level, about 28 suffix qualifiers are recognized. However, the first qualifier to key out which meets the properties of this soil is the Lixic qualifier. This qualifier is used when there is an *argic* horizon starting ≤ 100 cm from the soil surface and having a CEC (by 1 *M* NH4OAc, pH 7) of < 24 cmol kg-1 clay in some part ≤ 50 cm below its upper limit; and having an effective base saturation [exchangeable (Ca + Mg + K + Na) / exchangeable (Ca + Mg + K + Na + Al); exchangeable bases by 1 M NH4OAc (pH 7), exchangeable Al by 1 M KCl (unbuffered)] of ≥ 50% in the major part between 50 and 100 cm from the mineral soil surface. The soil is therefore classified as Petric Plinthosol (Lixic). This classification is in contrast with Adu (1995b), who had classified the same soil as Eutric and Dystric Plinthosol (FAO, 1988).

Conclusion

All the three pedons of Kpelesawgu series had similar morphological, chemical and physical properties. In terms of chemical properties, the soils are strongly acid in the subsoil and moderately acid in the topsoil. The soils contained small amounts of organic matter and exchangeable K. Exchangeable Ca and Mg content were moderate. They were also noted for low levels of N and available P. The ECEC of the soils is low but the PBS is high >45%. Effective agricultural production on these soils may be limited to pastures. These soils could also be left fallow as grazing land for cattle and small ruminants.

The previous classifications of this soil were found to be obsolete. Under Soil Taxonomy, the previous classifications recognized the existence of Plinthite in the soil profile but not the agronomically important ironpan. We propose the creation of a "Petro" subgroup under Plinthaqualf to accommodate the classification of the Kpelesawgu series. So that the soil would be classified as a Petro Plinthaqualf at the subgroup category. Alternatively, a "Petroplinthite" formative element could be added to the great group category of Aqualfs so that ironpan horizon of this soil could be captured in the nomenclature. In that case the soil would be classified at the great group category as Petroplinthaqualf.

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Table 1: Selected and physical properties of the Kpelesawgu series (Pedon 1)

Depth	Horizon	pHw	OM	Ca	Mg	K	Na	TEB	Ex. Acidity	ECEC	PBS	ESP	Sand	Silt	Clay	Texture	P_b
				Extractable cations													
cm		1:1	%	cmol kg⁻¹					cmol kg⁻		%		%				g cm⁻³
0 – 10	Ap 1	5.50	1.24	2.67	1.34	0.24	0.19	4.44	0.30	4.74	93.7	4.0	57.38	40.61	2.01	SL	1.36
10 – 20	Ap 2	4.47	0.80	1.60	1.07	0.15	0.11	2.93	0.95	3.88	75.5	2.8	71.24	26.76	2.00	SL	1.56
20 – 40	Btv 1	4.45	0.56	1.60	0.53	0.13	0.08	2.34	1.35	3.69	63.4	2.2	57.26	38.71	4.03	SL	1.54
40 – 60	Btv 2	3.90	0.49	1.34	0.80	0.13	0.07	2.34	2.10	4.44	52.7	1.6	52.58	41.41	6.01	SL	1.50
60 – 90	Btv 3	3.92	0.29	1.34	1.07	0.14	0.12	2.67	3.20	5.87	45.5	2.0	49.74	42.26	8.00	L	1.60
>90	Iron-stone																

Table 2: Selected and physical properties of the Kpelesawgu series (Pedon 2)

Depth	Horizon	pHw	OM	Ca	Mg	K	Na	TEB	Ex. Acidity	ECEC	PBS	ESP	Sand	Silt	Clay	Texture	P_b
				Extractable cations													
cm		1:1	%	cmol kg⁻¹					cmol kg⁻		%		%				g cm⁻³
0 – 10	Ap 1	5.87	0.71	2.40	1.20	0.25	0.07	3.92	0.40	4.32	90.70	1.60	65.80	32.15	2.05	SL	1.63
10 – 20	Ap 2	4.87	0.31	1.34	1.20	0.14	0.07	2.75	1.34	3.30	83.30	2.10	62.04	35.87	2.09	SL	1.72
20 – 35	Bv	4.21	0.31	1.07	0.53	0.11	0.06	1.77	1.07	3.22	54.97	1.90	61.00	36.00	3.00	SL	1.63
35 – 60	Btc	4.78	0.27	1.07	1.07	0.14	0.06	2.34	1.07	3.44	68.02	1.70	59.29	35.72	5.00	SL	1.60
>60	Bcm	Iron pan															

Table 3 Selected and physical properties of the Kpelesawgu series (Pedon 3)

Depth	Horizon	pHw	OM	Ca	Mg	K	Na	TEB	Ex. Acidity	ECEC	PBS	ESP	Sand	Silt	Clay	Texture	P_b
				Extractable cations													
cm		1:1	%	cmol kg⁻¹					cmol kg⁻		%		%				g cm⁻³
0 – 15	Ap1	5.34	0.56	1.74	1.20	0.19	0.13	3.26	0.45	3.71	87.9	3.50	63.26	34.73	2.01	SL	1.66
15 – 30	Ap 2	4.67	0.48	1.60	0.67	0.12	0.05	2.44	2.20	4.64	52.6	1.10	61.06	36.90	2.02	SL	1.60
30 – 45	Btv	3.88	0.31	1.07	0.67	0.11	0.13	1.98	2.30	4.28	46.3	3.00	59.08	36.88	4.04	SL	1.41
45 – 60	Btv	4.16	0.21	0.90	0.63	0.10	0.04	1.67	3.05	4.72	35.4	0.85	57.22	37.78	5.0	SL	1.42
>60	hard-pan																

PBS= Percentage Base Saturation, ESP = Exchangeable Sodium Percentage, OM = Organic matter, Pb= Bulk density, SL = Sandy Loam, L = Loam

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Conflicting Interest

No conflict of interest.

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Appendix A

Morphological description of the Kpelesawgu series (Pedon 1)

Depth (cm)	Horizon	Description
0 – 10	AP 1	Dark grayish (2.5YR 5/2) dry, dark brown (10YR 5/3) moist; sandy loam; weak fine granular; few fine roots; non sticky, non-plastic; clear smooth boundary; pH 5.50
10 – 20	AP 2	Dull yellow brown (10YR 7/3) dry, brown (7.5 YR 4/4) moist; sandy loam; moderate coarse angular and sub angular blocky; very few very fine roots; non sticky, non plastic; clear smooth boundary; pH 4.47
20 – 40	Bv	Dull yellow orange (10 YR 7/3), brown (7.5 YR 4/4) moist; sandy loam; moderate coarse angular and sub angular blocky; very few very fine roots; non sticky, non plastic; clear smooth boundary; pH 4.45
40 – 60	Btv 1	Light yellow orange (10 YR 8/4) dry, dull brown (7.4YR 5/4) moist; sandy loam; moderate angular and sub angular blocky; very few coarse roots; slightly sticky; slightly plastic; clear smooth boundary; pH 3.90
60 – 90	Btv 2	Light yellow orange (7.5 YR 8/4) dry; dull orange (7.5 YR 4/6) moist; loam; strong angular and sub angular blocky; very few very fine roots; slightly sticky slightly plastic; clear smooth boundary; pH 3.92
>90	Ironpan	Massive ironpan

Appendix B

Morphological description of the Kpelesawgu series (Pedon 2)

Depth (cm)	Horizon	Description
0 – 10	Ap 1	Grayish yellow brown (10YR 6/2) dry, grayish brown (7.5YR 4/2) moist; sandy loam; weak fine granular; common fine roots; non sticky non plastic; clear smooth boundary; pH 5.84
10 – 20	Ap 2	Dull yellow orange (10YR 6/3) dry, dull yellow brown (10 YR 4/3) moist; sandy loam; moderate coarse angular blocky; few fine roots; non sticky non plastic; clear smooth boundary; pH 4.87
20 – 35	Bv	Dull yellow orange (10YR 7/2) dry, dull yellowish brown (10YR 4/3) moist; sandy loam; coarse angular blocky; few fine roots; non sticky non plastic; clear smooth boundary; pH 4.21
35 – 60	Btc	Dull orange (7.5YR 7/3) dry, dull brown (7.5 YR 5/3) moist; sandy loam; structureless; no roots; many iron stone and manganese stone concretions; non sticky non plastic; clear smooth boundary; pH 4.78
>60	Ironpan	

Appendix C

Morphological description of the Kpelesawgu series (Pedon 3)

Depth (cm)	Horizon	Description
0 – 15	Ap 1	Dull yellow orange (10YR 6/3) dry, dark brown (10YR 3/3) moist; sandy loam; weak coarse granular; common fine roots; non sticky non plastic; clear smooth boundary; pH 5.34
15 – 30	Ap 2	Dull yellow orange (10YR 6/3) dry, dark brown (10 YR 3/4) moist; sandy loam; moderate coarse angular blocky; few fine roots; non sticky non plastic; clear smooth boundary; pH 4.60
30 – 45	Bv	Dull yellow orange (10YR 7/2) dry, brown (7.5YR 4/4) moist; sandy loam; coarse angular blocky; very few fine roots; non sticky non plastic; clear smooth boundary; pH 3.88
45 – 60	Btc	Dull yellow orange (10YR 7/3) dry, dull yellowish brown (10 YR 5/4) moist; sandy loam; structureless; few coarse roots; non sticky non plastic; few iron stone and manganese stone concretions; clear smooth boundary; pH 4.16
>60	Ironpan	

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