Morphological, Chemical and Physical Properties of Two Pan Soils in the Lower Volta Basin of Ghana

V. K. Avornyo[1], T. A. Adjadeh[2]* and J. K. Amatekpor[2]
[1] *Department of Agronomy, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana*
[2] *Department of Soil Science, University of Ghana, Legon, Accra, Ghana*
*Corresponding author; E-mail: *tadjadeh@ug.edu.gh*

Abstract

The morphological, chemical and physical properties of two pan soils, namely *Kpejeglo series* and *Agawtaw series* were studied. *Kpejeglo series* and *Agawtaw series* together constitute the largest soil association in the lower Volta basin of the Accra Plains. They also occupy a very large portion of the Ho-Keta plains. Two pedons of each series were studied and the results showed that both soils were slightly acidic in the A horizons but alkaline in the B horizons. The electrical conductivity of the soils followed the trend of the *p*H, showing an increase from the top to the bottom of the pedons. Although the soils generally contained high amounts of extractable bases, and had high CEC, the amount of organic carbon in the four pedons was very low, $\leq$ 1%. Percentage base saturation and exchangeable sodium percentage increased with depth in all the four pedons due to the presence of large amounts of calcium carbonate nodules and high levels of extractable sodium in the soils. There was an inverse relationship between the quantities of sand and clay in the two soils. While the quantity of clay in the A and B horizons of the soils increased with depth, the sand quantities decreased. The C horizons, however, showed higher percentage of sand relative to clay content. The bulk density of the hardpan horizons of Kpejeglo Pedon 2 (KP 2) was higher than that of the horizons above it but lower than that of the horizons below it. In the case of the hardpan horizon of Agawtaw Pedon 1 (AG1), it had a higher bulk density than the horizons above and below it. The bulk density values of the hardpan horizons of Kpejeglo Pedon 1 (KP 1) and Agawtaw Pedon 2 (AG 2) were not high and not very different from those of the other horizons. Soil strength measurements showed that the hardpan horizons had a significantly higher penetration resistance. The hardpan horizons of all the pedons of the two soils consistently recorded significantly higher penetration resistance than the surface horizons. From the results, soil strength appeared to be a better indicator of the presence of hard pan horizons than bulk density. The pans in both soils were provisionally classified as duripans (USDA Soil Taxonomy) or petroduric horizons (WRB of IUSS/ISRIC/FAO).

Introduction

The lower Volta basin is a vast expanse of arable land within the Accra Plains and the Ho–Keta plains that could hold the key to unlocking Ghana's agricultural potential if properly exploited. Detailed information on the soils that occur in the basin would be valuable in designing an integrated and sustainable development plan for the area. *Kpejeglo series* and *Agawtaw series* are two closely related pan soils that developed over acidic gneisses in the coastal savanna zone of the basin, and belong to the group of soils classified as Tropical Grey Earths (Brammer, 1962). *Agawtaw series* was classified by Dowuona (1985) as a Stratic Natraqualf and a Solodic Planosol according to the USDA (1975) and FAO-UNESCO (1974) systems, respectively. Avornyo (2007) classified the soils as Typic Duraqualf (Soil Survey Staff, 2003) and as Duric Solonetz (IUSS Working Group WRB, 2007), which agrees with the

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West African Journal of Applied Ecology, vol. **21**(2), 2013: 63–77.

classification of *Agawtaw series* as a Calcic Mollic Stagnic Solonetz by Asiamah (1995). *Agawtaw series* and associated soils cover more than 150,000 ha of the Accra Plains (Obeng, 1975). These soils constitute the largest single soil association in the Accra Plains (Kaiser Engineers & Constructors, 1965) and also occupy about 330 km^2 in the Ho-Keta plains (Brammer, 1962).

The presence of hardpan horizons in these soils reduces the effective soil volume available for moisture, root growth and nutrient storage, thus, reducing the quality of the soils for agricultural purposes (Brammer, 1962; Kaiser Engineers & Constructors, 1965; Obeng, 1975). The soils easily get flooded even with moderate precipitation due to the presence of subsurface hardpan horizons and are, thus, highly susceptible to erosion and run-off (Brammer, 1962; Kaiser Engineers & Constructors, 1965; Agyili & Tei, 1979). Consequently, vast expanses of land in the lower Volta basin, dominated by *Agawtaw series, Kpejeglo series* and associated soils remain uncultivated and are mainly used as grazing fields for livestock (Brammer, 1962; Obeng, 1978). Brammer (1962) and Kaiser Engineers & Constructors (1965) had suggested sub-soiling and amendment with gypsum and sulphur as ways of enhancing the productivity of the soils. There is, however, no information on any attempt at using the proposed management strategies on the soils in the Accra Plains.

The attributes of *Agawtaw series* and *Kpejeglo series* include the fact that they are located on gently sloping terrains, and much of them are close to the Volta lake which would make water for irrigation easily accessible. The locations of the soils are also in close proximity to the major market centres of Agormanya, Akatsi, Tema and Accra. Also, the nearness of the locations of the soils to Akosombo would make movement of farm produce via the Volta lake up north and beyond a cheap means of transportation. It is, therefore, not surprising that a lot of private investors are showing interest in large scale farming on lands that are largely made of *Agawtaw series* and *Kpejeglo series* in the Accra Plains. However, the last time these soils were characterized and classified was by Dowuona (1985). This study was, thus, designed to examine the present morphological, chemical and physical properties of *Agawtaw series* and *Kpejeglo series* as the initial step in characterizing them.

Materials and methods

Study site

According to Amatekpor (1999), the Volta basin as a geographical unit may be considered as either the geological formations in Ghana known as the Voltaian Formations, or all the geographical areas in Ghana drained by the Volta river and its tributaries. The Voltaian Formations, according to him, occupy about 40% of the total area of Ghana, whilst the Volta Drainage Basin has, within the boundaries of Ghana, a total catchment area of about 165,700 km^2 (i.e. about 70% of the total area of Ghana). The lower Volta basin is the part of the basin between the Akosombo dam and the Gulf of Guinea. Soil sampling for laboratory analyses was done at sites close to Adidome, the capital of the North Tongu District of the Volta Region. The climate of the District is tropical, greatly influenced by the SW monsoons from the South Atlantic and the dry Harmattan winds from the Sahara. The average annual rainfall varies from 900 mm to 1100 mm. Annual temperatures range from 22 to 33 ^{o}C. The average relative humidity is about 80%. The vegetation is coastal savanna, low grassland but dense along the Volta river and streams.

Location of pedons and sampling

The two pedons of *Kpejeglo series* (KP1 and KP2) were located on latitude 06^o 05' 17.9" N and longitude 00^o 31'17.8" E and latitude 06^o 05' 05.8" N and longitude 00^o 31' 30.6" E, respectively. The two pedons of *Agawtaw series* (AG 1 and AG2) were located on latitude 06^o 05' 22.7" N and longitude 00^o 31' 02.8" E and latitude 06^o 05' 21.7" N and longitude 00^o 31' 02.9" E, respectively. The elevation of the sites was 21 m a.s.l. The four pedons, two for *Agawtaw series* and two for *Kpejeglo series*, were dug through the hardpan to a depth of 2.0 m or to the bedrock. Core samples were taken from each of the pedons for bulk density determination using a hammer-driven core sampler. Disturbed samples were also collected for laboratory analyses.

Physical and chemical analyses

Bulk density. Undisturbed core samples oven-dried at 105 ^{o}C for 24 h, were used to determine the bulk density of the soils.

Particle size distribution. Particle size distribution was determined by the Bouyoucous hydrometer method as modified by Day (1965) using sodium hexametaphosphate (calgon) as dispersing agent.

Field penetration test. A cone penetrometer with a cone area of 3.23 cm^2 was used to determine the soil strength of the horizons. The resistance to penetration was recorded on a dial and transformed to force (N). The values were converted to KPa.

*Soil reaction, p*H *(H_2O and KCl).* For each horizon, *p*H was determined with a glass electrode in water and potassium chloride (KCl) solution using a 1:1 air-dried soil-water/ 1 mol l^{-1} KCl ratio after the samples had been stirred and allowed to stand for 1 h.

Electrical conductivity (EC). The electrical conductivity of the soils was determined by weighing 5 g of < 2 mm air-dried soil into 25 ml beakers after which 10 ml of distilled water was added, swirled to mix thoroughly and allowed to stand overnight. Conductance of the supernatant was read using a conductivity meter.

Cation exchange capacity and extractable bases. The cation exchange capacity (CEC) of the soils and their exchangeable bases were determined by the ammonium acetate (NH_4OAc) method using neutral 1 *M* NH_4OAc *p*H 7 solution. Calcium and magnesium contents were determined by EDTA titration while sodium and potassium were determined with the flame photometer. Percentage base saturation (PBS) was derived by expressing total extractable bases as a percentage of CEC while exchangeable sodium percentage (ESP) was determined by expressing extractable sodium as a percentage of the CEC.

Soil organic carbon. Organic carbon was determined by the Walkley Black (1934) procedure, which involved wet combustion of organic matter with a mixture of 10 ml of 1 *M* potassium dichromate and 20 ml concentrated sulphuric acid at about 125 ^{o}C. The residual dichromate was titrated against 1 *M* ferrous sulphate.

Determination of major oxides. The X-ray Fluorescence Spectrometer was used to determine the relative accumulation of major oxides in the soils in order to determine if they played any role in cementation of the pan. Soil samples were taken from above, within and beneath the hardpan from all the four profiles. The soil samples were pulverized, mixed with wax and subjected to a pressure of about 49 KPa to form pellets. These pellets were then put into the X-ray Fluorescence Spectrometer and the relative accumulation of oxides determined.

Results and discussion

Morphological properties of KP 1 and KP 2

The top 10 cm of KP 1 (i.e. Ap1 horizon) was loamy sand with a weak fine granular structure. The Ap1 horizon was underlain by the Ap2 horizon, also 10 cm thick, which also had a granular structure but with a sandy loam texture. Below the Ap horizons was a compact sandy clay loam (hardpan) horizon stretching down to a depth of 80 cm (i.e. Btcm and Btncm). Below this hardpan layer was a sandy clay loam horizon (i.e. Btnck1 and Btnck2) with columnar structure which graded into strong angular blocky when dry. The Cnk horizon contained common rounded soft and hard iron and manganese concretions, and common calcium carbonate nodules.

The morphological properties of KP 2 were similar to those of KP 1. The A horizon (Ap1 and Ap2; top 20 cm) was sandy loam in texture with a weak fine granular structure. The A horizon was underlain by a compact sandy clay loam horizon (hardpan), which stretched to a depth of 65 cm with moderate coarse columnar to coarse angular blocky structure. Below the hardpan layer was another sandy clay loam horizon enriched with calcium, magnesium and sodium (Table 2). The subsoil (i.e. Btnck1 and Btnck2) of this pedon also contained common rounded soft and hard iron and manganese concretions, and common calcium carbonate nodules.

Morphological properties of AG 1 and AG 2

The top 35 cm of AG 1 and 36 cm of AG 2 were sandy loam with a weak, fine granular structure. These surface horizons were designated as the Ap1 and Ap2. The Ap horizons of AG 1 and AG 2 were underlain by compact sandy clay and sandy clay loam (hardpan) horizons, respectively. In both pedons, the hardpan horizon (i.e. Btcm) extended to a depth of 60 cm. Below the hardpan layer was another sandy clay layer in AG 1 and sandy clay loam in AG 2. The layers below the hardpan (i.e. Btnck1 and Btnck2) in both pedons had columnar structure which broke into strong angular blocky when dry. These horizons, just like those of KP 1 and KP 2, had very high base saturation with calcium, magnesium and sodium being the dominant bases (Tables 3 and 4). The Cnk horizons, of the two pedons contained common rounded soft and hard iron and manganese concretions and common calcium carbonate nodules.

The morphological properties of the *Kpejeglo series* and the *Agawtaw series* were very similar, which shows that these two soils which occur in close association might have had similar pedogensis.

*Soil reaction (*p*H) and electrical conductivity*

The values for *p*H in water ranged from 6.1 to 8.4 (Tables 1–4). For all the pedons, the Ap horizons were slightly acidic. The B horizons showed slightly acidic soil reaction and became slightly to moderately alkaline with increasing depth. Very similar soil reaction results had been reported for *Agawtaw series* (Brammer, 1962; Kaiser Engineers & Constructors, 1965; Dowuona, 1985; Asiamah, 1995). The *p*H (KCl) of the

TABLE 1

Selected chemical and physical properties of Kpejeglo Pedon 1

					Extractable bases cmol/kg									*Particle size distribution %*				
Depth	*Horizon*	p*H* (*1:1*)	p*H* *KCl*	*OC* *%*	*Ca*	*Mg*	*K*	*Na*	*T.E.B*	*C.E.C*	*PBS*	*ESP*	*EC* *dS/m*	*Sand*	*Silt*	*Clay*	*Texture*	ρ_b (*Mg/m*^{3})
0–10	Ap1	6.4	5.3	0.7	1.6	2.8	0.06	0.4	4.8	6.5	73.8	6.2	0.01	77.7	14.8	7.5	LS	1.51
10–20	Ap2	6.1	5.1	0.6	1.8	4.0	0.05	0.6	6.5	7.3	89.0	8.2	0.02	75.1	14.9	10.0	SL	1.52
20–45	Btcm	6.3	5.2	0.6	8.8	4.8	0.05	3.0	16.7	20.1	83.1	14.9	0.27	58.7	21.3	20.0	SCL	1.56
45–80	Btncm	7.9	7.0	0.5	11.0	5.6	0.03	7.0	23.6	27.6	85.5	25.4	1.58	56.9	15.6	27.5	SCL	1.60
80–130	Btnck1	8.0	7.1	0.3	13.2	6.6	0.05	8.7	28.6	30.7	93.2	28.3	2.18	50.7	19.3	30.0	SCL	1.58
130–150	Btnck2	8.1	7.1	0.2	16.0	8.0	0.05	8.6	32.7	30.7	106.5	28.0	2.14	54.1	15.9	30.0	SCL	1.60
150–200	Cnk	8.3	7.1	0.2	15.0	5.0	0.04	7.7	27.7	18.4	148.9	41.8	1.40	67.1	16.6	16.3	SL	—

TABLE 2

Selected chemical and physical properties of Kpejeglo Pedon 2

					Extractable bases cmol/kg									*Particle size distribution %*				
Depth	*Horizon*	p*H* (*1:1*)	p*H* *KCl*	*OC* *%*	*Ca*	*Mg*	*K*	*Na*	*T.E.B*	*C.E.C*	*PBS*	*ESP*	*EC* *dS/m*	*Sand*	*Silt*	*Clay*	*Texture*	ρ_b (*Mg/m*^{3})
0–10	Ap1	6.7	5.6	1.0	2.6	3.6	0.12	0.4	6.7	8.8	76.4	4.5	0.02	73.7	16.3	10.0	SL	1.49
10–20	Ap2	6.5	5.4	0.8	3.2	5.0	0.08	0.4	8.7	10.0	87.0	4.0	0.01	76.3	11.2	12.5	SL	1.53
20–40	Btcm	6.9	5.3	0.8	7.8	7.0	0.05	2.1	16.9	20.7	81.6	10.1	0.06	64.7	12.8	22.5	SCL	1.57
40–65	Btnck 1	7.2	6.1	0.7	14.2	8.1	0.05	5.9	28.3	32.5	87.0	18.2	1.58	53.2	14.3	32.5	SCL	1.73
65–130	Btnck 2	8.2	7.2	0.3	16.2	8.2	0.05	7.0	31.5	33.5	94.0	20.9	1.76	48.6	23.9	27.5	SCL	1.65
130–165	Cnk	8.0	6.9	0.2	15.0	15.0	0.12	8.0	38.1	30.3	125.7	26.4	1.69	55.6	14.4	30.0	SCL	—

TABLE 3

Selected chemical and physical properties of Agawtaw Pedon 1

					Extractable bases cmol/kg									*Particle size distribution %*			
Depth	*Horizon*	p*H* *(1:1)*	p*H* *KCl*	*OC* *%*	*Ca*	*Mg*	*K*	*Na*	*T.E.B*	*C.E.C*	*PBS*	*ESP*	*EC* *dS/m*	*Sand*	*Silt*	*Clay*	*Texture*	ρ_b *(Mg/m³)*
0–12	Ap1	6.4	5.4	0.9	2.8	5.1	0.07	0.3	8.2	8.4	97.6	3.6	0.02	78.8	11.2	10	SL	1.43
12–35	Ap2	6.4	5.2	0.9	2.9	3.0	0.05	0.4	6.3	9.5	66.3	4.2	0.01	77.1	10.4	12.5	SL	1.45
35–60	Btcm	7.1	6.1	0.9	5.9	9.3	0.08	3.2	19.8	22.6	87.5	14.2	0.66	53.1	9.4	37.5	SC	1.60
60–90	Btnck1	8.0	6.9	0.4	11.0	9.4	0.07	6.3	28.8	32.0	90.0	19.7	1.17	53.9	11.1	35.0	SC	1.50
90–150	Btnck2	8.4	7.5	0.2	17.0	10.2	0.08	7.4	34.7	36.2	95.9	20.4	1.72	57.9	7.0	35.0	SC	1.49
150–200	Cnk	8.2	7.1	0.2	11.4	6.2	0.07	6.9	24.6	25.0	98.4	27.6	1.64	68.2	4.3	27.5	SCL	—

TABLE 4

Selected chemical and physical properties of Agawtaw Pedon 2

					Extractable bases cmol/kg									*Particle size distribution %*				
Depth	*Horizon*	p*H* *(1:1)*	p*H* *KCl*	*OC* *%*	*Ca*	*Mg*	*K*	*Na*	*T.E.B*	*C.E.C*	*PBS*	*ESP*	*EC* *dS/m*	*Sand*	*Silt*	*Clay*	*Texture*	ρ_b *(Mg/m³)*
0–12	Ap1	6.7	5.6	0.9	2.6	3.8	0.10	0.3	6.8	8.8	77.3	3.4	0.01	79.9	10.1	10.0	SL	1.46
12–36	Ap2	6.5	5.2	0.8	2.6	4.3	0.05	0.3	7.2	8.7	82.7	3.4	0.01	78.9	11.1	10.0	SL	1.56
36–60	Btcm	6.8	5.5	0.7	6.4	6.8	0.06	3.0	16.5	20.4	80.9	14.7	0.36	64.5	5.5	30.0	SCL	1.59
60–110	Btnck1	7.7	6.8	0.4	8.5	8.3	0.06	3.8	20.7	23.5	87.9	16.2	1.75	62.7	4.8	32.5	SCL	1.61
110–132	Btnck2	8.2	7.2	0.2	11.0	10.4	0.10	8.1	29.6	30.1	95.2	26.9	2.04	54.2	8.3	37.5	SC	1.58
132–200	Cnk	8.4	7.5	0.2	15.9	11.9	0.09	7.8	35.7	24.8	143.9	31.5	2.00	60.2	9.8	30.0	SCL	—

soils ranged from 5.1 to 7.5. The *p*H (water and KCl) values and distribution in the pedons (both Kpejeglo and Agawtaw) were very similar. The *p*H (water) range of 6.1 to 8.4 observed showed that the soils were highly base-saturated and could contain free $CaCO_3$. Kaiser Engineers & Constructors (1965), Dowuona (1985) and Asiamah (1995) had reported the presence of $CaCO_3$ in *Agawtaw series*. Almost all the horizons of the soils, especially the B and C, showed effervescence in dilute HCl, indicating the presence of $CaCO_3$. Buol *et al*. (1980) observed that when soil *p*H values are between 8.0 and 8.5, then exchangeable cation population is largely composed of Ca + Mg. The alkalinity observed in the B and C horizons of the soils indicates that 2:1 clay minerals were probably present (Brady & Weil, 1999).

The EC, which is an indirect method of determining soil salinity, showed that the A horizons of the two soils were non-saline while the B horizon ranged from non-saline to very slightly saline (Schoeneberger *et al.*, 2002). Electrical conductivity (EC) values of the soils followed a trend similar to that of *p*H, generally showing an increase from the top to the bottom of the pedons (Tables 1–4). In KP 1, the EC increased from 0.01 dSm^{-1} in the Ap1 horizon to 2.18 dSm^{-1} in the Btnck 1 horizon and then reduced to 1.40 dSm^{-1} in the Cnk horizon (Table 1). The EC values of KP 2 ranged from 0.01 dSm^{-1} in the Ap2 horizon to 1.76 dS^{-1} in the Btnck1 horizon and then reduced to 1.69 dSm^{-1} in Btnck2 (Table 2). Similar trends of EC values were observed for the two Agawtaw pedons. For AG 1, the values ranged from 0.01 dSm^{-1} in the Ap2 horizon to 1.72 dSm^{-1} in the Btnck2 horizon and then decreased to 1.64 dSm^{-1} in the Cnk horizon (Table 3). The values for AG 2 also ranged from 0.01 in the Ap1 horizon to 2.04 dSm^{-1} in the Btnck2 and then fell to 2.00 dSm^{-1} in the Cnk (Table 4).

Organic carbon

The soils of all the four pedons contained very small amounts of organic carbon. The four pedons showed a gradual reduction of organic carbon content with depth. In KP 1, organic carbon content reduced from 0.7% in the Ap1 horizon to 0.2% in the Cnk horizon (Table 1). The trend was not different in KP 2. There was a reduction from 1.0% in the Ap1 horizon to 0.2% in the Btnck2 horizon (Table 2). The percentage organic carbon content of AG 1 reduced from 0.9% in the Ap1 horizon to 0.2% in the Cnk horizon (Table 3). Similarly in AG 2 organic carbon content decreased from 0.9% in the Ap1 horizon to 0.2% in the Cnk horizon (Table 4). Low organic carbon content had been reported for these soils (Dowuona, 1985; Amatekpor & Dowuona, 2003). The low level of organic carbon could be due to low biomass production as a result of the sparse and predominantly low grass vegetation. The poor internal drainage of these soils could also be a factor affecting decomposition. Nartey *et al*. (1997) reported poor internal drainage as a problem affecting *in situ* decomposition of organic matter in some soils in Ghana.

Total extractable bases and CEC

The extractable bases from all the pedons were generally high (Tables 1–4). The levels of extractable Ca, Mg and Na were particularly high and generally increased with increasing depth in all the soil profiles, and this result agrees with those of Brammer (1962), Dowuona (1985) and Asiamah

(1995). Conversely, the levels of extractable K were very low and did not follow any particular trend. Although the total extractable bases in KP 1 followed the order Ca > Mg > Na > K, the A horizon showed the trend Mg > Ca > Na > K (Table 1). The Ap1 horizon contained 1.6 cmol/kg extractable Ca, which was the smallest while Btnck 2 contained the largest amount, 16.0 cmol/kg. Thus, Ca did not only show the highest amounts but also had the widest range and variability in the profile. The level of extractable Mg increased from 2.8 cmol/kg in the Ap1 horizon to a high of 8.0 cmol/kg in the Btnck 2 and then reduced to 5.0 cmol/kg in the Cnk horizon. The amount of extractable Na increased from a low of 0.4 cmol/kg in the Ap1 horizon to 8.7 cmol/kg in the Btnck1 producing a natric horizon. The soil (KP 1) contained very low amounts of K. The levels of extractable bases observed in KP 2 followed a trend similar to what was observed in KP 1 except for minor variations.

The two Agawtaw pedons also showed similar amounts of extractable bases. Similar to those of the Kpejeglo pedons, their A horizons showed the largest amount of extractable Mg followed by Ca and Na (Tables 3 and 4). The levels of extractable K in the two pedons were very low. In KP 1, total extractable bases increased from 4.8 cmol/kg in the Ap1 horizon to 32.7 cmol/kg in the Btnck2 horizon and then declined to 27.7 cmol/kg in the Cnk horizon (Table 1). In KP 2, total extractable bases increased from the top to the bottom of the profile (Table 2). The *Kpejeglo series* and the *Agawtaw series* showed marked similarity in the levels of total extractable bases. In AG 1, total extractable bases increased from 6.3 cmol/kg in the Ap2 horizon to 34.7 cmol/kg in the Btnck2 horizon and then declined to 24.6 cmol/kg in the C horizon (Table 3). The trend of extractable bases in AG 1 were similar to those observed in KP 1 except that Ap1 had a higher extractable bases than Ap2 in AG 1. In AG 2, however, there was an increase from 6.8 cmol/kg in the Ap1 horizon to 35.7 cmol/kg in the Cnk horizon. This increase from the top of the profile to the bottom was similar to that observed in KP 2.

The CEC of the soils generally showed a gradual increase from the top to the bottom of all the four pedons. Generally, as the clay content of the soils increased from the top to the bottom, the CEC also increased, and this agrees with the findings of Dowuona (1985) and Asiamah (1995). The CEC of the soils was moderately high. For KP 1, CEC increased from 6.5 cmol/kg in the Ap1 horizon to 30.7 in the Btnck2 horizon and then declined to 18.4 cmol/kg in the Cnk horizon (Table 1). A similar trend was observed in KP 2 where CEC increased from a low of 8.8 cmol/kg in the Ap1 horizon to a high of 33.5 cmol/kg in the Btnck1 horizon and then declined to 30.3 cmol/kg in the Btnck2 horizon (Table 2). The CEC of AG 1 also increased from 8.4 cmol/kg in the Ap1 horizon to 36.2 cmol/kg in the Btnck2 horizon and then reduced to 25.0 cmol/kg in the Cnk horizon. Also, in AG 1, CEC increased as total extractable bases and clay content increased. In AG 2, CEC increased from 8.7 cmol/kg in the Ap 2 horizon to 30.1 cmol/kg in the Btnck2 horizon and then reduced in the Cnk horizon to 24.8 cmol/kg (Tables 3 and 4).

The generally low extractable bases in the A horizon but relatively higher levels in the B and C horizons of the soils indicates eluviation from the A horizon into lower horizons. Asiamah (1995) and Amatekpor & Dowuona (2003) had reported similar findings showing moderate to high amounts of bases in Kpejeglo and Agawtaw. The relative abundance of primary minerals and weathering intensity in the soils could be inferred from the levels of Ca, Mg, K, and Na (Parker, 1970; Nartey *et al.*, 1997). The moderately high levels of these bases suggest the presence of weatherable minerals in the soils. Furthermore, the high CEC levels of the subsoil (B Horizon) indicates the presence of weatherable minerals and the possible presence of montmorillonite with associated high shrink swell potential. According to Grim (1968), mineral soils with CEC of 10–40 cmol/kg soil are likely to contain illite (clay mica). The high calcium carbonate content in the subsoil especially in the lower parts of the B horizons and the upper parts of the C horizons made extractable bases in some of the horizons higher than their CEC (Tables 1–4). It is instructive that the term "extractable bases" instead of "exchangeable bases" is prefered because soluble salts and some bases from carbonates can be included in the extract (Soil Survey Staff, 2003).

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

Base saturation and sodium saturation increased from the top to the bottom of all the four pedons. In KP 1, PBS increased from 73.8% in the Ap1 horizon to >100% in the Cnk horizon, while ESP increased from 6.2% in the Ap1 horizon to 41.8% in the Cnk horizon, resulting in a natric horizon from the Btncm horizon downwards (Table 1). Percentage base saturation in KP 2 also showed a similar trend, increasing from 76.4% in the Ap1 horizon to >100% in the Btnck 2 horizon (Table 2). Sodium saturation also increased with depth in KP 2, ranging from 4.5% in the Ap1 horizon to 26.4% in the Btnck2 horizon (Table 2). Both PBS and ESP increased with depth in AG 1 and AG 2 too. Percentage base saturation for AG 1 ranged from 66.3% in the Ap2 horizon to 98.4% in the Cnk horizon. Sodium saturation increased from 3.6% in the Ap1 horizon to 27.6% in the Cnk horizon, producing a natric horizon from the Btnck1 horizon downwards (Table 3). In AG 2, PBS increased from 77.3% in the Ap1 horizon to > 100% in the Cnk horizon, sodium saturation also increased from 3.4% in the Ap1 horizon to 31.5% in the Cnk horizon (Table 4).

The high base saturation of all the four pedons is indicative of the high levels of extractable bases. Base saturation > 100% recorded at the bottom of KP 1, KP 2 and AG 2 was due to the abundant calcium carbonate nodules present in the soils. The calcium was extracted from the nodules as well as the exchange sites on colloids. The levels of sodium saturation in the lower B horizons was >15%, thus, making the horizons natric. Sodium ions might have accumulated on the exchange sites of the clay through the process of alkalization probably due to the periodic flooding and drying of these soils. Dowuona (1985) and Agyili *et al.* (1993) had previously reported natric horizons in these soils. During the drying process of soils, the precipitation of calcium and magnesium in carbonates take place first, thereby, concentrating sodium in the soil solution and much of it is adsorbed unto the exchange sites (Van Beck & van Breeman, 1973). It is also possible that the locality of these soils were previously occupied by lagoons which later dried up. Amatekpor (1992) compared the properties of Akuse series (a Vertisol) before flooding and after 5 years of periodic flooding, and found that the soil had developed a natric horizon as a result of the intermittent wet condition.

Elemental analyses

The results of total elemental analyses are given in Tables 5–8. The elements were determined with the x-ray fluorescence spectrometer and expressed on oxide basis. Silicon (expressed as an oxide, SiO_2) was the dominant element in all the profiles. Manganese levels were generally very low. The relative abundance of the elements in KP 1 followed the trend Si > Al > Fe > Mg > Ca > Na > K > Ti. All of these elements increased with depth except Si which decreased with depth (Table 5). Silicon content of the soil decreased as clay content increased or as the texture became finer. In KP 2, the distribution of the elements was similar to that of KP 1 except for the greater abundance of Ca than Mg especially below the pan. Again, all elements increased with depth except for Si which decreased with depth (Table 6). The relative abundance of the elements in *Agawtaw series* was in the order Si > Al > Fe > Mg > Ca > Na > K > Ti. The relative abundance of the elements in AG 2 followed a trend similar to that of AG 1 (Table 8). There was a marked accumulation of Al and Fe in the pan horizon. Again, in AG 2, there was a high accumulation of Fe in the pan horizon.

High silica levels in the soil, especially in the coarse-textured A horizon, was probably due to high levels of quartz which is one of the polymorphs of silica. The decline in silica content as texture became finer with depth, as well as the increase in Al and Fe with depth, was a result of desilication. The results also suggest a relative abundance of silica in the sand and silt size fractions of the soils. Nartey *et al.* (1997) reported a decrease in silica concentration with increasing clay amounts in some soils of northern Ghana. The reduction in silica content with depth indicates that its source of supply is likely to be from above the soil, possibly from tropospheric eolian dust. The annual deposition of dust from the Sahara, carried by the Harmattan weather system, may be responsible for this high silica content of the surface horizons of the two soils. Tiessen *et al.* (1991) mentioned quartz (SiO_2) as the dominant mineral contained in the eolian dust of the 1987/88 Harmattan season in Ghana. In Japan, Naruse *et al.* (1986) traced the origin of fine quartz from some soils developed in the last Glacial and Holocene ages to eolian dust from the semi-arid and arid continent of Asia. Similarly, Adjadeh & Inoue (1999) reported that long range eolian dust was the source of quartz in the soils of the Kitakami mountain range in Japan.

Particle size distribution

The results of particle size analyses are given in Tables 1–4. The soils were generally sandy loam textured in the surface horizon, sandy clay loam and sandy clay in the B-horizon, and sandy loam and sandy clay loam in the C-horizon. There was an inverse relation between the amounts of sand and clay in the two soils studied. While the amount of clay increased with depth, sand quantities decreased. At the bottom of the pedons, particularly in the C horizon, there was an upturn in the amount of sand. High clay accumulation in the B horizon of all the four pedons could be indicative of clay eluviation from the horizons above it. The four pedons showed similar distributions of

TABLE 5
Total elemental analyses of Kpejeglo Pedon 1 (KP 1)%

Depth	*Description*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*TiO*	*SO_3*	*P_2O_5*	*MnO*	*Cl*
0 – 20	Above pan	87.72	6.58	0.95	1.16	1.21	1.44	0.36	0.20	0.10	0.09	0.03	0.02
20 – 80	Pan	74.04	9.71	2.44	1.88	1.40	1.71	0.33	0.35	0.13	0.07	0.09	0.06
80 – 200	Below pan	66.22	10.66	3.36	2.35	2.31	1.87	0.40	0.46	0.17	0.07	0.17	0.13

TABLE 6
Total elemental analyses of Kpejeglo Pedon 2 (KP 2)%

Depth	*Description*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*TiO*	*SO_3*	*P_2O_5*	*MnO*	*Cl*
0 – 20	Above pan	87.18	6.75	0.90	1.58	1.30	1.14	0.37	0.17	0.11	0.08	0.02	0.02
20 – 65	Pan	72.24	11.1	2.81	1.83	1.23	1.08	0.32	0.38	0.10	0.06	0.06	0.03
65 –150	Below pan	61.27	11.56	3.38	2.40	4.32	1.09	0.39	0.49	0.13	0.08	0.08	0.05

TABLE 7
Total elemental analyses of Agawtaw Pedon 1 (AP 1)%

Depth	*Description*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*TiO*	*SO_3*	*P_2O_5*	*MnO*	*Cl*
0 – 35	Above pan	85.40	7.14	1.88	1.69	1.16	1.67	0.46	0.32	0.11	0.09	0.05	0.02
35 – 60	Pan	61.03	14.51	5.70	2.14	0.76	2.19	0.51	0.53	0.14	0.08	0.13	0.04
60 – 90	Below pan	63.53	13.85	4.29	2.19	0.98	1.44	0.65	0.51	0.15	0.08	0.04	0.06

TABLE 8
Total elemental analyses of Agawtaw Pedon 2 (AP 2)%

Depth	*Description*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*TiO*	*SO_3*	*P_2O_5*	*MnO*	*Cl*
0 – 36	Above pan	85.26	6.77	1,75	1.63	1.14	1.05	0.47	0.30	0.11	0.08	0.04	0.02
36 – 60	Pan	66.55	11.97	6.15	1.91	0.73	1.88	0.46	0.39	0.12	0.08	0.17	0.04
60 – 110	Below pan	67.97	12.60	3.80	2.11	1.03	1.63	0.60	0.45	0.17	0.06	0.03	0.08

sand, silt and clay. However, the Agawtaw pedons, especially AG 1, was sandy clay in the B-horizons. The Kpedjeglo pedons were sandy clay loam in the B-horizons.

Bulk density (ρ_b)

The bulk densities (ρ_b) of KP 1 ranged from 1.51 Mg m^{-3} in the surface horizon to 1.60 Mg m^{-3} in the pan horizon and the dense B horizon (Table 1). The A horizon, thus, had a lower bulk density than the B horizon. The pan horizons had a slightly higher bulk density than the overlying A-horizons but at similar levels with those of the underlying horizons (Table 1). In KP 2, ρ_b increased with depth, varying from a low of 1.49 Mg m^{-3} in the surface horizon to a high of 1.73 Mg m^{-3} in the hardpan horizon, before reducing to 1.65 Mg m^{-3} below the hardpan layer (Table 2). In AG 1, the hardpan layer showed a higher ρ_b (1.60 Mg m^{-3}) than the layers above (1.45 Mg m^{-3}) and beneath (1.50 Mg m^{-3}) it (Table 3). In AG 2, ρ_b ranged from 1.46 Mg m^{-3} in the Ap1 horizon to 1.61 Mg m^{-3} in the Btknc horizon (Table 4). Differences in the levels of ρ_b between the horizons of AG 2 were negligible. The results showed that in pedons KP 2 and AG 1, the hardpan horizons had the highest ρ_b while in pedons KP 1 and AG 2, the hardpans did not necessarily show the highest ρ_b value. The higher bulk density observed in the B horizons as compared to the A horizons of the two soil series was most likely due to compaction and the higher amounts of clay. This result is supported by Brady & Weil (1999), who stated that bulk densities are generally higher deeper in the soil profile probably as a result of compaction caused by the weight of overlying layers, lower organic matter contents, less aggregation and fewer roots.

Compaction, low organic matter content (1.5% or lower) of the B horizons of the two soils and lack of roots, except for very few and very fine roots, found in the upper limit of the B horizon, might have accounted for the high bulk densities recorded in the B horizons. Furthermore, Brady & Weil (1999) stated that the growth of roots into moist soils is generally limited by bulk density ranging from 1.45 Mg m^{-3} in clays to 1.85 Mg m^{-3} in loamy sands. The bulk density of the surface horizons was well below 1.85 Mg m^{-3} but that of the B horizons, which had high clay content, was above 1.45 Mg m^{-3}, hence, the severe root restriction observed in the B horizon (Tables 9–12).

Field penetration test

Soil strength has been measured by the use of various types of penetrometers, the lack of standard design and method of usage, notwithstanding (Hillel, 1982). Results of soil strength show that the hardpan horizons had a significantly higher resistance to penetration (Tables 9–12). Consistently, the hardpan horizons in all the pedons of the two soils recorded significantly higher penetration resistance than the surface horizons. This high soil strength might explain the root restriction observed, particularly, in the hardpan horizons of these soils. Very few and very fine roots were observed in the hardpan horizons (Tables 9–12). Brady & Weil (1999) reported that root penetration is severely restricted when soil strength increases beyond about 2000 kPa. The soil strength values of the hardpan horizons (i.e. 1675–1748 kPa) were close to this critical value. Furthermore, it appears that soil strength rather than bulk density is a better indicator of hardpan.

TABLE 9

Soil strength and root distribution for Kpejeglo pedon 1 (KP 1)

Depth (cm)	*Description*	*Soil strength (KPa)*	*Root distribution*
0 –20	Above pan	758	Many fine roots
20 –80	Pan	1712	Very few, very fine roots
80 –200	Below pan	1529	No roots
t- Probability (Pan vs above pan)		*<0.001*	
t-Probability (Pan vs below pan)		*=0.02*	

TABLE 10

Soil strength and root distribution of Kpejeglo pedon 2 (KP 2)

Depth (cm)	*Description*	*Soil strength (KPa)*	*Root distribution*
0 –20	Above pan	993	Many fine roots
20 –65	Pan	1675	Very few, very fine roots
56 –150	Below pan	1482	No roots
t- Probability (Pan vs above pan)`<0.001			
t-Probability (Pan vs below pan)		*= 0.234*	

TABLE 11

Soil strength and root distribution of Agawtaw pedon 1 (AG 1)

Depth (cm)	*Description*	*Soil strength (KPa)*	*Root distribution*
0–35	Above pan	971	Many fine roots
35–60	Pan	1687	Very few, very fine roots
60–90	Below pan	1086	No roots
t- Probability (Pan vs above pan)		*<0.001*	
t-Probability (Pan vs below pan)		*=0.234*	

TABLE 12

Soil strength and root distribution of Agawtaw pedon 2 (AG 2)

Depth (cm)	*Description*	*Soil strength (KPa)*	*Root distribution*
0 –36	Above pan	1132	Many fine roots
36–60	Pan	1748	Very few, very fine roots
60–110	Below pan	1527	No roots
t- Probability (Pan vs above pan)		*<0.001*	
t-Probability (Pan vs below pan)		*=0.011*	

Conclusion

The results of the study show that the morphological, chemical and physical properties of *Kpejeglo series* and *Agawtaw series* were very similar. The soils contained small amounts of organic C and exchangeable K. They were also noted for low levels of N and available P (Brammer, 1962; Kaiser & Constructors, 1965; Asiamah, 1995). The soils, however, contained moderate to high amounts of exchangeable Ca, Mg and Na, particularly in the subsoil and bottom horizons.

The chemical and physical properties of the soils clearly show that they would be very difficult to manage as had been reported by earlier researchers (Brammer, 1962; Kaiser Engineers & Constructors, 1965; 1975; Obeng, 1975; Agyili & Tei, 1979; Asiamah, 1995). The soils did not only have subsurface hardpans but also showed high amounts of exchangeable Na. As reported by Brammer (1962) Kaiser Constructors (1965), the major problem of these soils is not the low levels of some nutrients in the top soils but the presence of subsoil hardpan and associated 2:1 clays and very high levels of exchangeable Na.

Effective agricultural production on these soils may be limited to shallow rooted crops like vegetables. Also, because the soils easily get flooded, low land rice production is possible if a moisture retention practice like bunding is used. However, for the cultivation of a wider variety of crops, especially deep-rooted ones, the hardpan would have to be broken followed by application of sulphur and gypsum to help leach out excess Na salts (Kaiser & Constructors, 1965, Obeng, 1975). Due to the high cost implications of improving the productivity of the soils for crop production, pasture development and cattle rearing have also been recommended (Brammer, 1962; Obeng, 1975).

Notwithstanding the difficulties inherent in managing *Agawtaw series* and *Kpejeglo series* for crop cultivation, their gently sloping nature, coupled with their proximity to water (i.e. the Volta Lake) and the major market centres of the country, make remediating them for crop production worth considering.

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