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Full Length Research Paper

Impacts of anthropogenic activities on physical and selected chemical properties of soils in the natural forest-savanna of Northern Ghana

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This study assessed the impacts of anthropogenic activities on the textural and selected chemical properties of the soils in the natural forest-savanna in northern Ghana by comparing the soil physicochemical status of protected forests and neighbouring unprotected forests which are prone to human pressures (except farming and settlements). Three study zones (Wungu, Serigu, and Mognori, which are parts of West Mamprusi, Bolgatanga and Bawku East Districts respectively) were used for the study. Ninety-six (96) composite soil samples (0-50 cm depth) were collected for analysis. The study results showed that the texture of soils generally showed little difference between the protected and unprotected forests within each study zone. Bulk density, Cation exchange capacity (CEC), and soil organic C, Total Nitrogen (TN), and phosphorus (P), values were generally higher in the protected sites than the unprotected. Exchangeable bases (Ca, Mg, K and Na) and available micronutrients (Fe, Mn, Zn and Cu) content were greater in the protected forests than the unprotected. The study therefore suggests the development of management systems for off-reserve forests in a direction which protects the fertility of the soils under these forests, and sustains forest productivity and people's livelihoods.

Key words: Forest-savanna, soil, physicochemical properties, soil health and fertility.

INTRODUCTION

Forests play an important role in protecting the soil, water resources and ameliorating the environment (FAO, 2002). Forest soils in particular play a vital role in determining the sustainable productivity of the forest ecosystems (Kumar and Babel, 2011). Therefore, soil fertility changes and the nutrient balances are taken as key indicators of forest ecosystem quality (Jansen et al., 1995). Hence, forest lands with good physical and chemical characteristics are essential in maintaining productivity in terrestrial ecosystems and driving processes that maintain environmental quality (Moussa et al., 2008) and sustainability (Hopmans et al., 2005; Liebig et al., 2006). At present, forest is a threatened natural resource. Anthropogenic activities such as overexploitation, over-grazing, inappropriate clearing techniques and unsuitable land-use practices have resulted in severe soil nutrient

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decline and decrease in productivity (ISRIC, 2007). It is further widely established that, human activities are increasingly altering the ways in which energy and elements cycle within and move between ecosystems including forests (Houghton et al., 1999; Jing-wei et al., 2011). Human-driven deforestation causes increased losses of carbon, nitrogen, phosphorus, and sulphur from terrestrial ecosystems. Losses of these elements following deforestation are most rapid in sites with high decomposition rates, especially in the tropics and on fertile soils (Vitousek et al., 1981). Over the past century tropical forests have been suffering from exceptional rates of change as they are degraded or destroyed by human activities (Wright, 2005). Approximately one-fifth of the world's population lives specifically within tropical regions consisting of savanna type vegetation (Schuttemeyer et al., 2006). Savannas occupy about 20% of the land surface of the world, and about 40% of Africa (Scholes and Walker, 1993). In Ghana, as in many areas in Africa, savanna woodlands provide valuable environmental services, are a critical refuge for native biodiversity, and also protect soil and water resources against degradation. With about 20% of the national population the northern and coastal savanna zones supply about 70% of Ghana's total supply of firewood and charcoal, estimated at 16 million cubic meter, and also provides medicinal plants, thatches, fencing poles, and fruits (e.g., shea-nut which is an increasingly important export commodity) (NSBC, 2002). However, while the pursuit of economic and social exploitation of forest resources has contributed to development in both rural and urban communities in the country, the manner in which it has sometimes been done has led to decline in forest environmental quality (Francois, 1995). As a result, the forest-savanna of northern Ghana continues to experience major biophysical environmental degradations closely associated with such activities as commercial and artisanal logging, large scale land conversion, fuel wood and charcoal production, slash and burn agriculture, grazing, harvesting of non-timber forest products, hunting and mining (Nsiah-Gyabaah, 1996; FAO, 2000). Hence, the preservation and conservation of this forest ecosystem is of paramount importance not just for the sake of production of commodities, but more so for maintaining its ecological balance and environmental reasons. An in-depth assessment and understanding of the extent and nature of the human-induced effects on the soil physicochemical properties of the forest-savanna of northern Ghana will therefore be a valuable tool in developing effective conservation mechanisms and ensuring long-term productivity of this forest ecosystem. This perspective further finds its relevance in the fact that there is a paucity of published information on the effects of human activities on the northern Ghanaian forest-savanna ecosystem variability. It is against this background that the current study was conducted. The objective of the study was to assess the induced effects of human activities on soil textural and selected chemical properties by comparing the physicochemical status of the soils under protected forests and neighbouring unprotected forests which are prone to human activities (except farming and settlements).

MATERIALS AND METHODS

Description of the study area

The study was conducted in the savanna ecological zone in northern Ghana (8°N, to latitude 11°N and longitudes 2°57'W and 0°34'E) (Figure 1). The climate in this area is characterised generally as tropical continental, or savanna, with a single rainy season, from May to October, followed by a prolonged dry season (FAO, 1998). Average ambient temperatures are high year round (about 28°C) but the harmattan months of December and January are characterized by minimum temperatures that may fall to 13°C at night, while March and April may experience 40°C in the early afternoon. The area is associated with a total annual rainfall of about 1000 to 1300 mm per annum. The rainy season is 140 to 190 days in duration, while the estimated reference evaporation is about 2000 mm/annum, creating a great seasonal deficit every dry season. The peak rainfall period is usually late August or early September. About 60% of the rainfall occurs within the three months, that is, from July to September.

Most of the geological formations in this area are overlain by a regolith comprising *in situ* chemically weathered material and, to a lesser extent, transported surface material. Typically, this weathered layer consists (from top to bottom) of a residual soil zone (usually sandy - clayey material possibly underlain by an indurated layer) and a saprolite zone (completely to slightly decomposed rock with decreasing clay content with depth) (Carrier et al., 2008). The soils of the study zones include Gleyic Lixisols (Bolgatanga District), Savanna Ochrosols (Bawku East District) and Savannah Gleisols which are found in West Mamprusi District (Jessica and Pablo, 2001; GSS, 2014; CEPA, 2000)

The vegetation cover typical of northern Ghana consists of mixed formations of fire resistant trees and shrubs. Moving northwards, within the savanna region, there is at first densely wooded and vigorous grassland (*Andropogon* spp.*)* with fire resistant shrubs, often referred to as woodland savanna or Guinea savanna. Further north, in an increasingly arid environment, grass savanna or sudan savanna is formed, with trees and shrubs either absent or very sparse (FAO, 1998). The total conserved of the northern Ghana savanna area is about 15 million hectares. The reserved forest which was established by the Forest Ordinance of 1910 (Francois, 1995) is made up of 11, 590 km² of production forests, 4,323 km² of protection forests and about 1,980 km² of game production reserves. It is estimated that 20,000 ha per annum of the reserved area is lost to agriculture, or through bush fires and other human activities such as bush burning, overgrazing, and mining coupled with over exploitation of plants by people in the form of fuel wood and charcoal, timber and medicinal products (FAO, 1998). The persistent exposure of this forest ecosystem to human activities constitutes a serious threat to its environmental sustainability and communities' livelihoods (Francois, 1995; FAO, 1998; Campbell et al., 2000).

Site selection and sampling

Three study zones (Wungu, Serigu, Mognori) were used for the comparative study. Each zone was made up of two neighbouring

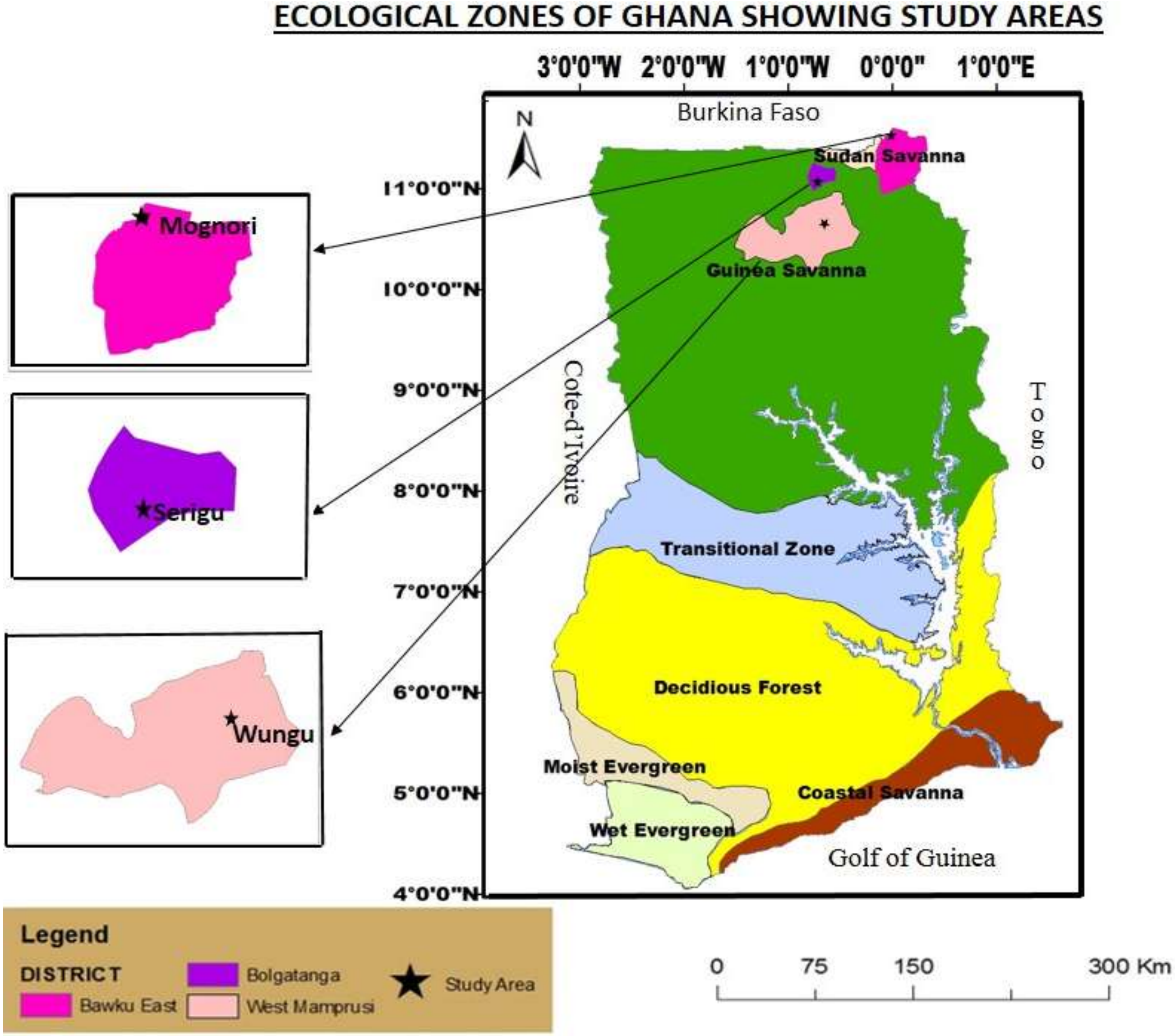

Figure 1. Map of Ghana showing the location of study areas.

forest types, namely the protected (a forest reserve or sacred grove) and unprotected types. The selection of the study zones was effected based on the distinct ecologies which can be distinguished within the interior savanna, and the level of protection and exposure to human activities of the protected and unprotected forest sites respectively. The unprotected sites have continuously been subjected to human activities (except farming and settlements), whilst the forest reserves and sacred groves have been well monitored and kept off from human disturbances. The effective monitoring and protection of the forest reserves and sacred groves represents an ideal opportunity to study the effects caused by forest sites long-term exposure to human pressures in the savanna ecological zone of northern Ghana. The study areas were named as follows: WP (Wungu protected forest) and WU (Wungu unprotected forest) for Wungu study site, SP (Serigu protected forest) and SU (Serigu unprotected forest) for Serigu study site, MP (Mognori protected forest) and MU (Mognori unprotected forest) for Mognori study site. Four 30 m × 30 m random plots were set in both the protected and neighbouring unprotected forest sites of each study zone in late August 2013 (late peak rainy season) and used for the soil sampling. Soil samples were collected from within all the four 1 × 1 m random subplots of each 30 × 30 m plot using soil coring method to 50 cm depth and separated into 10 cm layers (0 - 10, 10 - 20, 20- 30, 30- 40, 40- 50 cm). A total of 160 random soil samples (0-50 cm depth), were collected in both adjacent forest types of each study zone to make composite samples for the determination of selected physical and chemical properties.

Soil samples preparation and laboratory analyses

Soil samples were spread on a drying tray to remove roots and other debris and air-dried for 3 days and ground with a wooden pestle and mortar to loosen the aggregates. After grinding, the soil was screened through a 2-mm mesh and mixed thoroughly. The prepared samples were taken to the laboratory and analysed for the

Table 1. Methods of analysis of soil physicochemical properties.

S/N	Properties	Procedure	References
A	Mechanical analysis	Hydrometer method	Bouyoucos (1962)
B	Physico-chemical characteristics		
1	Organic carbon	Walkley and Black's wet digestion method	Motsara and Roy (2008)
2	Cation Exchange Capacity	1M NH_4OAc method estimated on flame photometer	Motsara and Roy (2008)
3	pH(1:1 Soil water suspension)	Glass electrode pH meter	Van Lierop (1990)
4	Macronutrients		
4.1	Total Nitrogen (N)	Modified Kjeldahl method using salicylic acid	Subbiah and Asija (1956)
4.2	Available Phosphorous (P)	Bray's method No.1 estimated on AAS	Olsen et al. (1954)
4.3	Available Potassium (K)	1M NH_4OAc method estimated on flame photometer	Page et al. (1982)
5.1	Available micronutrients : Zn, Fe, Cu and Mn	DTPA extract estimated on AAS	Lindsay and Norvell (1978)

determination of available macronutrients and micronutrients. Standard analytical methods were used in the analysis of soil samples (Table 1).

Statistical analyses of data

The results were subjected to analysis of variances (ANOVA) using the software programme SPSS, ver. 16.0 (SPSS Inc., Chicago, IL, USA) to determine treatment effects (that is, protected versus unprotected forests) for each study zone on collected data. The least significant difference (LSD) test was employed to compare the means for each study zone at 0.05 and 0.01 significance levels.

RESULTS AND DISCUSSION

Effects of human activities on soil physical properties

The textural analysis indicates that the soils have relatively high sand and low clay contents in Wungu and Serigu, and high silt and clay contents in Mognori in both the protected and unprotected forest sites (Table 2). Unlike in Mognori study site where the clay content was twice greater in the unprotected site than the protected, the difference in clay content between the two forest types was minute in Serigu and Wungu. Besides, the observed differences between the two forest types were only significant in Mognori ($P< 0.05$) in contrast to Wungu and Serigu sites where no significant difference ($P> 0.05$) was observed. The silt content was higher in the protected site than the unprotected in Serigu and Mognori as opposed to Wungu where the silt content was higher in the unprotected site (Table 2). The variation in silt content between the two forest types was significant in Wungu ($P< 0.01$) and Serigu ($P< 0.05$) while no significance ($P > 0.05$) difference was recorded in Mognori. Expect for Serigu site where the sand content was higher in the unprotected site, in Wungu and Mognori the sand content was higher in the protected site. The recorded difference in the sand content between the two forest types was significant in Wungu and Serigu ($P< 0.05$) as opposed to Mognori where there was no significant difference ($P > 0.05$). Soil bulk density (BD) values were significantly ($P< 0.01$) higher in the unprotected forest sites than the unprotected across the three study zones (Table 2). According to bulk density rating suggested by Batjes (1996), BD values ranked low ($b \leq 1.35$ g/cm^3) across the protected sites in contrast to the unprotected forest sites which recorded high bulk density values ($1.35< b \leq 1.55$ g/cm^3).

Effects of human activities on selected chemical properties

Soil pH, organic matter, organic carbon, total nitrogen, and available phosphorus

Except for Mognori site, soil pH values were generally higher in the protected sites than the unprotected (Table 3). However the magnitude of the observed differences in pH between the two forest types varied across the study zones. According to classification of soil pH suggested by Hazelton and Murphy (2007), the soil pH was moderately acid (pH 5.9) in WU, and neutral in WP (pH 6.7) and SU (pH 6.8), and mildly alkaline in SP (pH = 7.5), MP (pH = 7.2), and MU (pH = 7.5). Except for Mognori site where no significant ($P> 0.05$) difference in pH was observed between the two forest types, the variation in pH values between the protected and unprotected sites was significant in Wungu ($P< 0.01$) and Serigu ($P< 0.05$).

Results in Table 3 further show that soil organic matter contents ranged from good to medium (Tekalign, 1991) across the protected sites; with values ranging from 2.6, 4.8, and 4.44% in WP, SP and MP respectively. By contrast, organic matter contents were generally ranked low across the unprotected sites as values ranged from 1.5, 1.82, and 1.70 in WU, SU, and MU respectively. Soil organic matter was twice higher in WP than the unprotected and three times greater in SP and MP. The differences in soil organic matter contents between the

Table 2. Mean values of particle size distribution as affected by forest management type.

Forest type	% Sand	% Silt	% Clay	Texture	BD (gcm^{-3})
WP	73.15 ± 1.53	24.82 ± 1.52	2.03 ± 0.02	Loamy sand	1.38 ± 0.00
WU	56.12 ± 8.61	40.85 ± 8.22	3.03 ± 1.14	Sandy loam	1.46 ± 0.02
SP	58.93 ± 3.27	38.39 ± 2.52	2.68 ± 0.95	Sandy loam	1.22 ± 0.02
SU	71.26 ± 7.43	26.28 ± 6.72	2.53 ± 1.01	Loamy sand	1.43 ± 0.04
MP	28.32 ± 25.14	62.68 ± 26.00	9.01 ± 3.84	Silty loam	1.22 ± 0.10
MU	22.89 ± 1.18	57.09 ± 1.17	20.02 ± 0.02	Silty loam	1.44 ± 0.02

Within rows, means ± S.D., n = 4.

Table 3. Mean values of pH, organic matter (OM), organic carbon (OC) total nitrogen, and available phosphorus as affected by forest management type

Forest type	pH (1:1H_2O)	OM (%)	OC (%)	Total N (%)	Available P (mg/kg)
WP	6.7 ± 0.52	2.60 ± 0.07	1.50 ± 0.04	0.13 ± 0.00	9.57 ± 4
WU	5.9 ± 0.21	1.50 ± 0.11	0.87 ± 0.06	0.09 ± 0.01	2.45 ± 1
SP	7.5 ± 0.34	4.80±0.61	2.78 ± 0.35	0.24 ± 0.032	23 ± 15
SU	6.8 ± 2.33	1.82 ± 0.45	1.06 ± 0.26	0.1 ± 0.025	6 ± 1
MP	7.2 ± 0.47	4.44 ± 1.31	2.60 ± 0.76	0.23 ± 0.07	11.61 ± 10
MU	7.5 ± 0.29	1.70 ± 0.48	0.95 ± 0.28	0.09 ± 0.02	0.70 ± 1

Within rows, means ± S.D., n = 4

protected and unprotected forests were significant ($P< 0.01$) across the three study zones.

Soil organic carbon (SOC) contents were significantly ($P< 0.01$) higher in the protected sites than the unprotected across the three study zones. SOC values generally ranked optimum across the protected sites in contrast to the unprotected sites where values were all ranked low (Moges et al., 2013). The magnitude of the variation in the SOC contents between the protected and unprotected forests showed the same pattern as that of organic matter, that is, SOC content was twice higher in WP than WU and three times greater in SP and MP than SU and MU respectively.

Total nitrogen contents (Table 3) were significantly higher ($P< 0.01$) in all the protected sites than the adjacent unprotected forest sites. Moreover, on the basis of soil nitrogen ratings suggested by Tekalign (1991), available nitrogen values were ranked medium in all the protected sites as opposed to the generally low values recorded across the unprotected sites. Except for Wungu site which recorded moderate numerical variation in N content between the two forest types, the N content was twice and threefold higher in the protected forest than the unprotected in Serigu and Mognori sites respectively.

The available P contents (Table 3) of the soil under protected forests were markedly and significantly ($P< 0.01$) higher in the protected sites than the unprotected across the three study zones. On the basis of soil P concentration ratings suggested by Hazelton and Murphy (2007), P values were optimal (10 - 17 mg/kg) in WP and MP and high (17 - 25 mg/kg) in SP. However, P values across all the unprotected forest sites varied from low (5 - 10 mg/kg) to very low (< 5 mg/kg).

Cation exchange capacity (CEC) and exchangeable bases

Cation exchange capacity was higher in the protected sites than the unprotected (Table 4). However the level of the differences in CEC values between the two forest types varied across the three study zones. On the basis of CEC rating suggested by Hazelton and Murphy (2007), CEC values ranged from low (6 - 12 cmol (+) Kg^{-1} in WP), to moderate (12 - 25 cmol (+) Kg^{-1} in SP and MP) across the protected sites. Across the unprotected study sites CEC values ranked very low in WU and SU (CEC < 6 cmol (+) Kg^{-1}) and moderate in MU (12 - 25 cmol (+) Kg^{-1}) (Table 4). Significant ($P< 0.01$) differences in CEC values were recorded in Wungu and Serigu sites as opposed to Mognori site where no statistically significant ($P> 0.05$) variation was observed between the protected and unprotected forests.

The exchangeable bases (Ca, Mg, K and Na) greatly varied with study zone. Across the three study locations, the exchangeable bases values were higher in the protected sites than the unprotected. According to exchangeable Ca concentration rating (Hazelton and

Table 4. Cation exchange capacity and soil exchangeable Ca, Mg, K, and Na as affected by forest management type.

Forest type	Exchangeable Bases (cmol (+) Kg^{-1} soil)				
	Ca	**Mg**	**K**	**Na**	**CEC**
WP	1.5 ± 0.4	3.9 ± 1.07	0.24 ± 0.11	0.15 ± 0.02	6.11 ± 1.35
WU	0.5 ± 0.11	1.2 ± 0.29	0.16 ± 0.01	0.13 ± 0.01	2.4 ± 0.5
SP	3.9 ± 0.95	10.43 ± 2.35	0.47 ± 0.08	0.22 ± 0.042	14.91 ± 3.5
SU	1.2 ± 0.28	3.20 ± 0.75	0.17 ± 0.01	0.10 ± 0.01	4.75 ± 1.03
MP	6.2 ± 1.31	15 ± 3.5	0.36 ± 0.09	0.21 ± 0.02	21.69 ± 5
MU	5.2 ± 0.82	10.22 ± 5.18	0.30 ± 0.11	0.20 ± 0.1	16.01 ± 5.06

Within rows, means ± S.D., n = 4.

Murphy, 2007), Ca values were very low (0 - 2 cmol (+) Kg^{-1}) in WP, low in SP (2 - 5 cmol (+) Kg^{-1}) and moderate in MP (5 - 10 cmol (+) Kg^{-1}). Values in the unprotected forests were very low in WU (0.5 cmol (+) Kg^{-1}) and SU (1.2 cmol (+) Kg^{-1}) and moderate in MU (5.2 cmol (+) Kg^{-1}). The Mg contents were high in WP (3.95.2 cmol (+) Kg^{-1}) and very high in SP (10.43 me/100 g) and MP (15 5.2 cmol (+) Kg^{-1}). Across the unprotected forests Mg concentrations exhibited the following ratings: Moderate in WU (1.2 cmol (+) Kg^{-1}), high in SU (3.2 cmol (+) Kg^{-1}), and very high in MU (10.22 cmol (+) Kg^{-1}). The K values were low (0 - 0.2 cmol (+) Kg^{-1}) in WP and moderate (0.3 - 0.7 cmol (+) Kg^{-1}) in SP and MP. K contents across all the unprotected forest sites ranged from very low (0 - 0.2 cmol (+) Kg^{-1}) in WU and STU to moderate in MU (0.3 - 0.7 cmol (+) Kg^{-1}). The Na concentrations were ranked low (0.1 - 0.3 cmol (+) Kg^{-1}) in both the protected and unprotected sites across the three study zones. The variation in exchangeable bases (Ca, Mg, K and Na) between the two forest types was significant ($P< 0.01$), except for K, and Ca bases in Mognori study site were no significant ($P> 0.05$) differences were recorded.

Available soil micronutrients (Fe, Mn, Zn, and Cu)

Iron status: Data in Table 5 show that Fe contents were very high (> 10 mg/kg) for both forest types across the three study zones. Except for Mognori site, Fe contents were significantly lower in the protected forests than the unprotected. Significant ($P< 0.01$ and $P< 0.05$) variations in Fe contents between the protected and unprotected forests were recorded across the three study zones.

Manganese status: Table 5 shows that Mn values were significantly higher ($P< 0.01$) in the protected forest sites than unprotected. Mn values ranged from very high (> 6 mg/kg) to high (3.5 - 6 mg/kg) in the protected and unprotected forest sites respectively (Motsara and Roy, 2008).

Copper status: Results in Table 5 further shows that except for Wungu site, Cu concentrations in the soils were higher in the protected sites than the unprotected. The data show that Cu values were very high (> 3 mg/kg) in MP, and high (0.8 - 3 mg/kg) in SP and WP. Values recorded in the unprotected forest sites ranked very high in MU and WU and high in SU (Motsara and Roy, 2008). Significant ($P< 0.01$) difference was recorded in Cu status between the two forest types across the three study zones.

Zinc status: Zinc contents (Table 5) in the soils were higher in the protected forests than the unprotected. The observed differences in Zn values between the two forest types were significant ($P< 0.01$ and $P< 0.05$) in Serigu and Mognori sites as opposed to Wungu where no significant ($P> 0.05$) variation was recorded between the protected and unprotected forests. Zinc values ranked very high (> 5 mg/kg), and generally high (3 – 5 mg/kg) in the protected and unprotected sites respectively (Motsara and Roy, 2008).

DISCUSSION

The relatively low clay contents recorded across the three study zones are in consistent with findings reported by previous authors (Senayah et al., 2005). This is could be due to the loss of dispersable clay through erosion or leaching to the subsoil as soils in the savanna ecological zone of Ghana are very susceptible to erosion as well as compaction (Callo-Concha et al., 2012). The finding in this study substantiate this fact as the bulk density values were high ($1.35< b \leq 1.55$ g/cm^3) across the unprotected forest sites, indicating that the soils under these forests were compacted. This situation could be due to the adverse effects of anthropogenic activities across these forests, since it is established that deforestation leaves the land more susceptible to soil degradation including higher soil bulk density, lower hydraulic conductivity, and higher soil erosion (Spaans, 1989). The study finding therefore points to the need of regulating human activities across the off-reserve forests as well as stepping up

Table 5. Mean values of available micronutrients (Fe, Mn, Zn and Cu) as affected by forest management type.

Forest type	Micronutrients (mg/kg)			
	Fe	Mn	Zn	Cu
WP	62 ± 45.86	18 ± 9.02	7 ± 4.40	2 ± 0.7
WU	98 ± 29.60	4 ± 2.54	5 ± 3.56	4 ± 0.54
SP	26 ± 15.26	16 ± 7.18	9 ± 2.6	3.33 ± 1.41
SU	67 ± 9.60	5 ± 0.66	4.5 ± 2.30	1.43 ± 0.92
MP	67 ± 25.80	22 ± 3.06	5.8 ± 0.81	10 ± 0.31
MU	20 ± 7.74	5 ± 1.05	2.6 ± 1.33	11 ± 0.43

Within rows, means ± S.D., n = 4.

protection of existing reserves in the area so as to avoid further deterioration of the physical properties of the soils under these forests.

The low soil pH values recorded in the unprotected forest sites could be attributed to an advanced stage of removal of basic cations from the surface of the soils under these forests as a result of the effect of anthropogenic activities which led to the loss of nutrients mainly through, grazing, bushfires, and logging. The low values of exchangeable bases (Ca, Mg, K and Na) recorded in the unprotected sites as shown in Table 4 are in line with the above inference. Data contained in Table 4 show that protected sites exhibited higher exchangeable base contents probably as a result of better or sufficient nutrient cycling as these protected forest sites recorded significantly ($P< 0.01$) higher organic matter/organic carbon contents (Table 3) than the unprotected. Several studies have substantiated these facts (Teshome et al., 2013).

The low CEC (Table 4) recorded in unprotected forest sites was consistent with the low organic matter/organic carbon contents (Table 4) of the soils under these forests. Indeed, the correlation analysis (Table 6) showed that there was a positive correlation between CEC and organic matter/organic carbon across the three study zones. The low organic matter/organic carbon contents in the unprotected forest sites was probably due to insufficient inputs of organic matter in the soils of these forests as a result of constant removal of organic matter through, grazing, logging and bushfires.

The data on the soil chemistry of the six study sites further showed that total nitrogen (N) contents were generally low in the unprotected sites compared to those recorded in the protected forests. This finding was in line with previous studies which indicated that human activities such as overexploitation, overgrazing, and inappropriate clearing techniques have alterable effects on nitrogen cycle in ecological systems including savannas (Emma et al., 2012). A positive correlation (Table 6) was found between organic matter/organic carbon and available nitrogen across the three study zones suggesting that the generally low nitrogen values recorded in the unprotected sites were due to deforestation. The observed correlation between organic matter/organic carbon and available nitrogen was in line with the fact that most of the soil nitrogen is found in organic form (Singh and Mishra, 2012; Rangel, 2008).

The high and moderate phosphorous (P) contents of the soils in the protected forest sites vis - à-vis the low and very low values recorded in the unprotected forest sites could be attributed to the persistent removal of plant biomass and erosion as a result of the environmentally-degrading human pressures put on these unprotected forests. A positive correlation (Table 6) was found between organic carbon and available phosphorous across the protected areas. This indicates that high contents of organic matter increase the availability of phosphorous in soils. Indeed, Tisdale et al. (1997) buttressed this correlation by pointing out that, about 50% of phosphorous is found in organic form and that decomposition of organic matter produces humus which forms complex with aluminium (Al) and iron (Fe) and protects the P fixation. The low N and P contents recorded in the unprotected forest sites could result in continued decreases in the productivity of these forests over time should the ongoing anthropogenic activities remain unchecked. This foreseeable implication is supported by the fact that nitrogen is the major factor that controls the dynamics, biodiversity, and functioning of many ecosystems (Vitousek et al., 1981) and plays a central role in limiting primary production in terrestrial ecosystems (Bremen and De Wit, 1983). Besides, it is further established that deficiencies of other elements in the natural vegetation are usually only obvious once nitrogen and phosphorus constraints have been alleviated.

The available micronutrients (Fe, Mn, Zn and Cu) contents were generally higher in the protected forest sites than the unprotected. Earlier works (Jiang et al, 2009; Kumar and Babel, 2011) on the influence of land use systems on available micronutrients have corroborated this finding. Positive correlations were found between Mn, Zn, Cu and the organic carbon/organic carbon content across the protected sites indicating that the differences in micronutrient values between the protected and unprotected study sites might be due to

Table 6. Correlation matrix between selected characteristics of soils under protected and unprotected forest sites at each study zone.

Soil characteristics		pH	OM	OC	CEC	TN	P	Clay	Fe	Mn	Cu	Zn
pH	WP	1.0										
	WU	1.0										
	SP	1.0										
	SU	1.0										
	MP	1.0										
	MU	1.0										
OM	WP	0.560	1.0									
	WU	0.853	1.0									
	SP	-0.458	1.0									
	SU	-0.233	1.0									
	MP	-0.972*	1.0									
	MU	-0.804	1.0									
OC	WP	0.560	0.999**	1.0								
	WU	0.853	1.000**	1.0								
	SP	-0.456	1.000**	1.0								
	SU	0.231	0.953*	1.0								
	MP	-0.972*	1.000**	1.0								
	MU	-0.803	1.000**	1.0								
CEC	WP	0.856	0.906	0.906	1.0							
	WU	0.516	0.275	0.275	1.0							
	SP	0.499	0.468	0.544	1.0							
	SU	0.487	0.864	0.928	1.0							
	MP	-0.977*	0.997**	0.997**	1.0							
	MU	-0.794	0.278	0.277	1.0							
TN	WP	0.965	1.000**	1.000**	0.	1.0						
	WU	0.853	1.000**	1.000**	0.275	1.0						
	SP	-0.531	1.000**	0.995**	0.544	1.0						
	SU	-0.001	0.952	0.953	0.864	1.0						
	MP	-0.9541	0.990**	0.990**	0.996	1.0						
	MU	0.307	0.991**	0.320	0.280	1.0						
P	WP	0.490	0.938	0.920	0.833	0.342	1.0					
	WU	-0.721	-0.964*	-0.964*	-0.100	0.964*	1.0					
	SP	0.6825	0.332	0.333	0.968	0.2452	1.0					
	SU	-0.919	-0.537	-0.538	-0.779	-0.358	1.0					

Table 6. Contd.

	MP	-0.9541	0.044	0.043	0.097	0.1775	1.0					
	MU	-0.9189	-0.537	-0.538	-0.779	-0.358	1.0					
Clay	WP	0.207	-0.690	-0.694	-0.325	0.879	0.645	1.0				
	WU	0.059	-0.003	-0.003	0.853	-0.003	-0.750	1.0				
	SP	-0.620	0.919	0.922	0.313	0.954	0.067	1.0				
	SU	0.643	0.990	0.990*	0.954*	0.968*	-0.730	1.0				
	MP	-0.534	0.712	0.711	0.701	0.759	0.498	1.0				
	MU	-0.518	0.925	0.926	-0.108	0.655	-0.307	1.0				
Fe	WP	-0.839	-0.530	-0.502	-0.756	0.632	0.654	-0.156	1.0			
	WU	0.798	-0.856	-0.856	-0.656	0.537	-0.845	0.795	1.0			
	SP	-0.033	-0.901	-0.901	-0.847	0.145	0.707	0.708	1.0			
	SU	0.687	-0.831	-0.830	-0.857	0.627	-0.814	0.990	1.0			
	MP	-0.055	-0.013	-0.013	-1.000	0.133	0.838	0.114	1.0			
	MU	-0.500	-0.188	-0.197	0.604	-0.482	-0.599	-0.040	1.0			
Mn	WP	-0.490	0.938	0.920	0.833	-0.770	0.301	-0.031	0.420	1.0		
	WU	0.197	0.052	0.052	0.946	-0.679	0.675	-0.729	-0.965	1.0		
	SP	-0.933	0.125	0.124	0.759	-0.894	-0.894	0.374	-0.317	1.0		
	SU	0.330	0.848	0.847	0.698	0.678	-0.460	0.948	0.890	1.0		
	MP	0.188	0.121	0.121	0.062	0.014	0.982*	0.329	0.875	1.0		
	MU	0.261	0.257	0.246	-0.172	0.019	0.197	-0.194	0.657	1.0		
Cu	WP	0.880	0.220	0.202	0.583	0.831	-0.284	0.537	-0.899	-0.523	1.0	
	WU	-0.389	-0.138	-0.138	-0.413	0.707	0.362	0.011	0.194	-0.444	1.0	
	SP	-0.671	0.935	0.933	0.275	0.938	0.074	0.848	0.257	0.359	1.0	
	SU	0.808	-0.756	-0.755	0.867	0.553	-0.924	0.933	0.974*	0.765	1.0	
	MP	0.469	0.252	0.254	0.303	-0.243	0.159	0.400	-0.380	0.114	1.0	
	MU	-0.820	-0.788	-0.794	0.513	-0.038	-0.768	0.615	0.750	0.279	1.0	
Zn	WP	0.766	0.382	0.382	0.607	-0.943	-0.081	0.189	-0.292	-0.975*	0.488	1.0
	WU	0.242	-0.276	-0.276	-0.976*	-0.747	-0.259	-0.98	-0.299	0.538	-0.994**	1.0
	SP	-0.308	0.983	0.984	0.668	0.970*	0.469	-0.897	0.053	-0.024	0.855	1.0
	SU	0.456	-0.410	-0.410	-0.046	-0.390	-0.393	-0.349	-0.215	-0.636	0.011	1.0
	MP	0.160	0.070	0.071	-0.152	-0.175	-0.702	-0.003	-0.975*	-0.746	0.576	1.0
	MU	0.893	-0.451	-0.450	-0.983	0.702	0.971*	-0.078	-0.597	0.210	-0.628	1.0

***** Significant at $P < 0.05$, ****** and $P < 0.01$. OM = Organic matter; OC = Organic carbon; CEC= Cation exchange capacity; TN = Total nitrogen.

high inputs of organic carbon in the soils of the protected forest sites where the absence of human disturbances led to high levels of above-ground and below-ground biomass productivity and sustained inputs of organic matter in the soils (Nang and Dioggban, 2015). Kumar and Babel (2011) stated that availability of micronutrients enhanced significantly with increase in organic matter because: (i) Organic matter is helpful in improving soil structure and aeration; (ii) Organic matter protects the oxidation and precipitation of micronutrients into unavailable forms and (iii) Supply soluble chelating agents which increase the solubility of micronutrient contents. Hence, the available Mn, Zn, and Cu were found to increase with increase in CEC (Table 6) of soils under protected due to more availability of exchange sites on soil colloids of which humus was probably an important component as the soils under investigation had relatively low clay contents.

The Cu, Fe, Mn, and Zn contents values were above the critical limits for plant production across the six study sites indicating that deficiency in these micronutrients was very unlikely for any vegetation type growing on these soils. However the high contents of Fe in the soils of the unprotected forests could lead to the formation of complexes leading to hard pan formation; restricting rooting depth and causing infiltration and drainage problems in the soil (Mustapha et al., 2011). Besides, in view of the fact that Cu, Fe, Mn, and Zn contents were lower in the unprotected sites than the protected it could be inferred that if human activities continue unabated the concentrations of Cu, Fe, Mn, and Zn of the soils under these forests could decrease further reach levels that would be incompatible with adequate plant productivity.

Results from the present study indicate that the effect of anthropogenic on the forest-savanna of northern Ghana led to degradation of the soil physical properties and decrease in the macronutrients (N, P, K) and micronutrients (Cu, Mn, Zn) levels. Hence, differences in forest management systems (protected forests versus anthropogenic activities prone forests) have significant influence on the soil quality and health and its sustainable productivity. It could therefore be concluded that if the ongoing human pressures on forest resource, including the reserves, remain unchecked, the following undesirable consequences could arise in the long run:

1. Gradual deterioration of the physical and chemical properties of the forest soils under investigation and subsequent decline in the nutrients supplying capacity of these soils.
2. Gradual decrease in plant biomass productivity of these forests and decrease in forage availability and livestock production in the region as a result.
3. More encroachments on existing reserves and more deforestation in the region
4. Threat to forest resource conservation in the region and communities' livelihoods.

The study therefore indicates the need for employing best forest management practices that will ensure effective monitoring and regulation of human activities in the off-reserve forest areas and prevent encroachments on the existing reserves. The effective enforcement of these management prescriptions along with vigorous reforestation programmes would be the way forward towards mitigating the ongoing deterioration of the plant-soil system, sustaining forest productivity and protecting people’s livelihoods. For in a region where inhabitants depend heavily upon forest resources for their livelihoods, the degradation of the forest-savanna of northern Ghana is a serious threat to the sustainability of their subsistence lifestyle (O’Higgin, 2007).

Conflict of Interests

The author has not declared any conflict of interest.

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Full Length Research Paper

Goodness of fit of three infiltration models of a soil under long-term trial in Samaru, Northern Guinea Savanna of Nigeria

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Good strategies for water conservation, runoff or flood control and erosion management can be achieved by proper understanding of soil water infiltration characteristics. Three infiltration models Kostiakov's (1932), Philip's (1957) and Horton's (1940) were used to evaluate the infiltration characteristics of soils in a long-term fertilizer experiment in the Northern Guinea Savanna Agro Ecological zone with regard to the effects of long term land use and soil management. A double ring infiltrometer was used to conduct infiltration measurement on ten plots having different combination of Dung (D), Nitrogen (N), Phosphorus (P), and Potassium (K) fertilizer treatments. Thus, the treatments combinations were DNPK, DN, DK, DP, D, NPK, N, P, K and CT (no fertilization). Soils were predominantly sandy loam and bulk density and organic carbon were significantly influenced by the fertilizer combinations. Linear least sum of squares was used to obtain the model fitting parameters. Measured infiltration rates for plots that received dung (singly or in combination with mineral fertilizer) were significantly higher ($p<0.05$) than for the CT plots. Kostiakov's and Philip models showed good agreement with measured infiltration due to large R^2 (0.9956 and 0.986) recorded, respectively except Horton's model, which gave low regression coefficient between measured and calculated data. Based on R^2 values obtained from comparing measured and calculated cumulative infiltration, Kostiakov's and then Philip's equations provided best predictions over Horton. Fitting parameters obtained are suggested for use of site-specific or management-specific solutions of infiltration-related application. Further work is required to obtain reliable fitting parameters for Horton's infiltration equation of the trial field.

Key words: Kostiakov, Philip, Horton, infiltration characteristics, DNPK plots.

INTRODUCTION

Infiltration characteristics of a soil are a useful property required in several hydrology-based studies that describe rate of water entry into the soil. Soil management and cultural practices, which have direct influence on soil

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Table 1. Fertilizer combinations for the various treatments in the experimental plots (Abdulkadir and Habu, 2013).

Treatment	Abbreviation	Rates (kg ha^{-1})		
Dung	D	0	2500	5000
Urea	N	0	67.5	135.0
Single super				
Phosphate (SSP)	P	0	13.5	27.0
Muriate of potash	K	0	29.0	58.0

Each fertilizer applied at 3 levels of 0, 1, 2, (3 x 3 x 3 x 3 = 81). Each row of the application rates represents the level number 0, 1, 2 respectively.

water movement, affect coefficients of determination of infiltration models (Davidoff and Selim, 1986; Franzluebbers et al., 2002). Influence of several factors such as mulching, residue incorporation, soil compaction and bulk density on soil infiltration characteristics have been reported by Davidoff and Selim (1986) and Franzluebbers et al. (2002). They concluded that the predictive ability of these models varies among management and cultural practices, which influence water infiltration into soils. Water infiltration is also believed to increase with reduction in bulk density, establishment of cover crops, mulching, and incorporation of crop residues (Shukla et al., 2003a). Knowledge of soil infiltration characteristics is a required input in increasing irrigation water use efficiency, design of irrigation systems, and decrease water and soil losses, all of which are crucial factors in agriculture (Ogban and Utin, 2014). Infiltration data is also an important parameter in field drainage applications (Haghighi et al., 2011).

However, field measurements of soil infiltration are cumbersome, expensive, time-consuming and give only local scale results (Shukla et al., 2003b; Lake et al., 2009). As such infiltration equations or models offer a viable option to estimate field infiltration characteristics of soils (Shukla et al., 2003a; Abdulkadir et al., 2011). Many infiltration models have been evaluated in different location of the world to test model fit with measured data models (Wudivira et al., 2001; Shukla et al., 2003a). For example, the superiority of Kostiakov (1932) and Green and Ampt (1911) equation over three other equations (Horton, 1940; Holtan, 1961; Philip, 1957) in the evaluation of their predictive abilities of under specific conditions was reported by Turner (2006). Better performance of Revised Modified Kostiakov (2007) was recorded by Mirzaee et al. (2014) in the evaluation of eight infiltration models with different numbers of fitting parameters in different soil texture classes. Shukla et al. (2003a) obtained a better result with the three parameter Horthon equation than nine other infiltration models for soil with different land use and soil management systems. Despites these findings, none of such work was conducted on a long-term fertilizer trial in Samaru, Northern Guinea Savanna of Nigeria. However, earlier work in the region focused on Talsma and Palange (1972), Kostiakov (1932) and Philip (1957) equation used to estimate the infiltration characteristics of soil (savanna Alfisol), such as those by Mudiare and Adewumi (2000), Wudivira et al. (2001) and Abdulkadir et al. (2011).

The objective of this study is therefore to test three infiltration models (Table 1) for their capability of describing water infiltration properties of a soil under a long-term management practices. A second objective was to develop fitting parameters for the three infiltration models.

MATERIALS AND METHODS

Experimental site

The study was carried out on selected plots in the long-term dung (D) and mineral fertilizer (NPK) trial field (that is, DNPK) of the Institute for Agricultural Research, Samaru (latitude11° 16’ North, longitude 07° 63’ East and 686 m altitude) in the Northern Guinea Savanna Ecology of Nigeria. The region is characterized by leached tropical ferruginous soils classified as Typic Halplustalf according to USDA soil taxonomy (Ogunwole et al., 2001). Each plot has a fertilization history with dung (D), nitrogen (N), phosphorus (P), and potassium (K) or their combinations under continuous cultivation from 1950 to 2008 (Ogunwole, 2008). A detailed description of these management practices vis a vis fertilizer combinations and application rates for each of the trial plot is presented in Table 1.

Plot descriptions and history of use

The long-term DNPK experiments was laid in 1949 and full experiments started in 1950 and is the oldest fertilizer experiment in West Africa that was modeled after the Rothamsted long-term trials in the United Kingdom (Amapu, 2007). It has 81 plots in 34 replicated factorial design randomly arranged with a plot size of 220 m^2. There are 27.4 m long ridges, which are 75 cm apart in each plot. Discarded areas of 0.91 m separate the plots from each other. The 81 treatments exist under combinations of DNPK fertilizers. The plots received different management practices that ranges from crop rotation, tillage practices, lime and micro nutrient application, and changes in mineral fertilizers as sources of the major nutrient and cultivated crops. Ogunwole and Ogunleye (2005) gave a detailed description of these management practices. Specifics of

Table 2. Infiltration models studied and parameters associated with each model.

Model no	Name	Equation	Parameter
1	Kostiakov (1932)	$I = Bt^n$	B and n
2	Philip (1957)	$I = St^{1/2} + At$	S and A
3	Horton (1940)	$f_p = f_c - f_0\ f_c\ e^{-\beta t}$	f_c, f_0 and β

the management practices adopted in the selected plot for this study can also be found in Ogunwole and Ogunleye (2005).

Soil sampling and analysis

The surface 20 cm soil depth of 10 selected plots were sampled for disturbed soils in three (3) replicates after sub-dividing each of the main plots (220 m^2) into three equal sized sub-plots. The replicate samples were bulked to obtain a composite sample per plot. The soil samples were appropriately labeled, air dried, ground to pass through 2 mm sieve and stored in polythene bags for routine analyses. Hydrometer method (Gee and Bauder, 1986) was used in determining particle size distribution in the soil. The textural classes of the soil were obtained from the textural triangle of SPAW hydrology model (Version 6.02.72) by computing percentage clay and sand fractions. Soil organic carbon was determined by dichromate oxidation method (Nelson and Sommers, 1982).

Field infiltration test

A double ring infiltrometer consisting of an inner ring of 300 mm in diameter and an outer ring of 550 mm in diameter both of 300 mm in height were inserted 100 mm into the ground. The rings were ponded with water to the brim. The depth of water percolation/infiltration in the inner ring was measured with a ruler at 1 min interval for the first 5 min, 5 min interval for the next 15 min, 30, 60 and 120 min to give a total of 120 min for each of the measurements within a plot. The time was read from a stop watch and all infiltration measurements were carried out in February, 2013 during dry season. Data collected were used to calculate infiltration rate and cumulative infiltration. Measured infiltration data were fitted into 3 different infiltration models (Kostiakov's, Philip's and Horton's) to determine the best-fit model for soils of the study plots. Linear regression analysis of Microsoft excel was used to obtained the model parameters. The model performance was tested by R^2 value obtained when comparing the measured vs. predicted infiltration values using 1:1 regression analysis of the Microsoft excel also. Undisturbed soil samples at depths of 0 to 15 cm and about 50 cm apart from the infiltrometer, were collected using a soil core sampler. The samples were carefully transported to the laboratory for bulk density determinations.

In this study, three infiltration models were examined. The equations representing each model are summarized in Table 2. The first was the Kostiakov (1932) model express as:

$$I = Bt^n$$

where I is the accumulated infiltration (m) and t is time (s). The parameters B and n represent the intercept and slope of logarithmic relations between I and t and they were determined from the logarithmic form of equation earlier by plotting log I against log t, which results in a straight line as the data fits into the equation.

Model 2 in Table 2 was that developed by Philip (1957) express as:

$$I = St^{1/2} + At$$

where I is cumulative infiltration, *S* is the soil water sorptivity, *A* is the soil water transmissivity and t is time. A linear graph of cumulative infiltration divided by $t^{0.5}$ was plotted against the successive time to obtain the parameters A and S as the intercept and slope. After knowing A and S, the new infiltration rate was calculated by fitting these parameters into the Philip equation. Infiltration rate was calculated for each plot and later compared with the field measurement using linear regressions from Microsoft Excel.

Model 3 was an empirical exponential infiltration equation proposed by Horton (1940) and express as:

$$f_p = f_c + (f_o - f_c)\ e^{-\beta t}$$

where f_p, f_c and f_0 are infiltration rate at time, t, final infiltration rate at t=120 and infiltration rate at t=0, respectively, β is an empirical constant related to delay of time.

RESULTS AND DISCUSSION

Selected soil properties of the study site are given in Table 3. Soils were predominantly sandy loam, and silty loam in texture with very low organic carbon status, which may indicate poor soil aggregation and fertility (Jones et al., 1975; El-Swaify et al., 1987; Ogunwole and Ogunleye, 2005). DK, D and DN plots had higher sand fraction, respectively, while the P, N and DNPK plots were found to have higher clay content as well. The increase sand fractions of DK, D and DN treatment plots may be the result of a higher resistance of the soil to continuous cultivation (Ogunwole and Ogunleye, 2005). Soils in all plots have low bulk density, thus indicating the ease of root penetration and water uptake by plant (Lawal and Girei, 2013). Several studies have shown the positive effect of dung or organic fertilizer applications on bulk density and moisture retention (Ogunwole, 2008).

Considering the plot of cumulative infiltration versus time of all the treatments, an initial rapid increase in infiltration that stabilizes with time was observed (Figure 1). Soil inherent heterogeneity in all the plots may have influenced infiltration characteristics of soils in this study. Variability in cumulative infiltration for some treatments was higher than in other treatments. Such variability was more pronounce for DK, P and N plots as shown in Figure 1. Results also indicate that for the early stages of infiltration, cumulative infiltration between the treatments were not different even in the control plot. This finding indicate that for a given quantity of applied irrigation or rainfall water, larger proportion will infiltrate into the soil of K, DK and D treated plots than all other treatments plots,

Table 3. Selected soil properties of the study plots.

Plots	Soil organic carbon (%)	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Textural class
D	1.04	1.43	59.19	34.49	6.32	Sandy Loam
DK	1.68	1.43	61.36	32.66	5.65	Silty Loam
NPK	0.63	1.43	57.19	32.32	6.99	Sandy Loam
N	1.02	1.43	50.32	42.33	7.32	Silty Loam
DNPK	1.41	1.53	46.02	46.66	7.32	Silty Loam
DP	1.51	1.44	55.94	38.24	5.82	Sandy Loam
CT	1.08	1.44	50.02	43.32	6.65	Sandy Loam
P	1.86	1.43	52.68	39.67	7.49	Sandy loam
DN	0.74	1.44	59.02	32.32	5.32	Sandy Loam
K	0.80	1.43	57.19	35.83	6.99	Sandy Loam

N: Nitrogen; P: Phosphorus; K: Potassium; D: Dung; CT: control; FC: Field Capacity; PWP: Permanent Wilting Point.

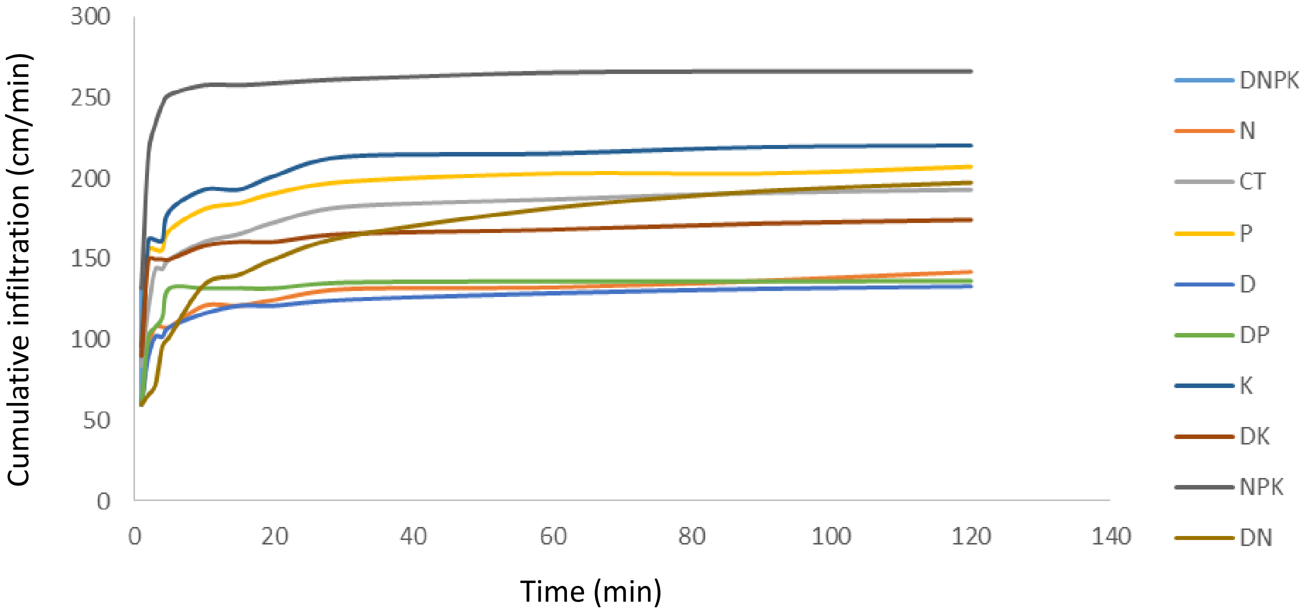

Figure 1. Cumulative infiltration versus time for all the treatments. The different colours refer to the different treatments. D: Dung; N: nitrogen; P: phosphorus; K: potassium; CT: control.

with probable less runoff occurrence in these plots. The same trend as observed in the plot of cumulative infiltration versus time above applies to plot of infiltration rate against time, but here, infiltration rate progressively decreases with time for all the plots (Figure 2).

High infiltration rate observed in the K, DK and D treated plots might be due to low bulk density and organic carbon presence in such plots (Table 3). A positively correlation between soil hydraulic properties and dry large macroaggregates, dry mean weight diameter and bulk density in such plots is also reported by Girei (2015) to be another factor resulting in such scenario. The role played by organic matter in improving soil structure and binding of soil particle into stable aggregates that enhance pore space and infiltration was shown by Poudel et al. (2001) and Turner (2006). Shehu (2013) and Schnug and Haneklaus (2002), reported relationships between the improved soil mechanical stability and increased infiltration rates. High infiltration rate, good tilth and adequate aeration for plant growth are generally known to be improved by well aggregated soils with large pores whose continued presence depends on the stability of soil aggregates (Kemper and Rosenau, 1986). Low infiltration values recorded despite the addition of organic manures in some plots might be connected with the presence of few large macroaggregates. Spatial variability of soil properties within the field (Cambardella et al., 1994) could be another reason for the low

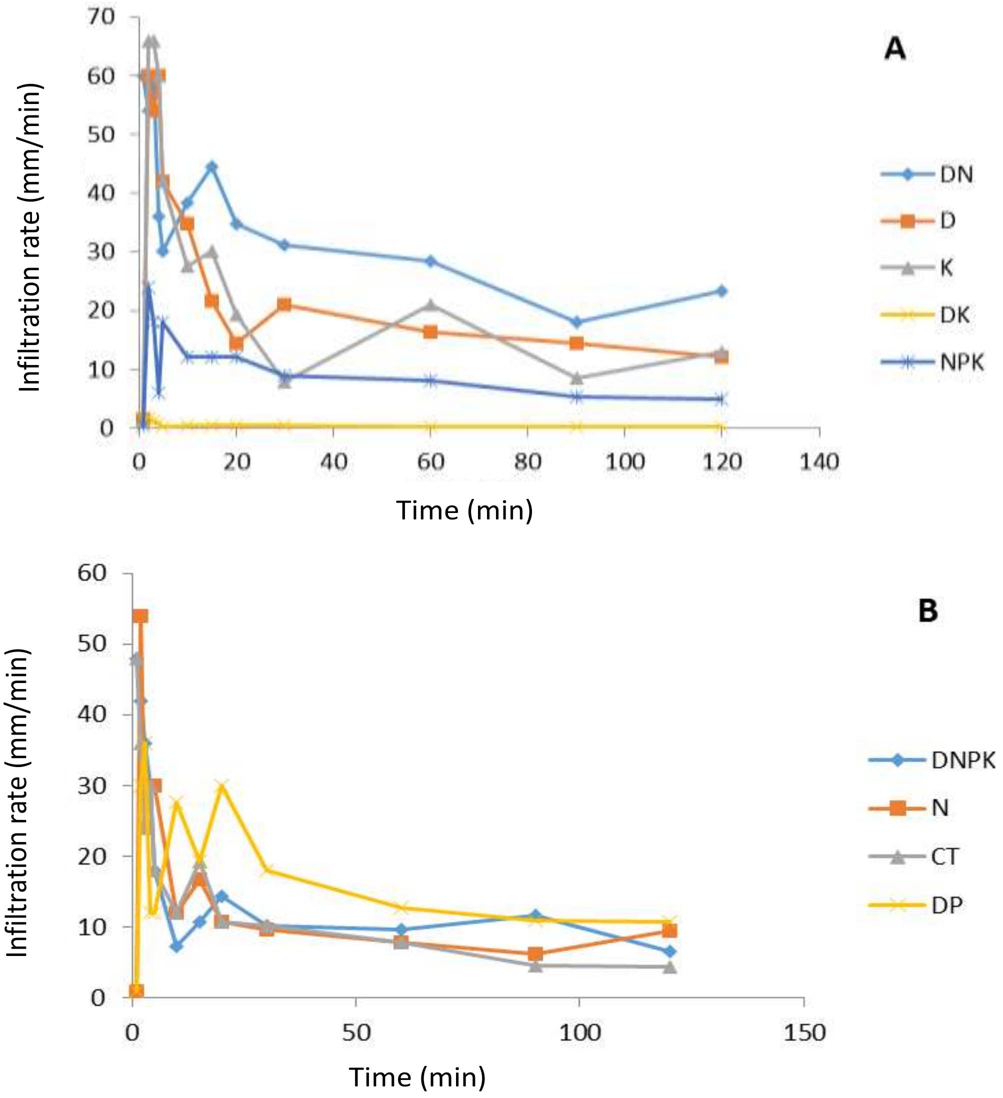

Figure 2. Infiltration rate versus time for all the treatments. The different colours and symbol refer to the different treatments. D: Dung; N: nitrogen; P: phosphorus; K: potassium; CT: control.

infiltration rate observed in the study.

Infiltration models

Kostiakov's model

B and n are the two parameters evaluated from measured infiltration data, for this equation. Both values were very high in virtually across all the treatments. The higher the value of n, the steeper the slope and the greater the rate of decline of infiltration. The greater the value of B the greater the initial infiltration value (Naeth et al., 1991; Turner, 2006). The value of n was consistently less than one as observed in Table 4. Mbagwu (1990) reported similar findings. Plot treated with DNPK recorded the least value of B (Table 4). Mbagwu (1994) found that the two soil properties with greatest influence over the B term are the effective porosity and bulk density.

All the linear curve fittings used to estimate the parameters of the Kostiakov infiltration equation yielded coefficients of determination (r^2) close to unity (Tables 4). This was further established when fitting parameters were computed directly into the Kostiakov model which yielded calculated model values with average means r^2 values of 0.9956 for all points (Table 4). This confirms the close relationship between observed and predicted infiltration rates. It also confirms the applicability of Kostiakov equation in estimating infiltration parameters therefore predicting cumulative infiltration of Guinea Savanna soils of Nigeria.

Linear regression plots of observed versus predicted

Table 4. Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Kostiakov's infiltration model.

Trt	n	B	r^2	Equation
CT	0.685	1.5241	0.961	I=1.5241*t^0.685
DNPK	0.709	1.0093	0.977	I=1.0093*t^0.709
DP	0.748	1.1885	0.996	I=1.1885*t^0.748
P	0.579	1.2883	0.995	I=1.2883*t^0.579
NPK	0.715	1.9272	0.998	I=1.9272*t^0.715
K	0.658	1.5346	0.987	I=1.5346*t^0.658
DK	0.634	1.7458	0.997	I=2.7458*t^0.634
N	0.759	1.2794	0.989	I=1.2794*t^0.759
D	0.634	1.7378	0.997	I=1.7378*t^0.634
DN	0.828	1.0864	0.998	I=1.0864*t^0.828
Mean	-	-	0.9895	-

†Trt treatment, B and n are Kostiakov fitting parameters, r^2 coefficient of determination.

Table 5. Linear regression coefficients and relationships between measured and predicted.

Trt	Regression equation	r^2
CT	Y=1.0688X-0.621	0.9840
DN	Y=1.0545X-0.630	0.9970
DNPK	Y=1.1085X-0.578	0.9928
DP	Y=1.4468X-0.303	0.9968
P	Y=0.951X=0.278	0.9971
NPK	Y=3.7932X-0.329	0.9977
D	Y=1.0124X-0.122	0.9992
K	Y=1.0615X-0.546	0.9947
DK	Y=0.9977X+0.191	0.9984
N	Y=1.0635X-0.587	0.9979
Mean	-	0.9956

†Y is the measured and X is the predicted cumulative infiltration.

cumulative infiltration of all plots gave regression lines with slopes closed to unity (Table 5). This is evidence that Kostiakov's model is sensitive and capable of illustrating the differences among treatments.

Earlier studies of two infiltration models by Shehu (2013) in Samaru showed superiority of Kostiakov over Philip's equation. However, Abdulkadir et al. (2011) reported that earlier comparative studies on two infiltration models in Samaru, using non-linear least square initially and later linear least-square regression, reveals the superiority of Philip's equation over the Kostiakov's equation. Also Dashtaki et al. (2009) reported a better performance for Horton model than Kostiakov and Philip models.

Philip's equation

The S parameter recorded here depends on the initial soil infiltration. It was largest in D (1.833) and DK (1.784) treatments. Similar findings were reported by Shukla et al. (2003b) who concluded that application of manure improved soil structure, thus improving the water transmission properties of the soil. Other factors such as antecedent soil moisture of the soil, or macro or biopores is also suspected to have influence the S parameter recorded as reported by Shaver et al. (2002) and Shukla et al. (2003a). Variation of the S parameter among treatments may be caused by the differences in continuity and arrangements of soil pores. The A parameter (Soil water transmissivity) is a gravity factor, which is due to the impact of pores on the flow of water through soil under the influence of gravity (Ogban and Utin, 2014). It governs the final steady state infiltration rate. It was more predominant in plots treated with NPK (1.257) followed by DP (0.185). However, for all plots studied, non recorded negative A value.

Table 6. Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Philip's infiltration model.

Trt	S	A	r^2	Equation
CT	1.194	0.166	0.557	I=1.194*t^0.5+0.166*t
DN	1.00	0.387	0.958	I=1.00*t^0.5+0.387*t
DNPK	1.138	0.137	0.726	I=1.138*t^0.5+0.137*t
DP	0.835	0.185	0.928	I=0.835*t^0.5+0.185*t
P	1.30	0.063	0.885	I=1.30*t^0.5+0.063*t
NPK	1.54	1.257	0.654	I=1.54*t^0.5-1.257*t
K	1.69	0.144	0.737	I=1.69*t^0.5+0.144*t
DK	1.784	0.157	0.939	I=1.784*t^0.5+0.157*t
N	1.373	0.276	0.901	I=1.373*t^0.5+0.27*t
D	1.833	0.143	0.876	I=1.833*t^0.5+0.143*t

[†]S and A; Philip's fitting parameters; Trt: Treatment, r^2=coefficient of determination.

Table 7. Linear regression coefficients and relationships between measured and predicted cumulative infiltration from Philip's infiltration Model.

Trt	Regression equation	r^2
CT	Y = 1.043X - 0.288	0.989
DN	Y = 0.975X + 0.187	0.984
DNPK	Y = 0.977X + 0.153	0.995
DP	Y = 1.038X - 0.265	0.987
P	Y = 1.063X - 0.559	0.987
NPK	Y = 0.992X+0.627	0.981
D	Y=1.0298X -0.347	0.996
K	Y=1.0827X-1.485	0.954
DK	Y=1.0084-0.1315	0.999
N	Y=1.0115X-0.081	0.996
Mean	-	0.986

[†]Y is the measured and X is the predicted cumulative infiltration.

A very good r^2 value was recorded for the fitting parameters of Philip's infiltration equation; A and S (Table 6). The coefficient of determination r^2 value (0.986) obtained where closed to unity when comparing predicted with measured cumulative infiltration, although lower than those obtained with Kostiakov's equation (0.996) (Table 7). This indicates the fitness of the infiltration data into Philip's model.

However, the superiority of Philips model over Green and Ampt's and linearized Philip's model was reported by Swartzendruber and Youngs (1974) in their studies of three physical-based infiltration models. This is not the case here. The ability of the Philip's equation together with other equations to simulate the long term infiltration rates of surface reclaimed mine soil relatively well was reported by Cook et al. (1982). Shukla et al. (2003b) also reported the superiority of Philips (1957) together with Green and Ampt (1911) in the prediction of infiltration coefficients of soils over nine other models.

Horton's equation

A wide variation was observed when calculated infiltration rate was compared with field measured result using Horton equation for this study. The same observation was made when infiltration measurement was repeated in the second year on the same plots in order to validate the former observation of fitting Horton's model. Wudivira et al. (2001) reported failure of Horton equation in the measurement of infiltration rates of soils using non-linear least square regression when comparing three infiltration models in Samaru and attributed the apparent failure of the Horton equation to difficulty of the iteration procedure to handle three parameters at the same time. Same reason was suspected to cause the observed result. However, a good performance of Horton model was observed by Abdulkadir et al. (2011) using linear and non-linear least-squares regression procedures simultaneously. Also, an overall best performance of three-parameter Horton model in Ohio was observed by Shukla et al. (2003b). Berndtsson (1987) reported a better fit of Horton model over Philips infiltration models for semi-arid soils in Northern Tunisia. Dashtaki et al. (2009) reported a better performance for Horton model than Kostiakov and Philip models. However, such was not the case in this study.

Conclusion

For model verification and goodness of fit, the three models were used to describe the experimental data for each treatment plot. Among the three models, Kostiakov (1932) gave the best representation of the infiltration rate – time relationship with higher mean r^2 value of 0.9956. The fitting parameters B, n, A, and S were time dependent and were higher in plots treated with organic manure singly or in combination than other treatment. Treatments had significant influence on both initial and final steady infiltration parameters of the two infiltration models.

This gives a clear indication of the good performance and the superiority of the two models (Kostiakov, 1932; Philip, 1957) in estimating or predicting infiltration characteristics of an Alfisols soils under a long term fertilizer trial in Northern Guinea Savanna of Nigeria. Further study of infiltration characteristics of the trial exploring other Models is recommended to improve its hydraulic data.

Conflict of Interests

The authors have not declared any conflict of interest.

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