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Relationship between landscape positions and selected soil properties at a Sawah site in Ghana

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A study was conducted at a sawah site in Ghana to examine the relationship between landscape position and some selected soil properties with the aim of generating adequate data for modeling landscape relationships and to aid both researchers and farmers in taking critical management decisions. Soil properties namely total porosity, moisture content, infiltration rates, hydraulic conductivity, sand content, silt content, clay content, gravel concentration, bulk density, soil pH, total nitrogen, soil organic matter and cation exchange capacity were collected and analysed. Data were collected at the foot slopes, middle slopes and at the upper slopes from four major landuses (maize, oil palm, natural vegetation and plantain) in the study area. Simple statistical parameters such as mean and standard deviation were used to analyse the data. Moisture content, total porosity, soil pH, organic matter and carbon and total nitrogen increased downslope whilst sand content, clay content, bulk density occurred at upper slopes decreased downslope. Management practices appeared to have influenced infiltration rate, hydraulic conductivity and silt content.

Key words: Landscape position, soil properties, *sawah,* landuse.

INTRODUCTION

There have been several attempts to relate soil properties to landscape position for many landscapes (Norton and Smith, 1930; Kleiss, 1970; Dahiya et al., 1984; Wysocki et al., 2001). This may be partly due to the realization of the role topographic position plays in influencing runoff, soil erosion and hence soil formation (Babalola et al., 2007). Soil properties such as clay content has been found highly correlated with topographic position (Wang et al., 2001) while soil organic matter has been shown to vary with topographic position (Miller et al., 1988). One of the reasons for the study of topographic position and soil properties is to help provide useful information for inland valley rice farmers in West Africa.

One peculiar feature of the inland valleys abundant in West Africa is their site-specific hydrology, underlain mainly by the prevailing landforms and topography (Obalum et al., 2011). As a result of this many inland valleys in the subregion, are being exploited for the development and production of rice (West Africa Rice Development Association, WARDA 2008). A key aspect of this agricultural development is the adoption of the *sawah* technology for rice production (Wakatsuki et al., 1998). By definition, *sawah* refers to a bounded, puddled and leveled rice field with inlet and outlet for irrigation and drainage, respectively.

As a hydrophilic crop, one of the most important factors normally considered in site selection for rice production is the availability of source of water. Moisture retentive capacity of the soil is as important as the source of water itself, and is controlled mainly by the textural and structural attributes of the soil. The importance of such an

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index soil property as texture in adjudging inland valleys suitable or not for rice cultivation in the West African setting has earlier been highlighted (Carsky and Masajo, 1992). In Nigeria for instance, Olaleye et al. (2008) reported that the major constraint to lowlands for rice cultivation in the western region is unfavourable soil texture and that this provokes sub-optimal water and nutrient status. Similarly, bulk density is considered the most important index of soil structure in *sawah*-managed fields. It is important to state that even though Toure et al. (2009) documented the importance of toposequence in the hydrology and drainage of the inland valley ecosystems of West Africa. However, most of the available research information about soil conditions in the West African inland valleys focused mainly on fertility and/or pedo-mineralogy (Issaka et al., 1996, 1997; Buri et al., 1999, 2000; Annan-Afful et al., 2004, 2005; Abe et al., 2006, 2007, 2009; Udo et al., 2009). The physical aspect has been sparingly studied, with little or no emphasis on the effects of topography (Annan-Afful et al., 2004; Abe et al., 2009)

Thus, the objective of the study was to examine how some selected soil physico-chemical properties varies and among landscape positions at a *sawah* site. Results generated in the study will provide useful information to researchers and farmers in modeling landscape relationships and in taking critical management decisions.

MATERIALS AND METHODS

Description of study site

The study was conducted at a *sawah* experimental site located at Biemso of the Ashanti Region of Ghana. The study area (Figure 1) is located in the Ahafo Ano South district of Ashanti Region. Its geographic location is within N 06°, 52' 53.2" and W 001°, 50' 47.3". The mean annual precipitation in the region is 1301 mm (averaged for the period from 1974 to 2004). The rainfall pattern in the area is bimodal (with two peaks). The geology of the study site consists of rock of the Lower Birimian formation comprising *phyllites*, *greywackes*, *schists* and *gneiss* whiles the soils fall under the Akumadan –Bekwai/Oda Complex association (Adu, 1992). The topography of the area is high to moderate steep slopes with the highest point having a slope not greater than 20%. The terrain gradually slopes towards the valley where rice is cultivated under *sawah* technology and then finally to the Biem River. The uplands were under cultivation with crops such as maize, plantain and oil palm.

Field studies

Field studies were conducted January to March, 2009. Four hillslopes representing the major land use structure of the site were selected. A transect was used to link all land uses and landscape positions. The method of Brubaker et al. (1993) was used as a guide in the soil sampling. In this method, six categories of landscape positions were identified as upper interfluve, lower interfluve, shoulder, upper linear, lower linear, and foot slope. Each of the hillslopes were divided into three landscape positions, upper slope (US), middle slope (MS) and foot slope (FT). The US position represents the upper interfluve and lower interfluve and receives little or no overland flow but may contribute runoff to downslope position. The MS position comprises shoulder, upper linear and lower linear and receives overland flow from the upper slope and contribute runoff to the FS slope. The FS represents the base of the hillslope. Water and sediments running off the FS enter the *sawah* rice fields. The landuses for the study were maize, oil palm, natural vegetation and plantain fields.

Soil samples were collected from all landscape positions in the study site. Twelve sampling points were selected from every hillslope (plot). The top soil (0 to 20 cm depth) was sampled with a cylindrical metal sampler of 5 cm diameter and 5 cm height. From the same sampling position and depth, 200 g of soil was also collected, bagged in plastic bags and taken to the laboratory for soil physical and chemical analysis.

At each sampling point, hydraulic conductivity test was carried out using a minidisk infiltrometer (Decagon Devices, 1998) with a suction of 0.5 cm and radius of 1.59 cm. The readings were recorded at every 30 s during the experiment. Data collected were used to calculate the water infiltration rates of the soil. A total of 96 infiltration tests were performed with 24 tests on each plot. The hydraulic conductivity of soil was calculated using the method of Zhang (1997), which works well for measurements of infiltration into dry soil. The method requires measuring cumulative infiltration against time and fitting the results with the function:

$$I = C_1 t + C_2 \sqrt{t} \quad (1)$$

Where C_1 and C_2 are parameters relating to hydraulic conductivity and sorptivity respectively.

The hydraulic conductivity of the soil (K) was computed using the relationship

$$K = \frac{C_1}{A} \quad (2)$$

Where A is a constant calculated according to Van Genuchten (1980) as

$$A = \frac{11.65\left(n^{0.1}-1\right)\exp\left[7.5(n-1.9)\alpha h_0\right]}{(\alpha r_0)^{0.91}} \qquad n \leq 1.9 \quad (3)$$

Here n and α are the retention parameters according to Van Genuchten (1980); r_0 is the radius of the infiltrometer; h_o is the suction at the disk surface. The Van Genuchten soil parameters were obtained from Carsel and Parrish (1988) as cited by Decagon Devices (1998).

Laboratory studies

Soil samples were air dried for 3 to 5 days and then passed through a 2-mm sieve. Gravels which did not pass through the sieve, after removal of any adhering material were weighed and their content was recorded as a percentage of the whole sample. The particle size distribution was determined by the method proposed by Van Reeuwijk (2002). Bulk density was determined by the metal core sampler method (Blake and Hartge, 1986) whilst the particle density was assumed to be 2.65 g cm^{-3}. The Walkley-Black procedure as described by Nelson and Sommers (1996) was used to determine organic matter. The total Nitrogen content of the soil was determined using the Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982). The cation exchange capacity (CEC) was obtained by a method described by Black (1965). Soil pH was measured potentiometrically in 1:1 soil-water ratio (Hendershot et al., 1993). Soil organic matter (SOM) was then

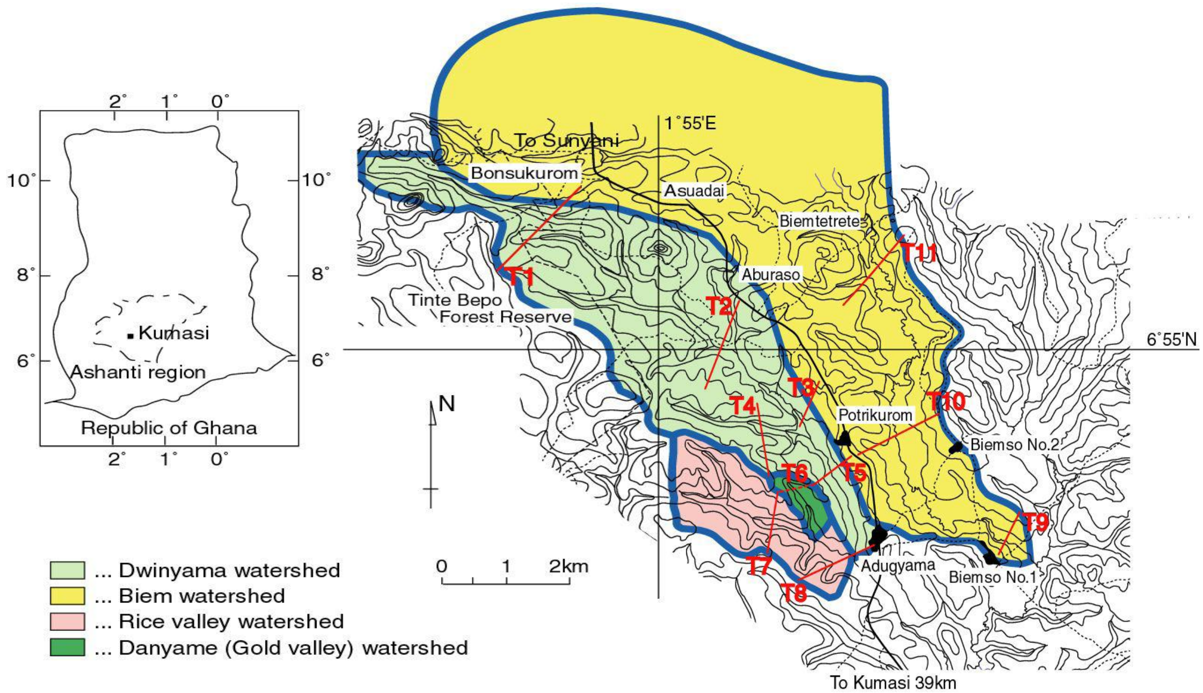

Figure 1. Location of the study site.

obtained by multiplying soil organic carbon values by a factor of 1.724. The total porosity (TP) was calculated using the equation and relationship developed by Danielson and Sutherland (1986) as:

$$TP = \frac{1 - Bulk \text{ density} \, (\text{gcm}^{-3})}{2.65 \, \text{gcm}^{-3}} \quad (4)$$

Soil moisture content (M_c) was also calculated as:

$$M_c = \frac{\text{mass of wet soil - mass of oven dried soil}}{\text{mass of oven dried soil}} \quad (5)$$

RESULTS AND DISCUSSION

Landscape position and soil hydraulic properties

Table 1 shows the average values of some hydraulic properties obtained from the study in relation to the position on the landscape. The values of soil moisture content were highest at the foot slopes (FS) under all land use. This is very much expected and is an indication of seepage and the concentration of runoff from upper slopes as was found by Tsegaye et al. (2006). This also indicates that soil mosture content is highly influenced by slope position. Total porosity (TP) values ranged from 45.10 to 59.65%. Except for plantain land use, total porosity values were highest at the foot slopes (FS). This could be explained by the higher sand content as observed from the study (Table 2). Sand particles have large macropores which have direct effect on total porosity (USDA, 2001). With respect to the soil moisture content and total porosity, Obalum et al. (2011) reported similar observation in the same district where this study was conducted.

Infiltration rates and hydraulic conductivity were highly variable as shown by their standard deviation in Table 1. This explains the temporal and spatial variability of both infiltration and hydraulic conductivity (Antonio et al., 2001; Zhang, 1997; Bagarello and Iovino, 2003). Both factors under fallow land and oil palm land uses were highest at the MS position. This may be due to higher water content at the foot slope which reduces water intake. However, infiltration rates and hydraulic conductivities under maize and plantain cultivation recorded relatively higher values at the foot slopes than at the upper slopes. This may be partly due to the low total porosity at the upper slopes. In general, the fluctuation in infiltration rates and hydraulic conductivity is partly due to differences in soil physical and chemical properties such as particle size distribution, antecedent moisture content, organic matter, and cation exchange capacity as reported by Messing and Jarvis (1993) and Shelton (2003).

The results from the study indicate that water content and total porosity are both influenced by landscape position. However, the response of infiltration rates and hydraulic conductivity to landscape position is variable implying that both factors are also affected by other soil properties.

Table 1. Average values of soil hydraulic properties in relation to landscape position.

Land use	Landscape position	Parameter	TP (%)	Mc (%)	If (mm/h)	K (mm/h)
Fallow	FS	Mean	59.65	0.41	425.33	42.43
		Std. Dev.	8.70	0.28	35.07	3.19
	MS	Mean	49.69	0.28	601.78	60.06
		Std. Dev.	3.90	0.13	191.71	15.65
	US	Mean	48.90	0.15	332.70	29.30
		Std. Dev.	0.72	0.10	18.45	2.59
Maize	FS	Mean	53.71	0.27	542.89	33.68
		Std. Dev.	1.62	0.01	255.71	14.70
	MS	Mean	45.10	0.14	182.00	31.43
		Std. Dev.	2.64	0.04	89.16	9.50
	US	Mean	46.40	0.08	327.09	46.54
		Std. Dev.	1.90	0.02	20.91	3.18
Oil palm	FS	Mean	53.32	0.35	215.56	23.60
		Std. Dev.	3.42	0.09	77.75	8.43
	MS	Mean	47.91	0.27	419.78	43.49
		Std. Dev.	2.86	0.04	101.67	4.25
	US	Mean	49.17	0.14	397.77	31.03
		Std. Dev.	1.31	0.06	21.66	2.87
Plantain	FS	Mean	50.88	0.32	249.11	10.87
		Std. Dev.	5.44	0.22	89.77	9.43
	MS	Mean	54.32	0.23	41.78	4.11
		Std. Dev.	6.27	0.10	14.49	1.22
	US	Mean	52.52	0.16	312.63	23.87
		Std. Dev.	3.08	0.04	111.16	13.41

M_c=Soil moisture content; I_f= infiltration rate; K= hydraulic conductivity; US=upper slope; MS = middle slope; FS= foot slope.

Landscape position and soil physical properties

The average values of soil physical properties on the slope are shown in Table 2. Generally, highest values of clay occurred at the MS position. This observation did not conform to expectation that clay content are commonly higher at foot slopes due washing away of clay-rich materials from upper slopes as explained by Babalola et al. (2007). However, observations similar to this study were reported by Malo et al. (1974).

Observed sand content and bulk density values appeared to be highest at the upper slopes. Percentage gravel content was also highest at US position for all land uses.

The low bulk density and gravel content at FS position indicates low level of soil compactness and associated improvement in root penetration (Ogban and Babalola, 2003), and hence favourable root activity (Ogban and Babalola, 2009). In addition, changes in gravel content may explain why there were changes in soil physical properties (Fasina et al., 2007). Highest values of sand content at US position could also be explained by the effect of soil erosion. According to Ovales and Collins (1986), sand particles due to their size are normally deposited at the upper slopes.

Generally silt content at the study site were high. This is an indication of the soils in the site to form stable aggregate. The results from the study have also shown that silt content at the catchment is variable. This could be explained by the fact that silt content at the study site is not only affected by factors such as the landscape position but on others such as porosity and hydraulic conductivity.

In general, properties, such as percentage sand, clay, gravel and bulk density were affected by topographic position. However, the fluctuations in silt content as observed from Table 2 suggests that topographic position does not wholly affected silt content.

Landscape position and soil chemical properties

Table 3 presents average values of soil chemical properties in relation to landscape position under the four

Table 2. Average values of soil physical properties in relation to landscape at site.

Land use	Landscape position	Parameter	Sand (%)	Silt (%)	Clay (%)	Gravel (%)	γ(g/cm^{-3})
Fallow	FS	Mean	20.34	61.63	18.03	0.00	1.07
		Std. Dev	1.47	1.67	0.82	0.00	0.23
	MS	Mean	23.68	56.24	20.08	43.22	1.33
		Std. Dev.	0.68	2.83	0.61	5.60	0.10
	US	Mean	34.00	55.00	11.00	35.33	1.35
		St. Dev.	1.02	0.90	0.50	2.56	0.02
Maize	FS	Mean	27.02	54.94	18.04	0.00	1.23
		Std. Dev.	0.97	0.46	0.67	0.00	0.04
	MS	Mean	31.86	48.13	20.01	60.65	1.45
		St. Dev.	1.23	1.94	0.47	1.80	0.07
	US	Mean	38.00	49.00	13.00	71.81	1.42
		Std. Dev.	1.52	1.49	0.70	6.53	0.05
Oil palm	FS	Mean	18.74	61.21	20.05	0.00	1.24
		St. Dev.	1.29	2.03	0.56	0.00	0.09
	MS	Mean	22.16	61.80	16.04	49.18	1.38
		Std. Dev.	0.60	0.85	1.23	7.83	0.08
	US	Mean	40.00	51.00	9.00	57.41	1.35
		Std. Dev.	1.30	1.03	0.50	5.12	0.03
Plantain	FS	Mean	15.01	68.89	16.1	0.00	1.30
		Std. Dev.	0.60	0.77	0.65	0.00	0.14
	MS	Mean	14.34	63.59	22.07	49.44	1.21
		Std. Dev.	0.57	1.05	1.11	5.74	0.17
	US	Mean	38.00	51.00	11.00	59.46	1.26
		Std. Dev.	1.50	1.41	1.32	7.23	0.08

main landuse. Soil nutrients (SOM and TN) were quite moderate. Highest concentration of SOM and TN occurred at the FS position whiles least concentrations occurred at US position. The high concentrations of these nutrients at foot slopes suggest that overland flow and surface runoff may have transported these soil nutrients to the foot slope. This observation is consistent with findings made by Wang et al. (2003), Chen (1987), Khormali et al. (2007), Babalola et al. (2007) and Onweremadu (2007). The values of these soil nutrients under plantain land use at the foot slope were almost the same as those at the upper slope. The slightly higher values at the foot slope may be partly due to vegetation cover.

Soil pH values were in the range of 4.2 to 6.73 and increased down the slope. The least values of soil pH at the US positions indicate that acidity decreases down the slope. It must be stated that the prevalence of acidity at the upper slopes is an indication of strong chemical weathering and leaching of plants nutrients as reported by Babalola et al. (2007).

Agronomically, increased pH up to 8.5 is good for soils at foot slopes. Onweremadu (2007) reports that increased pH at foot slopes account for high total nitrogen, cation exchange capacity and organic matter. This means soils at foot slopes have high capacity for supporting crop growth. The increased pH at foot slopes account for increased cation exchange capacity (CEC). According to Kamprath (1970) and Tsegaye et al. (2006) when rainfall percolates through the soil, it most likely leaches basic cations such as Ca and Mg and replaces them with acid forming cations such as H^{+}, Al^{3+} and Fe^{2+}, making the soils in upper slope acidic.

Conclusion

The study assessed the influence of landscape position on soil properties as well as the relationship between infiltration rates with aim of generating enough soil data for erosion modeling. The study has revealed that soil properties such as water content, total porosity, sand content, clay content, bulk density, soil pH, organic matter and carbon and total nitrogen are influenced by topographic position. On the other hand, responses of soil properties such as infiltration rate, saturated hydraulic

Table 3. Average values of soil nutrients in relation to landscape position.

Land use	Landscape position	Parameter	pH(1:1)H_2O	OrgC(%)	TN(%)	SOM (%)	CEC
Fallow	FS	Mean	5.64	2.61	0.25	4.5	14.04
		Std. Dev.	1.17	1.28	0.19	0.81	1.32
	MS	Mean	6.45	2.38	0.12	4.1	14.24
		Std. Dev.	1.29	0.32	0.07	1.35	0.6
	US	Mean	4.7	0.5	0.1	0.86	6.06
		Std. Dev.	0.71	0.12	0.05	0.12	0.72
Maize	FS	Mean	6.39	3.2	0.19	5.52	15.19
		Std. Dev.	1.23	1.06	0.09	1.3	2.3
	MS	Mean	5.73	1.64	0.15	2.83	12.01
		Std. Dev.	1.52	0.39	0.1	0.73	1.04
	US	Mean	4.8	1.4	0.1	2.41	4.06
		Std. Dev.	2.23	0.45	0.06	0.88	1.25
Oil palm	FS	Mean	6.73	2.26	0.27	3.9	14.02
		Std. Dev.	2.08	1.45	0.12	1.2	2.3
	MS	Mean	6.60	1.72	0.22	2.97	13.78
		Std. Dev.	1.39	0.47	0.12	1.1	1.4
	US	Mean	4.60	0.06	0.1	0.10	3.04
		Std. Dev.	1.21	1.12	0.11	0.02	2.34
Plantain	FS	Mean	7.75	1.13	0.15	2.95	14.81
		Std. Dev.	1.35	1.04	0.06	0.61	2.02
	MS	Mean	4.73	1.44	0.11	2.48	5.67
		Std. Dev.	1.55	0.21	0.08	1.2	1.06
	US	Mean	4.20	0.7	0.1	1.20	1.91
		Std. Dev..	0.5	0.02	0.03	0.68	0.34

conductivity and silt content to landscape position were variable. These changes may be attributed management practices. There is the need for further and more detailed study on soil and soil-related properties to generate sufficient data for modelling soil nutrient transfer from upper catchments to the valley.

REFERENCES

Abe SS, Masunaga T, Yamamoto S, Honna T, Wakatsuki T (2006). Comprehensive assessment of the clay mineralogical composition of lowland soils in West Africa. Soil Sci. Plant Nutr. 52:479-488.

Abe SS, Oyediran GO, Masunaga T, Yamamoto S, Honna T, Wakatsuki T (2007). Primary mineral characteristics of topsoil samples from lowlands in seven West African countries. Japanese J. Trop. Agric. 51:35-39.

Abe SS, Oyediran GO, Masunaga T, Yamamoto S, Honna T, Wakatsuki T (2009). Soil development and fertility characteristics of inland valleys in the rain forest zone of Nigeria: Mineralogical composition and particle-size distribution. *Pedosphere,* 19:505-514

Adu SV (1992). Soils of Kumasi region, Ashanti Region, Ghana. Memoir No.8. Ghana Soil Research Institute.

Antonio CDA, Angulo-Jaramillo R, de Souza ES, Netto AM, Carneiro CJG, Montenegro AAA (2001). Determination of Hydraulic Conductivity and Sorptivity of Soil using a Disk Infiltrometer. Br. J. Agric. and Environ. Eng. 1802-1899.

Annan-Afful E, Iwashima N, Otoo E, Asubonteng KO, Kubota D, Kamidohzono A, Masu MT, Wakatsuki T (2004). Nutrient and bulk density characteristics of soil profiles in six land use systems along topo-sequences in inland valley watersheds of Ashanti region, Ghana. Soil Sci. Plant Nutr. 50:649-664.

Annan-Afful E, Masunaga T, Wakatsuki T (2005). Soil properties along the toposequence of an inland valley watershed under different land uses in the Ashanti region of Ghana. J. Plant Nutr. 28:141-150.

Babalola TS, Fasina AS, Tunku P (2007). Relationship Between Soil Properties and Slope Position in a Humid Forest of South Western Nigeria. Medwell Online Agric. J. 2(3):370-374.

Bagarello V, Iovino M (2003). Field Testing Parameter Sensitivity of the Two-Term Infiltration Equation Using Differentiated Linearization. Soil Sci. Soc. Am. J. 2:358-367.

Black CA (1965). Methods of Soil Analysis. Part 2. Chemical and microbialogical properties. First edition. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin, USA. Agronomy 9:371-373.

Blake GR, Hartge KH (1986). Bulk density. In: Klute, A. (ed.). Methods of soil analysis. Part 1. Physical and mineralogical methods. Second edition. ASA and SSSA, Madison, WI, Agron. Monogr. 9:374–390.

Bremner JM, Mulvaney CS, (1982). Nitrogen-total. In: Page,A.L., et al. (Eds.), Methods of Soil Analysis. Part 2, 2nd Edition. ASA and SSSA, Madison, WI, Agron. Monogr. 9:595–624.

Brubaker SC, Gones AJ, Lewis DT, Frank K (1993). Soil Properties Associated with Landscape Position. Soil Soc. Am. J. 57:235-23.

Buri MM, Ishida F, Kubota D, Masunaga T, Wakatsuki T (1999). Soils of flood plains of West Africa: General fertility status. Soil Sci. Plant Nutr. 45:37-50.

Buri MM, Masunaga T, Wakatsuki T (2000). Sulfur and zinc levels as limiting factors to rice production in West Africa lowlands. *Geoderma,* 94:23-42.

Carsel RF, Parish RS (1988). Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resour. Res. 24:755-769.

Carsky RJ, Masajo TM (1992). Effect of Toposequence Position on Performance of Rice Varieties in Inland Valleys of West Africa. Resource Crop Management Research, Monograph No. 9. IITA, Ibadan.

Chen Y (1987). Remote Sensing of Iron enriched Paleosols in the Eastern Palouse Region. M.Sc. thesis. Washington State University, Pullman, WA, USA.

Dahiya S, Richter J, Malik RS (1984). Spatial Variability. A Rev. Int. J. Trop. Agric. 11:1-102.

Danielson RE, Sutherland PL (1986). Porosity. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison WI. pp. 443-461.

Decagon Devices (1998). Measuring Soil Hydraulic Conductivity with a Disk infiltrometer. Application Note. AN7002-10. USA.

Fasina AS, Omolayo FO, Ajayi OS, Falidun AA (2007). Influenec of Land use on Soil Properties of Three Mapping Units in Southwestern Nigeria - Implications for Sustainable Soil Management. Medwell Online Agric. J. 2(3):879-883.

Hendershot WH, Lalande L, Duquette M (1993). Soil reaction and method of exchangeable acidity. In: Catter, M. R. (Ed). Sampling and method of analysis. Can. Soc. Soil Science, Lewis publisher London. Pp. 141-145.

Issaka RN, Masunaga T, Kosaki T, Wakatsuki T (1996). Soils of inland valleys of West Africa: General soil fertility parameters. Soil Sci. Plant Nutr. 42:71-80.

Issaka RN, Ishida F, Kubota D, Wakatsuki T (1997). Geographical distribution of selected soil fertility parameters of inland valleys in West Africa. *Geoderma,* 75:99-116.

Kleiss HJ (1970). Hillslope sedimentation and soil formation in northeastern Iowa. Soil Science Society of America Proceedings 34:287-290.

Kamprath EJ (1970). Exchangeable aluminum as a criterion for liming leached mineral soils. Soil Sci. Soc. Amer. Proc. 34:252-254.

Khormali F, Ayuobi SH, Kananro FF, Fatemi A, Hemmati KH (2007). Tea Yield and Soil Properties as Affected by Slope Position and aspect in Lahijan area, Iran. Int. J. Plant Prod. 1(1), ISSN 1735-6814.

Malo DD, Worcester BK, Matzddorf KD (1974). Soil-Landscape relationships in a closed drainage system. Soil Sci. Soc. Am. Proc. 38:813-818.

Messing I, Jarvis NJ (1993). Temporal variation in the hydraulic conductivity of a tilled clay soil as measured by tension infiltrometers. J. of Soil Science. 44:11-24.

Miller MP, Singer MJ, Nielsen DR (1988). Spatial variability of wheat yield and soil properties on complex hills. Soil Sci. Soc. Am. J. 52:1133-1141.

Nelson DW, Sommers LE (1996). Total Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 3. SSSA Book Series No. 5. SSSA Madison, WI.

Norton EA, Smith RS (1930). The influence of topography on soil profile character. J. Amer. Soc. Agron. 22:251-262.

Obalum SE, Nwite JC, Oppong J, Igwe CA, Wakatsuki T (2011). Variations in selected soil physical properties with landforms and slope within an inland valley ecosystem in Ashanti Region of Ghana. J. Soil Water Res. 6(2):73-82.

Ogban PI, Babalola O (2003). Soil characteristics and constraints to crop production in inland valley bottoms in southwestern Nigeria. Agric. Water Manage. 61:13-28.

Ogban PI, Babalola O (2009). Characteristics, classification and management of inland valley bottom soils for crop production in subhumid southwestern Nigeria. Agro-Sci. 8:1-13.

Olaleye AO, Akinbola GE, Marake VM, Molete SF, Mapheshoane B (2008). Soil in suitability evaluation for irrigated lowland rice culture in southwestern Nigeria: Management implications for sustainability. Commun. Soil Sci. Plant Anal. 39:2920-2938.

Onweremadu EU (2007). Availability of Soil Nutrients in Relation to Land Use and Landscape Position. Int. J. Soil Sci. 2(2):128-134.

Ovales FA, Collins ME (1986). Soil Landscape Relationships and Soil Variability in North Central Florida. Soil Sci. Soc. Am. J. 50:401-408.

Shelton IJ (2003). Soil Erosion- Causes and Effects. Fact Sheet. ISSN 1198-712X. Ontario Ministry of Agriculture and Food and Rural Affairs.

Toure A, Becker M, Johnson DE, Kone B, Kossou DK, Kiepe P (2009). Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast. Field Crops Res. 114:304-310.

Tsegaye TD, Barreto R, Islam KR, Mbuya OS, Mezemir WF (2006). Comparison of selected soils properties at landscape positions under tropical forest ecosystems of Puerto Rico. Journal of Alabama Academy of Science Vol. 77(3-4):193-209.

Udo BU, Utip KE, Inyang MT, Idungafa MA (2009). Fertility assessment of some inland depression and floodplain (wetland) soils in Akwa Ibom State. Agro-Science 8:14-19.

United States Department of Agriculture, USDA (2001). Rangeland Soil Quality Information- Infiltration. Rangeland Soil Quality Information Sheet 5. USDA, Natural Resources Conservation Services.

Van Genuchten MTH (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44:892-898.

Van Reeuwijk LP (2002). Procedure for Soil Analysis. Technical Paper 9. Sixth edition. ISRIC-FAO.

Wakatsuki T, Shinmura Y, Otto E, Olanian G (1998). African-based *sawah* system for the integrated watershed management of small inland valley in West Africa. In: FAO Water Reports No. 17: Institutional and Technical Opinion in the Development and Management of Small-Scale Irrigation. FAO, Rome. pp. 56-79.

Wang J, Fu BJ, Qiu Y, Chen LD (2001). Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China. J. Arid Environ. 48:537-550.

Wang Y, Buermann W, Stenberg P, Smolander H, Ha¨me T, Tian Y, Hu J, Knyazikhin Y, Myneni RB (2003). Hyperspectral remote sensing of vegetation canopy: Leaf area index and foliage optical properties. Remote Sensing Environ. 85:304-315.

West Africa Rice Development Association, WARDA. (2008). Africa Rice Trends, 2007. The Africa Rice Center, Cotonou.

Wysocki DA, Schroeneberger PJ, Lagary AE (2001). Geomorphology of Soil Landscapes. In: Summer, M.E (Eds). Handbook of Soil Science. CRC Press. Boca Raton , FL, USA.

Zhang R (1997). Determination of soil sorptivity and hydraulic conductivity from the disc infiltrometer. Determination of soil sorptivity and hydraulic conductivity from the disc infiltrometer. Soil Sci. Soc. Am. J. 61:1024-1030.