World Research Journal of Agricultural & Biosystems Engineering
ISSN:2319-3913 & E-ISSN: 2319-3921, Volume 2, Issue 1, 2013, pp.-24-27.
Available online at http://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000005

SOIL INFILTRATION CHARACTERISTICS OF EUTRIC GLEYIC FLUVISOL UNDER COCOA PLANTATION

ESSIEN O.E.*

Department of Agricultural and Food Engineering, University of Uyo, P.O. Box 4309, Uniuyo- 520003, Uyo, Nigeria.
*Corresponding Author: Email- obotessien@uniuyo.ed.ng

Received: August 02, 2013; Accepted: September 20, 2013

Abstract- Infiltration rates, cumulative infiltration and hydraulic conductivity were investigated for soils under the cocoa plantation and predictive functions were formulated. Infiltration rate and hydraulic conductivity were measured using double-ring infiltrometer and single auger-hole method respectively, and data processed with SPSS version 17 software. The constant infiltration rate was 55.2 cm/hr. (13.248 m/day) for the poorly drained clay, which was higher than typical value of its texture, hence, indicating the influence of bioturbation by cocoa roots and other soil ecosystem engineers on regulation of water balance under cocoa plantation. Predictive empirical infiltration rate equation was formulated and conformed to Kostiakov predictive model with significant coefficient of association (R^2 = 0.901, p <0.1). The drainage characteristics engendered adequate drainage to sustain cocoa tree growth with least flood submergence. The cumulative infiltration equation followed the pattern of Philips infiltration model. Subsequent re-evaluation, periodically (say every decade), to link plantation soil water balance with plantation age is recommended.

Keywords- Cocoa plantation, eutric gleyic fluvisol, infiltration rate, Kostiakov model, soil drainage properties

Citation: Essien O.E. (2013) Soil Infiltration Characteristics of Eutric Gleyic Fluvisol under Cocoa Plantation. World Research Journal of Agricultural & Biosystems Engineering, ISSN:2319-3913 & E-ISSN: 2319-3921, Volume 2, Issue 1, pp.-24-27.

Introduction

Infiltration rate is a characteristics of the surface soil and varies greatly with the soil texture and cover being greatly influenced by depth and type of vegetative cover over the soil surface which dampen the kinetic energy impact of large raindrops from dislodging surface soil particles, and producing surface sealing and crusting. In forested land sand plantation, infiltration, water storage capacity and drainage are affected by the interception of storey trees, canopies, the litter layers on forest floors, and the bioturbation influence of soil ecosystem engineers (roots, earthworms, termites, ants and other macro-fauna) [1].

The hydrological dynamics in forest plantations are also observed to change after plantation establishment [2]. A tropical secondary forest (as represented by cocoa plantation) may affect climate, soil and hydrology differently from primary forests or agricultural areas [3]. Comparing three land uses the primary forest, a former banana-mixed cocoa plantation and an abandoned pasture re-growth showed that the forest type or vegetation showed significant difference in lateral subsurface flow (drainage) response to intense rainfall in soil under them with respect to soil depth [3]. The infiltration rate in forested area has been shown to vary with understory vegetation and foliar cover age. For instance, the basal area of regrowth affects water yield [3]. The vegetation influences the distribution of rainfall, which is the source of infiltration water [4] although research are sparse on this area. Most plantation establishments do actively modify the soil to reduce runoff and improve infiltration [5] but these effects are age-dependent water use trend occurring under vegetation, even though not many publications are examining this condition [6]. Thus, surface intake by infiltration rate and subsurface drainage by hydraulic conductivity characteristics are affected by the forested vegetation type.

Cocoa tree, a drought sensitive crop, can only withstand water-logging for a short period, although it needs constant rain (1500-2000 mm) [7]. Therefore, soils under cocoa plantations must retain adequate moisture as well as offer good drainage properties, because cocoa plant with deep-rooted tap root system requires deep and well drained soils [8], which are contingent on high infiltration rate and saturated hydraulic conductivity [9]. Hence, both soil infiltration and hydraulic conductivity are implicated in soil sustenance of productive cocoa plantation. The unavailability of which information makes it necessary to investigate the physical properties and hydrological characteristics of the supporting soil under the cocoa plantation.

Also spatial variability of litter layers or surface soil properties on forest floor can be major factors determining the infiltration rate [10]; however, no infiltration rate relationship with these properties are sufficiently documented for the soil ; these would need specific field or basin-scale determination of infiltration rate under the plantation condition and age. In the cocoa plantation at Nkari in Enyong creek catchment, Nigeria, the infiltration and its relationship with soil properties were yet to be studied and documented with the 4-5 years cocoa plants in the plantation and the varied soil series of the sub catchment area [11]. Therefore, 1) the infiltration rate, cumulative infiltration and characteristics of the supporting soil under young cocoa plantation are to be investigated, both for baseline information and management to sustain the plantation under no flood condition; and 2) the empirical predictive models for infiltration rate and cumulative infiltration capacity of the cocoa plantation soil are to be established.

Materials and Methods

Nkari Swamp Description

Nkari Swamp is located in the north-eastern border of Enyong Creek wetland in northern Akwa Ibom State, and lies within longitude 7° 39[1] E - 7° 50[1] E, and latitudes 5° 03[1] N - 5° 27N in the present Ini Local Government Area, with a swamp area of 1900 ha as part of Itu River swamp (3170 ha) (AKADEP, 1995). It has a 1.5km wide flood plain bordering the Itu River with several large swamp arm extending into the dissected river terraces. The swamp profile is generally flat with slopes less than 1% but with gentle undulations of river terrace up to 2 m forming small islands of dry land. The area falls within 1:50,000 map sheet Ikot Ekpene 322 NW.

Soils

The predominant soils are the poorly drained clays of series EN 51 in central and eastern areas and EN 52 in western and north central parts. The imperfectly drained clays of series EN 31 and medium textured soils of EN 32 occur mainly as narrow strips along the edges of the uplands and as levee soils along the Itu River. A few small patches of the poorly drained medium textured series EN 53 and EN 54 occur in the eastern half of the swamp. Small areas of very poorly drained soils are found.

Vegetation and Land Use

The dominant vegetation and land use pattern is mixed forest and cocoa plantation which occupy the northern side along the Itu River spanning about 50% of the swamp. The cocoa plantations are in most cases not continuous pure stands as they contain oil palms and various trees and woody shrubs. The swamp grass and rice farms occupy the lower flood plains.

The Soil Group EN 51 in the Cocoa Plantation

Soil series or group are groups of soils having the same parent materials, with development by the same pedological processes so that they have similar profile characteristics. The universal parent material in the swamp soils is riverine Alluvium which is divided into different types according to its texture and the nature of textural changes with depth [11,12]. The material is predominantly clay marked by minor amounts of sand and rare occurrence of gravel as contaminant [11]. Therefore, the soil series are distinguished according to the soil texture, and down-the-profile texture sequence and by soil wetness indicated by the degree of gleying. The textural groups are the broad groups of coarse, medium and fine with subgroups of comprising clay and silty clay, as primary group, and sandy clay and gravelly clay as second group. The degree of gleying combines the intensity of the gleying and the depth at which it occurs [11,12]. The EN 51 soil group is the poorly drain clays classification or *eutric glyceric fluvisol* [13,14]. It covers about 50% of the wetland soils in Enyong catchment. The topsoil varies between 10cm and 20cm in thickness and their textures range from sandy clay loam, silty clay and even silt loam. The colour varies from dark yellowish brown to grayish brown and dark reddish brown. The mottling ranges from none to strong brown mottles. The structure is commonly moderately and weakly developed medium subangular blocky, and sometimes is strongly developed coarse blocky [11].

Infiltration, Hydraulic Conductivity and Particle Size Measurement

The infiltration rates of surface soil under the cover of cocoa plantation were measured in 2010 in January and February when any high water levels in the swamp edges or levees and even in the flood plain had been lowered. Infiltration rates were measured by double ring methods [15]. The cocoa plantation covered varied toposeqence and soil series as observed in Nkari study area [11]. In addition to EN 51 soil group, cocoa plantations were distributed to imperfectly drained clays (EN 31 series) and to medium textured soils existing as a narrow strips along the edges of the uplands and as levees soils along the Itu River. Therefore, at least one infiltration measurement was made at each of these locations, to obtain different infiltration rate measurements. Due to transport limitation, prewetting was prevented. The saturated hydraulic conductivity, Ksat, of the soil profile that supports the soil surface infiltration characteristics was also investigated by field measurement using standard in-situ single-auger hole method at the grid centres along the transects across the plantation.

The particle size was determined by hydrometer method [16] for particles at specific grid points cut-out transects in the cocoa plantations. Then the USDA soil classification triangle was used to find the texture.

Statistical Analysis

Data and regression models were statistically analyzed using SPSS version 17 (Words) software. Infiltration charts were plotted with computer. Regression equations were compared to Kostialov and Philips infiltration models. Correlations between the observed and predicted models were extracted.

Results

Field data were used to plot the graphs of infiltration rate and cumulative infiltration [infiltration capacity] under cocoa plantation. The curves for infiltration rate, I (cm/hr) on secondary axis and cumulative infiltration F (cm) for *eutric gleyic fluvisol* or poorly drained clays are shown in [Fig-1].

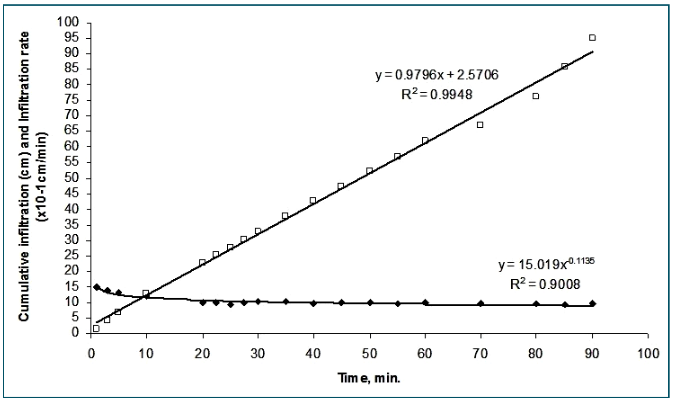

Fig. 1- Plot of measured cumulative infiltration and infiltration rate with time for Cocoa plantation soil (*Eutric gleyic fluvisol*)

[Table-1] shows the infiltration rates for different soil characteristics of the EN 51soil groups and silt/clay ratios for two depths of cocoa plantation floor at Nkari wetland.

Table 1- Soil group, particles sizes, silt/clay ratio, infiltration rates, permeability of soil under cocoa plantation, Nkari

Soil group	Depth, cm	
	0-19	19-39
EN 51	Poorly drained clays	
pH	4.77	4.69
Sand %	32.6	21.6
Silt %	32	22
Clay %	35.4	56.4
Silt/Clay ratio	0.904	0.39
SOM	2.87	1.02
Texture	CL	C
Infiltration rate, cm/hr.	55.2	
(m/day)	(0.552)	
Ksat, m/day	6.8	
N/B: CL = Clay loam; C = Clay	**The soil is a texture contrast duplex*	

Discussion

Physical soil Properties

The supporting soil is required to contain significant percentage of sand in some areas and high proportions of silt and clay dominating in other areas [17]. [Table-1] shows that the cocoa plantation soil, the *eutric gleyic fluvisol* of the Allluvial deposits contains significantly high percentage of silt and clay with high proportion of sand. It is adequate for sustained growth of cocoa [17,18]. Rainfall is required to constantly maintain the soil, as the crop is drought or heat sensitive [7,19]. The distribution of rainfall [Table-2] shows adequacy.

Table 2- Monthly and annual rainfall in the cocoa plantation catchment (1972-1999)

Months	Mean Rainfall, mm
Jan	10.7
Feb	30.7
Mar	131.9
Apr	188
May	252.2
Jun	275.4
Jul	292.3
Aug	304.9
Sep	339.5
Oct	224.9
Nov	54.6
Dec	10.7
Total	2113.9

November, December and January, February and March (i.e. 5 months) in the catchment are the months when irrigation, especially sprinklers or the drip type, may be supplied. However, because of the forest-like nature of the cocoa plantation [9], intercepting solar radiation and reducing soil temperature, mitigation of the negative warming effects of the climate change (dry season) may be expected. This s one aspect that more research is needed to avert restricted production [9,19].

Infiltration Rate and Cumulative Capacity

From the graphical plot [Fig-1], the constant infiltration rate was 0.92 cm/mm or 60.5 cm/hr. or 60 x 10^{-2} m/hr. The cumulative infiltration capacity, from [Fig-1] also was read as 61.9cm in 1hr or 95 cm in 1½ hrs. constant infiltrating. The equation for model infiltration rate was (from [Fig-1]) obtained as a power function given as:

$$I = 90.073t^{-0.1133},\ R^2 = 9056. \quad (1)$$

where I = infiltration rate, cm/hr, and t is time, min, elapsed since infiltration started. Also, the cumulative infiltration capacity, from [Fig-1], was obtained as a linear function given by:

$$F = 0.9916t + 2.2536,\ R^2 = 0.9951 \quad (2)$$

Comparative Models

Two model forms were compared to the empirical regression equations models obtained above. These were the earliest infiltration model or Kostiakov's (1932) model given as:

$$f = at^b \quad (3)$$

where f is infiltration rate in time (mm/hr) and t is time since infiltration started (hrs), a and b are soil parameters depending on antecedent soil water content and soil structural stability [20].

Patenting the cocoa plantation infiltration rate empirical equation in the form of Kostiakov's model gave the Kostiakov form of the cocoa plantation infiltration rate equation as a power function given by:

$$I = 90.073\ t^{-0.1133} \quad (4)$$

Thus, Kostiakov parameter a = 90.073, and b soil dependent parameter = 0.1133.

The second model form was the Philips (1957) two-term quadratic equation for cumulative infiltration given as:

$$F = St^{½}\ tct \quad (5)$$

Equation [Eq-2], the cumulative infiltration equation for the cocoa plantation soil, can be made to confirm with this model [Eq-5] by taking similar terms between the decomposed components of the Philips equation, [Eq-5], and the decomposed components of the empirical cumulating infiltration of the cocoa plantation soil, [Eq-2]. Thus:

$$St^{½} = 0.9916t = S = 0.9916\ t^{½} \quad (6)$$

$$Ct = 2.2536 = C = 2.2536t^{-1} \quad (7)$$

Substituting t into these partial functions showed the variation of S and C with elapsed time. In the alternative, therefore [Eq-5] is equated to empirical [Eq-2]. Thus:

$$F = St\ ½ + Ct = 0.9916t + 2.2536 \quad (8)$$

By inserting the values of t and F into [Eq-8], a series of equation with S and C as unknown variables are obtained, which can solved simultaneously using determinant matrix to obtain minimum values of silt and clay with relatively high percentage of sand. It is therefore adequate for cocoa plantation.

Basic Infiltration Rate

The empirical constant infiltration rate in the cocoa plantation's e*utric gleyic fluvisol* soil, by field measurement was 0.92 cm/min or 55.2cm/hr while the model basic form using the kostiakov model was 53.7676 or 54 cm/hr. or 54 x 10^{-2} m/hr. The difference between the empirical (field data based) infiltration rate and the Kostiakov model form was not significant (at $P < 0.01$; r = 0.995), [Fig-2]. Thus, the Kostiakou model was efficient predictive function of the cocoa plantation infiltration rate under *eutric gleyic fluvisol* soil group.

Prediction of cumulative infiltration performance on the *eutric gleyic fluvisol* soil type also conformed to the two-term Philip's equation. The difference between the field data-based cumulative infiltration function was not significantly different from profile by Philip's equation, [Fig-3]. Already the dominant soil group (EN 51) was *eutric gleyic fluvisol*, which is gleyed poorly drained wetland. It is not necessary to encourage flooding on such a gleyed land. As such, infiltration rate should be aligned for proper management of the area. Thus, irrigation by flooding is not recommended.

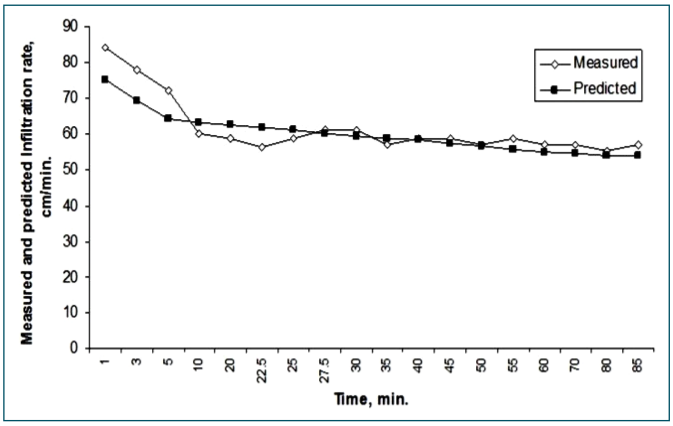

Fig. 2- Comparison of measured and predicted (Kostiokov's model) infiltration rate

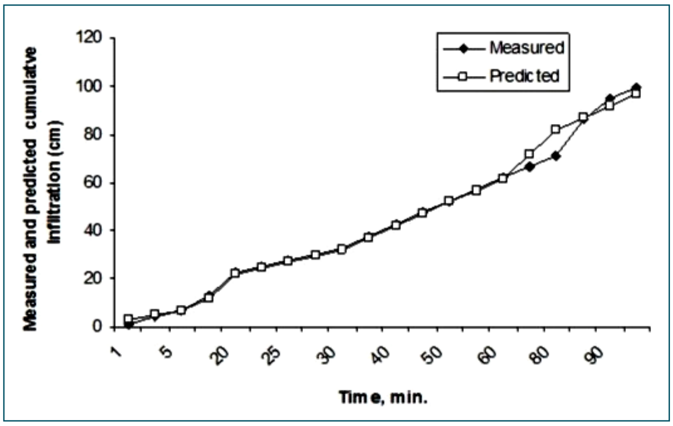

Fig. 3- Comparison of measured and predicted (Philip's model) cumulative infiltration

Conclusion

Investigation of the soil under cocoa plantation showed that the soil group, *eutric gleyic fluvisol* supported the sustenance of cocoa plantation with good soil drainage properties. The infiltration rate, cumulative infiltration and saturated hydraulic conductivity of the soil were determined, and data processed, using SPSS software version 17. The constant infiltration rate was 55.2 cm/hr and was efficiently correlated with the Kostiakov infiltration model with $R^2 = 0.901$ and no significant difference ($p < 0.01$) between the empirical and Kostiakov models. The model parameters were in consonance with the Kostiakov. However, the high value of infiltration rate under the cocoa plantation was indicative of the bioturbation and growth influence of plantation and soil ecosystem engineers.

Re-evaluation in 10 year's interval is needed to re-assess goodness of fit of predictive model with empirical infiltration equation for all soil groups under the canopy.

Acknowledgement

The author expresses profound gratitude to AKADEP for access to archive data.

Conflict of Interest:

The author confirms that to the best of his knowledge, no conflict of interest exists.

References

[1] Moreira F.M., Huising E.J. and Bignell D.E. (2008) *Handbook of Tropical Soil Biology*, Earthscan, London, 1-6.

[2] Goldberg V. and Bemhofer C. (2001) *Ann. Geophys*, 19, 581-587.

[3] Godsey S., Elsenbeer H. (2002) *Hydrol. Process*, 16(7), 1519-1522.

[4] Vanclay J.K. (2009) *Forest Ecology and Management*, 257(2), 385-389.

[5] Evans J. and Turnbull J. (2004) *Plantation Forestry in the Tropics*, Oxford University Press, Oxford, 1-467.

[6] Zimmermann B., Elsenbeer H. and De Moraes J.M. (2000) *Forest Ecology and Management*, 222, 29-38.

[7] Raw Material Research and Development Council (2004) *Report on Survey of Agro Raw Materials in Nigerian*, Cocoa, Maiden ed., RMRDC, Abuja, Nigeria.

[8] Okpeke L.K. (2005) *Tropical Tree Crops*, Spectrum Books Ltd., Ibadan, Nigeria.

[9] Oguike P.C. and Henshaw I.E. (2013) *Int'l Journal of Agric. and Rural Development*, 16(1), 1343-1347.

[10] Hiraoka M. and Onda Y. (2010) *American Geographical Union*: Code 2010 AGUFMH31F1065.

[11] Akwa Ibom Agricultural Project (1995) *Northern Akwa Ibom Swamp Development Study*, Stage 2 Report 5, 1-12.

[12] Akamigbo F.O.R. and Asadu C.L.A. (1983) *East African Agric. For J.*, 48, 81-91.

[13] Soil Survey Staff (1975) *Agric. Handbook* No. 436.

[14] FAO-UNESCO (1985) *Soil Map of the World*, FAO of UN, Rome.

[15] Bhattacharya A.K. and Michael A.M. (2003) *Land Drainage Principles, Methods and Application*, Konark Publishers Pvt. Ltd., 151-206.

[16] Liu C. and Evett J.B. (2000) *Grain-Size Analysis of Soil,* ASTM D 422, Prentice Hall, New Jersey.

[17] Ololade I.A., Ayaji I.R., Gbadamosi A.E., Mohammed O.Z. and Sunday A.G. (2010) *Modern Applied Sciences*, 4(5), 35-43.

[18] Fashina A.S., Omotosho S.O., Shitu O.S. and Adenikinju A.P. (2007) *American-Eurasian J. Agric. and Environ Science*, 2(3), 312-317.

[19] Centre for Agricultural and Rural Cooperation (2012) *Spore,* 159, 1-9, CTA, Wageningen.

[20] Oyebode M.A. and Yahaya A.S. (2008) *Journal of Agricultural Engineering and Technology,* 16(2), 44-52.