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EFFECTS OF SOME SOIL PHYSICAL PROPERTIES ON THE INFILTRATION RATES OF FALLOW AND CULTIVATED SOILS AROUND MINNA, NIGERIA

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ABSTRACT

The infiltration characteristics of soils of Gidan-Kwano and Shintako sites under fallow and cultivation were evaluated using a double-ring infiltrometer in Minna area in the Nigerian Southern Guinea Savanna zone. Some infiltration related soil physical properties were also studied. It was observed that cultivated soil had significantly higher volumetric moisture content than the soil under fallow. Soils under fallow exhibited significantly higher infiltration rates than those under cultivation. Infiltration rate was found to decrease with an increase in total-porosity, micro-porosity and bulk density. The higher clay content of the Gidan-Kwano soil resulted in a lower infiltration rate compared to the Shintako soil with a sandy texture. Leaving strips of fallow or woodland is recommended on farmlands in order to maintain good soil structure and adequate infiltration rates. This will reduce incidence of surface runoff and enhance erosion control.

Keywords: Infiltration rates, bulk density, total-porosity, micro-porosity, soil moisture content, fallow soil, cultivated soil.

INTRODUCTION

The Nigerian Guinea Savanna zone is characterized by high rainfall intensity, variability and seasonality. A considerable proportion of the rains are associated with high intensity which frequently result in appreciable soil compaction, reduced infiltration capacity, soil erosion and a reasonable amount of runoff, particularly in the absence of surface cover. Evaporative demand is quite high too. The soils possess poor structural stability and inherent low fertility status. Although, rainfall is inadequate (1,000 – 1,400 mm annually) in this zone, the distribution of water within the soil profile and the proportion that remains in the root zone for the plants to utilize are perhaps more crucial limitations than the total rainfall.

The rate at which a soil can absorb water supplied to its surface is an important physical property commonly used in evaluating the infiltration characteristics of the soil. Infiltration is the term applied to the process of water entry into the soil. This process is of great practical importance since its rate often determines the amount of runoff which will form over the soil surface and hence, also determines the hazard of erosion during rainstorms. Where the rate of infiltration is limiting, the entire water economy of the rooting zone of plants may be affected. Therefore, knowledge of the infiltration process as it relates to soil physical properties and mode of water supply is needed for efficient soil and water management. The practice of occasional shallow cultivation to break up surface crusts has been shown to be an effective means of increasing infiltration, moisture conservation, and consequently reducing surface runoff and erosion. Timely shallow tillage in sandy soils of semi-arid West Africa after rainfall events can conserve moisture and increase yield dramatically as demonstrated by Payne (1999). Baumhardt *et al* (1992) and Cassel *et al* (1995) however noted that the improved infiltration promoted by mechanical disruption of surface crusts is short-lived on bare soil, as the surface seal reforms with each rain of moderate or high intensity. However, Baumhardt *et al.* (1992) reported that

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intercepting raindrop impact to prevent crust formation is a more effective practice for increasing infiltration than cultivation to break up surface crust. Ohu and Folorunso (1989) demonstrated that the use of vehicular traffic during seedbed preparation for crop production in loose sandy soils of North-eastern Nigeria resulted in higher soil bulk density and penetration resistance with increase in the number of tractor passes. The hazardous effects of erosion following torrential rainfall or application of irrigation water in large volumes and the amount of runoff which forms over the soil are a function of the infiltration rate of the soil. Erosion leads to the removal of soil material and a consequent decline in the nutrient-holding capacity of soils which results in declining crop yields or the necessity for increased inputs in order to maintain yields (Boardman *et al.*, 1990).

Considering the problems of soil compaction, erosion, runoff and moisture stress arising from cultivation practices and the climatic conditions prevalent in the Guinea Savanna zone, it is essential to know the rate at which water will move into soils under a wide range of conditions. It is the infiltration capacity of the soil that determines the rate at which water can be applied to the surface without runoff. In the Nigerian Guinea Savanna, efforts are being directed towards water management and conservation activities such as irrigation and control of flood and erosion. More information is therefore, needed as it pertains to studies on the water intake characteristics and related physical properties of soils in various locations of the zone. The present work is based on the assessment and evaluation of the infiltration characteristics and the associated physical properties of soils of the Minna environment. The objective of this study is to evaluate the influence of two land management practices and some soil physical properties on infiltration rate.

MATERIALS AND METHODS

The research work was done at two locations (Gidan-Kwano and Shintako villages) within the Minna environment in Niger State of Nigeria. According to the classification of Keay (1959), Laurie (1974), Onochie (1977) and Sanford and Isichei (1980), Minna is found in the Southern Guinea Savanna zone of Nigeria. It is situated between latitudes 6° 00′ and 7° 00′ North and longitudes 9° 30′ and 9°45′ East. The topography is slightly flat to undulating. The soils at the sites are developed from precambium Basement Complex and are mostly sandy. The Gidan-Kwano and Shintako soils are classified as Plinthustalf and Paleustalf respectively (Eze, 2000). The vegetation is mainly Savanna grassland with scattered trees and shrubs. The physicochemical properties of the soils under study are shown in Table 1.

The experimental design employed was the randomized complete block design with four replications, two treatments (fallow soil and cultivated soil i.e. landuse practice), and two experimental sites as listed above. The plot size was $25m^2$ (i.e. 5 x 5m). The five-year fallow soils at both sites were divided into two main plots. One of the plots was left fallow (control plots) while the second plot lying directly opposite was cropped for one year to yellow maize (TZR-Y) on the flat. The cultivated plots were tilled manually. The main plots were further divided into four subplots to serve as replicates.

Sixteen soil samples were collected with a soil auger at each of the two depths, 0 – 20cm and 20 – 40cm, and bulked for physicochemical analysis following standard laboratory procedures (IITA, 1979). Four undisturbed core samples were also collected from each plot at the soil surface with the aid of a bulk density sampler, having core rings, for determinations which included volumetric moisture content, bulk density and porosity. Infiltration rate measurements were taken on all the plots under fallow and the cultivated plots lying opposite, using a double-ring infiltrometer at the two sites under study as recommended by Ahuja *et al.*, (1976) and Michael (1992). Volumetric moisture content, bulk density, porosity and infiltration rates were determined before soil cultivation, (0 week) and subsequently at intervals of 4, 8 and 12 weeks.

The data collected were subjected to statistical analysis such as analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) in order to determine the significant difference between means. Also, correlation analysis was carried out.

RESULTS AND DISCUSSION

Table 1 shows the soil physical and chemical properties of bulked sub-samples of the 0 – 20cm and 20 – 40cm depths at the two experimental sites. The bulk density values at the two depths in both sites did not vary considerably. The values range from 1.68 to $1.72gcm^{-3}$. The results of the soil analysis indicated that the clay content at the two depths was observed to be higher in the soils at Gidan-Kwano, while the Shintako soils had higher values of percent sand. This accounts for the clayey and sandy textures of the Gidan-Kwano and Shintako soils respectively. No doubt, the textural characteristics of a soil would have a serious bearing on the rate of water entry into its surface.

Tables 2 to 7 indicate that in the current study, no trend was observed with respect to change or variation in any of the physical parameters tested (bulk density, porosity, volumetric moisture content and infiltration rate) over time for both fallow and cultivated soils in the 2 sites. This is an indication that it is not only the length of time over which a given soil is being subjected to a particular land use practice that affects its physical properties but also, the level or intensity of the land management practice goes a long way to influence the physical properties of the soil appreciably. The increases and decreases in the values observed in relation to time of sampling may be due to data variation resulting from spatial variability. Also, the variation in water content values may be closely related to rainfall input during periods of sampling.

Table 1: Physico-Chemical Properties of Soil Samples of Gidan-Kwano and Shintako Sites

Soil Properties	Gidan-Kwano Site		Shintako Site	
Soil Depth, cm	0 - 20	20 – 40	0 – 20	20 – 40
PH (1:2.5) in Water	6.80	6.87	6.90	6.85
PH(1:1.5) in 0.01M $CaCl_2$	6.44	6.38	6.44	6.53
Bulk Density, gcm^{-3}	1.72	1.68	1.69	1.68
Sand, %	75.52	68.02	83.02	81.02
Silt, %	6.78	6.78	3.28	3.78
Clay, %	17.70	25.20	13.70	15.20
Textural Class	Sandy loam	Sandy clay loam	Loamy sand	Loamy sand
Organic Carbon, gkg^{-1} Soil	17.70	9.00	13.90	18.90
Organic Matter, gkg^{-1} Soil	30.50	15.50	24.00	32.60
Total N, gkg^{-1} Soil	0.80	1.20	1.40	1.10
Available P, $mgkg^{-1}$ Soil	7.53	7.53	8.05	9.63
Exchangeable Na^+, $cmolskg^{-1}$ Soil	0.54	0.53	0.54	0.59
Exchangeable K^+, $cmolskg^{-1}$ Soil	0.14	0.17	0.14	0.15
Exchangeable Ca^{2+}, $cmolskg^{-1}$ Soil	3.44	2.08	1.76	1.52
Exchangeable Mg^{2+}, $cmolskg^{-1}$ Soil	1.88	5.08	2.88	3.04
Exchangeable Acidity ($H^+ + Al^{3+}$), $cmolskg^{-1}$ Soil	1.60	1.20	1.60	1.60
C.E.C., $cmolskg^{-1}$ Soil	7.60	9.06	6.92	6.90
Base saturation, %	78.95	86.75	76.88	76.81

Contrary to the finding of Marshall and Holmes (1988), results in Tables 2 show that there was no significant difference between the bulk density of the soil under fallow and the cultivated one in the two sites under study ($P > 0.05$). This could be attributed to the fact that the impact of tillage was not severe enough to cause considerable disturbance and compaction of the surface soil which would have otherwise culminated in an appreciable difference between the bulk density of the two soils. Most cultivation practices are known to give rise to a temporary loosening, and hence, a decrease in soil bulk density in the cultivated layer.

Table 2: Bulk Density, gcm^{-3}, of Cultivated and Fallow Soils at Gidan-Kwano and Shintako Sites

	Gidan-Kwano Site					Shintako Site				
Land Use	Before Cultivation	4 WAC	8 WAC	12 WAC	Mean	Before Cultivation	4 WAC	8 WAC	12 WAC	Mean
Cultivated	1.64	1.54	1.67	1.60	1.61^a	1.66	1.68	1.78	1.69	1.70^a
Fallow	1.66	1.54	1.75	1.67	1.65^a	1.66	1.72	1.75	1.68	1.70^a
Mean	1.65^b	1.54^a	1.71^b	1.63^b		1.66^a	1.70^a	1.76^b	1.68^a	

= NS

Landuse x weeks interaction ($P > 0.05$) = NS

Results presented in Tables 3 and 4 indicate that in the two sites, land use practice did not influence total-porosity and macro-porosity significantly ($P > 0.05$). However, Brady (1984) observed that compaction resulting from the effect of cultivation often easily destroy macro-pores. Table 5 shows that micro-porosity was significantly higher in the cultivated soil than in the one under fallow in the Gidan-Kwano site, whereas, in the Shintako site the difference was found to be insignificant ($P > 0.05$) although, numerically higher in the cultivated soil in this site. This finding could be attributed to the fact that cultivation may have destroyed most of the macro and medium-sized pores in the cultivated layer. This obviously would result in a greater proportion of micro-pores in this layer than in the undisturbed, fallow soil. A change in the pore-size distribution toward successively smaller pores results from cultivation practices (Ohu and Folorunso, 1989).

Table 3: Total-Porosity, %, of Cultivated and Fallow Soils at Gidan-Kwano and Shintako Sites.

Land Use	Gidan-Kwano Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean	Shintako Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean
Cultivated	37.24	41.74	40.04	40.97	39.99^a	36.19	37.08	34.72	37.19	36.29^a
Fallow	35.08	42.62	34.75	37.03	37.37^a	36.77	33.71	34.96	36.08	35.38^a
Mean	36.16^a	42.18^b	35.39^a	39.00^{ab}		36.48^a	35.39^a	34.84^a	36.63^a	

Landuse x weeks interaction ($P > 0.05$) = NS   = NS

Table 4: Macro-Porosity, %, of Cultivated and Fallow Soils at Gidan-Kwano andShintako Sites

Land Use	Gidan-Kwano Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean	Shintako Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean
Cultivated	2.57	9.05	7.11	5.34	6.01^a	2.87	7.31	6.00	11.38	6.89^a
Fallow	2.87	8.16	5.83	6.37	5.80^a	2.75	6.63	7.64	9.57	6.64^a
Mean	2.72^a	8.60^c	6.47^b	5.85^b		2.81^a	6.97^a	6.82^b	10.47^c	

Landuse x weeks interaction ($P > 0.05$) = NS   = NS

Note: Data on the same row or column carrying the same superscript differ insignificantly from each other ($P>0.05$).
WAC: Weeks after Cultivation

Table 5: Micro-Porosity, %, of Cultivated and Fallow Soils at Gidan-Kwano and Shintako Sites

Land Use	Gidan-Kwano Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean	Shintako Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean
Cultivated	34.67	32.69	32.93	35.63	33.98^b	33.32	27.99	28.72	25.81	29.40^a
Fallow	32.21	34.46	28.92	30.66	31.56^a	34.02	27.08	27.32	26.51	28.73^a
Mean	33.44^a	33.57^a	30.92^a	33.14^a		33.67^b	28.42^a	28.02^a	26.16^a	

Land use x weeks interaction ($P > 0.05$) = NS   = NS

The absence of significant difference in volumetric moisture content (Table 6) between fallow and cultivated soils observed in the Gidan-Kwano site could be due to the clayey nature of the soil of this site which indicates a likely greater proportion of micro-pores which are mostly water filled, with a consequent negligible and masked effect of cultivation. Also, the volumetric moisture content of the cultivated soil was found to be significantly higher than that of the fallow soil in the Shintako site ($P > 0.05$). This observation probably results from the roughness of the surface of the cultivated soil, which could have considerably reduced the rate of evaporation of water from the soil surface. It should be noted that the micro-porosity value of the same cultivated soil was found to be numerically higher than that of the soil under fallow, although, the difference was not statistically significant. Brady (1984) and Michael (1992) reported that micro-pores are mostly filled with water under normal field condition. Hence, it is not surprising that the cultivated soil had considerably higher volumetric moisture content.

Table 6: Volumetric Moisture Content, %, of Cultivated and Fallow Soils at Gidan- Kwano and Shintako Sites

Land Use	Gidan-Kwano Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean	Shintako Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean
Cultivated	27.12	14.42	25.32	18.54	21.35^{a}	12.76	16.15	23.66	17.27	17.46^{b}
Fallow	24.05	14.96	28.16	21.63	22.20^{a}	14.52	15.31	19.20	15.56	16.14^{a}
Mean	25.58^{c}	14.69^{a}	26.74^{c}	20.08^{b}		13.64^{a}	15.73^{b}	21.43^{c}	16.41^{b}	

Land use x weeks interaction ($P > 0.05$) = NS   = NS

Data on the same row or column carrying the same superscript differ insignificantly from each

The results shown in Table 7 reveal that in all cases, cultivated soils had significantly lower infiltration rate values than the soils under fallow ($P > 0.05$). Cultivation may have destroyed the granular nature of the soils, compacted them and reduced the proportion of macro-pores with a consequent increase in micro-porosity in the cultivated soils compared to the fallow, undisturbed soils with an obviously greater proportion of macro-pores. Ahmed and Duru (1985) in Samaru attributed this finding to mainly earthworm activity, penetrating and decaying roots. The increased micro-porosity of the cultivated soils could have been responsible for their lower infiltration rates than those of the fallow soils in line with the findings of Brady (1984), Pritchett and Fisher (1987), and Boardman *et al.*, (1990).

Generally, infiltration rates of both cultivated and fallow soils in the Shintako site were observed to be higher than those of Gidan-Kwano site in this study. This result so obtained is not surprising, considering the sandy texture of the soils in the Shintako site as opposed to that of the soils in Gidan-Kwano with higher clay content. Infiltration rate has been found to be 10 times higher on loamy sand than on clay loam as reported by Kohnke (1968). Babaji (1982) and Babalola (1986) attributed this trend to the very high proportion of large and continuous aeration pores in coarse-textured soils, and the tendency of colloidal particles in fine-textured soils to swell upon hydration, thereby, reducing the cross-sectional area available for flow. Pore-sizes may be reduced with a consequent restriction to water movement and infiltration because the particles in fine-texture soils tend to adhere and pack closely. However, consequent upon the fact that the soil tend to be porous with more conducting pores, infiltration is enhanced in coarse-textured soils (Babaji, 1982). Brady (1984), Speirs and Frost (1985), Pritchett and Fisher (1987), Marshall and Holmes (1988), and Michael (1992) reported independently that any impedance to water movement (such as high clay content) into and through the soil profile adversely affects its infiltration rate. Thus, the soil layer with the lowest permeability, either at the surface or beneath it, usually determines the infiltration rate.

Table 7: Infiltration Rate, $cmhr^{-1}$, of Cultivated and Fallow Soils at Gidan-Kwano and Shintako Sites

Land Use	Gidan-Kwano Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean	Shintako Site: Before Cultivation	4 WAC	8 WAC	12 WAC	Mean
Cultivated	5.47	9.16	7.75	8.80	7.79^{a}	31.56	35.13	13.90	17.41	24.50^{a}
Fallow	10.81	13.75	36.70	18.98	20.06^{b}	19.12	42.55	31.36	22.50	31.38^{b}
Mean	8.14^{a}	11.45^{ab}	22.22^{b}	13.89^{ab}		30.34^{bc}	38.84^{d}	22.63^{ab}	19.95^{a}	

Landuse x weeks interaction ($P > 0.05$) = 0.0121   = 0.0232

Data on the same row or column carrying the same superscript differ insignificantly from each other ($P>0.05$).

WAC: Weeks after Cultivation

Table 8 shows correlation coefficients associating some soil physical properties with infiltration rate. Results indicate that total-porosity correlated significantly with infiltration rate (r = -0.38*), but negatively. This result in which infiltration rate decreased with an increase in total-porosity may be due to the fact that the total-porosity was dominated by micro-pores. This could be true because, whereas, macro-porosity was observed to be poorly correlated with infiltration rate (r = -0.05), micro-porosity was found to be significantly correlated with it (r = -0.46*), but inversely. This is expected, since micro-pores tend to restrict water movement and impede infiltration (Brady, 1984).

Table 8: Correlation Table of Some Soil Physical Properties with Infiltration rate

Parameters Correlated	Correlation Coefficients
Infiltration rate and Total-porosity	-0.38*
Infiltration rate and Macro-porosity	-0.05
Infiltration rate and Micro-porosity	-0.46*
Infiltration rate and Bulk density	-0.41*
Infiltration rate and Volumetric Moisture Content	0.25

*: Significant at 0.05 Probability level.

This, thus, establishes the fact that the proportion of the individual pore spaces rather than their combined volume is the important consideration. Results also show a significantly negative correlation between bulk density and infiltration rate (r = -0.41*). It is obvious that high bulk density values, as reported by Brady (1984) and Ahmed and Duru (1985) are closely associated with low infiltration rates in soils. It is worth mentioning that bulk density only has an indirect influence on infiltration rate. It rather modifies the pore-size distribution which has a direct bearing on infiltration rate. Volumetric moisture content was found to be poorly correlated with infiltration rate (r = 0.25). This is obvious, considering the fact that volumetric moisture content has been found not to influence the equilibrium rate, but only makes the soil to attain final rate slowly or quickly depending on the moisture content (Lal and Greenland, 1978). Philip (1957) reported that soils which are already wet attain final infiltration rate more quickly when rain falls upon them.

SUMMARY AND CONCLUSION

The purpose of this study was to determine the infiltration rates of selected soils under fallow and cultivation. It was undertaken with the ultimate aim of evaluating the impact of cultivation on water intake rate and some other physical properties of soils that affect infiltration characteristics. Among the factors that affect infiltration rate, micro-porosity, soil textural characteristics and landuse practice were observed to be the most important. Micro-porosity correlated with infiltration rate (r = -0.46*), indicating that individual pore spaces rather than the total volume is important. Another factor that affects the rate of water entry into the soil is soil textural characteristics. This is evident from the sandy, coarse texture of Shintako soils which resulted in higher infiltration rates compared to the Gidan-Kwano soils with higher clay content. Generally, the soils under fallow showed appreciably higher infiltration rates than those subjected to cultivation.

The Nigerian Guinea Savanna zone is characterized by high rainfall intensity and seasonality which often leads to erosion hazards and severe water shortages. It then entails that, for the purpose of water conservation and management, and erosion control in large farms, it is advisable to leave strips of land under fallow between large plots within the farm. This will ensure that running water on the soil surface down-slope is adequately absorbed into the soil, thereby, reducing its erosivity. Also, in order to maintain good soil structure, the soil should be left fallow after continuous cultivation for quite a long period of time.

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