HORIZONTAL INFILTRATION AND TRACE ELEMENT MEASUREMENTS FOR SAVANNAH SOILS IN ZARIA, NIGERIA.

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(*Submitted 6 August,2005 Accepted 30 May, 2006*)

Abstract

Laboratory investigations of horizontal infiltration were carried out on three Zaria soils (Samaru, Tudun Wada and the Kubanni river basin Fadama wet-land soils) in Nigeria, which are principally alfisols. Diffusivity was found to be $-77.5 \times 10^{-2}\ cm^2 s^{-1}$, $-8.4 \times 10^{-2}\ cm^2 s^{-1}$ *and* $-117.0 \times 10^{-2}\ cm^2 s^{-1}$ *respectively for the three soils. Other infiltration characteristics including, sorptivity and water flux through the soils were also measured.. Concentration data for twenty-one elements (Sb, Ba, Ce, Co, Cr, Cs, Eu, Hf, Fe, La, Lu, Nd, K, Rb, Sc, Na, Ta, Th, U, Yb, Zn) were also determined for the three soils. The study revealed that although the mineralogy of the soils appeared similar based on their mean elemental compositions, the Fadama soils showed high sorptivity, indicative of water-logged conditions which is characteristic of wet-lands.*

Key words: *Nigerian Soils, Darcy's equation, infiltration,* k_o*-standardization, neutron Activation analysis*

1. Introduction

Information on water diffusion rates under different field conditions is needful for the study of semi-arid tropical soils, notably the *Alfisols*. Permeability differs for different soil-orders and even within a given group; depending on the nature of the pores, tortuous flow-paths for soil-water, texture, as well as other soil characteristics.

Laboratory investigations using horizontal soil-packed columns with a water-head maintained at a given potential attempts to simulate *in situ* conditions and are known to be useful in soil-physics investigations under laboratory conditions (Marshall *et al*., 1979; IAEA, 1976; IAEA, 1983). As a complimentary data on soil infiltration characteristics, the concentration of elements for each soil is equally needful for an *a priori* understanding of soil mineralogy, which in turn affects water diffusion.

The aim of this study is therefore the application of Darcy's equations for the development of fundamental diffusion relations that were used in obtaining soil-water flux, diffusivity and sorptivity data. The trace element concentrations determined for the different soils investigated are complimentary to the data obtained for the soils investigated. The methodology developed in this work could be a model-process for soil investigations under laboratory conditions.

2. Materials and Methods

2.1. Sample preparation

The soils were sampled from three principal agricultural zones in Zaria, Nigeria where dry season farming is prevalent (Samaru, Tudun Wada and the Kubanni river basin wetland - *Fadama*). These soil samples were collected and conveyed to the laboratory for analysis. The soils on arrival at the laboratory were air-dried, ground to powdered form with the use of an agate mortar and sieved using a mesh of stainless-steel having an aperture of 250 ?m (sieve-size of BS410 Endecotts® Ltd. London). They were then packed into a transparent graduated plastic column of length 60 cm and diameter 1.5 cm; set in a horizontal position and connected to a burette with a constant water-head as described in IAEA, 1983. The theory and fundamental equations used for the determinations in this study are hereby described.

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2.2 Theory of horizontal infiltration method

Horizontal infiltration measurement yields data for the maximum rate at which a soil in a given condition at a given time can absorb water through diffusive processes. Diffusion, defined as the movement of molecules from the point of higher concentration towards a lower concentration, arises from the random motion of particles within the phase that contains them due to the associated thermal energy. Although, an experimental set-up in the laboratory can model a water-flow system that is entirely horizontal, such a condition is hardly realized under natural field conditions. That not withstanding, laboratory investigations ever remain as starting points for *in situ* investigations. For the purposes of studying water infiltration, Darcy's equation (Phillip, 1957; Crank, 1956) is taken to be of the form:

$$J = -K\frac{dh}{dx}$$

$$J = -K\frac{dh}{d\theta}\frac{d\theta}{dx}$$

$$-D\frac{d\theta}{dx} \qquad (1)$$

where:

J= the flux of water ($cm^3cm^{-2}s^{-1}$),
K = the hydraulic conductivity ($cm.min^{-1}$),
h = the matric potential head (cm),
x = the horizontal water infiltration distance (cm), or
is the slope of the soil-water characteristic.
D= the soil-water diffusivity ($cm\ s^{-1}$), and also noting that K, D and $\frac{dh}{dq}$ depend on the water content (θ).

From equation 1, infiltration rate of water into homogenous semi-infinite1 horizontal soil column for laboratory investigations as was the case in our work according to IAEA (1976) is given by the equation:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[D(\theta)\frac{\partial\theta}{\partial x}\right]$$

for $2 = (\theta)t^{12}$ (2)

where t is the infiltration time The function $\phi(\theta)$ is known as the Boltzmann transformation (B) and depends on the soil-water Diffusivity $D(\theta)$ for the particular soil. Equation 2 is a non-linear partial differential equation and can be considered as a single-valued function of a new variable which is also a function of x and t, hence the use of the Boltzmann function in transforming it to an ordinary differential equation.

Also, equation 2 is subject to boundary conditions which governs the water-flow such that:

(1) initially, water is uniformly distributed through out the length of the column and has a constant value θ_o (presumably air-dry): and

(II) the infiltration is started by bringing the end of the column (at x=0) into contact with a constant source of water and for all values of time t

(III) water content at x >0 is constant and has a value (presumably saturated).

These conditions are easily met in a laboratory set up, when a homogenous horizontal soil column of length 60 cm and uniform cross-section is instantaneously brought into contact with the water source through a porous disc, assuming that the flow is occurring only due to gradients of matric forces. It has been shown (IAEA, 1976; Ghildyal and Tripathi 1987) that cumulative infiltration, I, into a horizontal soil column in a specified time t will be given by:

$$I = t^{1/2}\int_0^{\theta}\phi(\theta)d\theta = t^{1/2}\int_0^{\theta}B(\theta)d\theta = St^{1/2} \qquad (3)$$

where $B(\theta)$ is equivalent to the Boltzmann transformation , $t^{1/2}$ is taken out of the integral because the integration takes place at specified t (constant) and also depends upon the soil-water diffusivity $D(\Theta)$ for a particular soil while S is the sorptivity ($cm.\ s^{-1/2}$). These equations form the basis for calculating diffusivity, sorptivity, flux rate, according to the method proposed by Ghildyal and Tripathi (1987) for which we obtained our results as shown in Table 2.

2.3 Analysis by instrumental neutron activation analysis

Replicate sample from the three soils (Samaru, Tudun Wada and the Kubanni river basin *Fadama* wet-lands) used for horizontal infiltration measurements were weighed and encapsulated into polyethylene vials and irradiated for eight hours at the 100 kW Reactor of the Technical University of Budapest at a thermal neutron flux of 2×10^{12} n $cm^{-2} s^{-1}$. The activity of the irradiated samples were allowed to decay for 7 days, 30 days and thereafter counted for 6,000 s and 10,000 s respectively using a HpGe detector whose efficiency at several energies as was useful for the k_o-standardization were validated using the Monte Carlo Method (Ewa et al., 2001). The k_o- standardization method now routinely used (Kennedy et al., 1999; Sasajima et al., 1999) for the determination of the concentrations of elements has excellent sensitivity attainable for many elements, good traceability, less reliance on multi-element standards and relative ease of identification of systematic errors (De Corte et al., 1987). Details of the technique could be found in Balla et al., 1998 and De Corte et al., 1989. The comparator (standard) used in this analysis was Gold while Zirconium foils were used as flux monitors. The nuclear properties of both the comparator and flux foils used in the investigations are listed in Table 1.

Table 1. Nuclear Data for the comparator and flux foils

Product Nuclide	Nuclear reaction	Eγ(keV)	Half-life(s)	Q_o
^{198}Au	$^{197}Au(n,\gamma)^{198}Au$	411	232934	15.7
^{95}Zr	$^{94}Zr(n,\gamma)^{95}Zr$	724	5532192	5.05
^{95}Zr	$^{94}Zr(n,\gamma)^{95}Zr$	756	5532192	5.05
^{97}Zr	$^{94}Zr(n,\gamma)^{97}Zr$	743	60264	248

The ratio of the resonance integral (I_o) to the thermal absorption cross-section (σ) for the target nuclides are expressed as Q_o. Measurement of the thermal/epithermal flux ratio ($\varphi_{th}/\varphi_{ep}$) was achieved by using the ^{94}Zr - ^{96}Zr pair.

3. Results and Discussions

Diffusivity is important, notably under semi-arid conditions because it is an assessment of the rate at which water penetrates the soil. The flux of water by horizontal infiltration is highest for the *Fadama* (wet-land) soils which are loamy (Table 2). Soils differ in their ability to absorb or retain water up to saturation points. This property is called sorptivity and is characteristic of loose and easily worked soils, notably the sandy types. It is important to farmers within the semi-arid belt of the savanna where little rainfall should be optimized by plants in order to grow within the short period of adequate moisture (Sanchez, 1976; Ashton, 1956).

Table 2. Results of horizontal infiltration parameters

Zaria Soil Type	Diffussivity ($cm^2 s^{-1}$)	Sorptivity ($cms^{-1/2}$)	Flux-rate of water ($cm^3 cm^{-2} s^{-1}$)
Samaru	-77.5×10^{-2}	6.3×10^{-3}	23.6×10^{-2}
Tudun Wada	-8.4×10^{-2}	19.0×10^{-3}	6.0×10^{-2}
Wet-Lands (*Fadama*)*	-117.0×10^{-2}	5.8×10^{-3}	33.5×10^{-2}

The sorptivity of the Tudun Wada soil (19.0×10^{-3} cm $s^{-1/2}$) an upland soil is much higher than others while the loamy-clay soil of the *Fadama* (wet-lands) are known to absorb slowly, although with higher capacity (Flux) and much longer retention than others due to the presence of allumino-sillicates, small pore sizes, heavy concentrations of clay minerals as well as the swelling index of clay soils.

These soils investigated are predominantly Alfisols of sub-order Aqualfs, and are usually plastic when wet but form hard surface pans during the prolong dry-seasons, due to the ustic moisture regime of the West African savanna soil belt (Miller and Donahue, 1997). They are characterized by hard concretions as a result of residual accumulations of hematite (Fe_2O_3) consolidated with clay (Kaolinite- $Al_2Si_2O_5[OH]_4$, K-Feldspar - $KAlSi_3O_8$) and remain in association with other minerals of the soils. This makes the soil qualify for the ferruginous tropical type according to D'Hoore (1968). Table 3 shows the elements that make up the minerals showing high concentration of iron in the soils within the range of 0.8 - 4.15% and high mean values of K (1.56%) for the wet-land soils. Elements like Zn, Th, Sc, Rb, Cr, Ce and Ba were relatively higher for Tudun Wada soils than others.

The highly leached up-land Samaru soil having a structurally sandy texture and less consolidated form, unlike the others, showed the least concentrations in the elements determined due to increased leaching of surface minerals. From the element concentration data it appears that the mineralogy of the basement rocks from which these soils derive may likely be similar as the Th/U ratios respectively (3.5, 3.4) appear slightly close (Adams and Weaver, 1958; Senftle and Keevil, 1947) for the Samaru and Tudun Wada soils respectively, with the wet-land *Fadama* soils having a lower value of 3.0 yet within the same range. For agrarian purposes therefore, the *Fadama* (wet-land) soils with high sorptivity should be preferred for crops that can withstand water-logged conditions. It is for this reason that farmers grow along the *Fadama* basins, crops like rice (*Oryza sativa*), sugar cane (*Saccharum officinarum*) and sweet potatoes (*Ipomoea batatas*) known to thrive better under these conditions since they require pro-longed saturated moisture conditions. for their growth. On the other hand farmers prefer planting cereals like maize (*Zea mays*) and shallow root-crops such as ground-nuts (*Arachis hypogaea*), on the upland Samaru soils. From an inventory of crops grown along the basins it appears that farmers have justified these results from the nature of crops grown in the three areas under study.

Table 3: *Concentration (g/g or as specified) of elements determined for the Zaria soils.

Elements	Nuclides	Eγ (keV)	Zaria (Nigeria) Soils			Range
			Samaru (Up-land)	T-Wada (Up-land)	*Fadama* (Wet-land)	
Antimony	Sb-124	602.7, 1691	1.31(0.11)	1.86(0.09)	2.14(0.13)	1.20 - 2.32
Barium	Ba-131	496	610.0(11.7)	493.1(41.1)	468.5(2.3)	466.1-
621.73Cerium	Ce-141	145.4	58.1(0.7)	176.7(1.2)	165.4(9.2)	57.46 - 77.86
Chromium	Cr-51	320	31.71(1.99)	58.15(1.24)	57.1(4.9)	29.72 - 62.08
Cobalt	Co-60	1173, 1332	2.04(0.27)	7.72(0.09)	6.99(0.19)	1.64 - 7.88
Caesium	Cs-134	604.7, 795.8	1.40(0.08)	3.34(0.07)	2.96(0.03)	1.35 - 3.41
Europium	Eu-152	1408	0.625(0.01)	1.15(0.01)	0.99(0.02)	0.62 - 1.16
Hafnium	Hf-181	482	35.41(0.41)	25.60(0.32)	25.16(2.42)	22.74 - 35.82
Iron(%)	Fe-59	1099.2, 1291.5	0.82(0.01)	4.07(0.07)	3.79(0.18)	0.80 - 4.15
Lanthanum	La-140	487, 1596.5	26.46(0.02)	62.02(0.70)	60.71(0.29)	26.44 - 62.95
Lutetium	Lu-177	208.4	0.59(0.01)	0.68(0.02)	0.62(0.03)	0.58 - 0.69
Neodymium	Nd-147	91, 531	20.21(5.91)	26.34(0.54)	24.66(0.94)	14.3 - 26.88
Potassium(%)	K-42	1524.7	1.46(0.01)	1.42(0.02)	1.56(0.01)	1.46 - 1.6
Rubidium	Rb-86	1076.6	71.66(2.11)	108.9(3.5)	98.39(5.67)69.55-	
112.33Scandium	Sc-46	889.3, 1120.3	3.65(0.14)	6.36(0.16)	6.07(0.28)	
Sodium(%)	Na-24	1368.5	0.01(1.0E-04)	0.02(0.003)	0.02(0.001)	0.01 - 0.02
Tantalum	Ta-182	1221.4	2.12(0.07)	3.89(0.09)	2.63(0.71)	2.05 - 3.98
Thorium	Pa-233	312	15.48(0.50)	26.50(0.63)	23.23(0.61)	14.96 - 23.83
Uranium	Np-239	228.2, 277.6	4.43(0.29)	7.88(0.61)	7.86(0.52)	3.76 - 8.48
Ytterbium	Yb-175	396.3	3.55(0.19)	4.44(0.24)	4.08(0.10)	3.36 - 4.67
Zinc	Zn-65	1115.5	6.2(0.2)	211.8(4.8)	188.9(0.9)	6.2-216.63

4. Conclusions

In this investigation, horizontal infiltration measurements under laboratory conditions were made for three Zaria (Nigeria) soils (Tudun Wada, Samaru, wet-land *Fadama*) of economic importance to farmers within the area studied. Data for diffusivity, water flux, sorptivity and concentration for elements in these soils were obtained. Since most of the plant root systems undergo lateral growth while the others consolidate the tap-root system, horizontal infiltration studies will assist our knowledge of hydro-trophic stimuli for root-systems. This study is particularly important for its usefulness in soil characterization as well as sensitizing agriculturists on soil water management problems. Further work and more sample sites, though cost prohibitive, should be taken in future, in order to obtain statistically important results for the region under study. That not withstanding, our work will serve as a research model for laboratory investigations of physical laws governing water transport in soils.

Acknowledgment

This work was supported by the *Kubanni River Basin Project Fund* of the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria. The International Atomic Energy Agency is hereby acknowledged for granting one of us Dr. I.O. B. Ewa, Fellowship at the Institute of Nuclear Techniques, Technical University of Budapest (TUB), Hungary, where the trace element analysis was carried out. The use of the reactor for neutron activation analysis and computing facilities such as the Monte Carlo Code from the University of Budapest is hereby acknowledged.

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