EFFECTS OF COMPACTION, MOISTURE AND DEPTH ON THE PARAMETERS OF THE KOSTIAKOV EQUATION

EFECTOS DE LA COMPACTACIÓN, HUMEDAD Y PROFUNDIDAD SOBRE LOS PARÁMETROS DE LA ECUACIÓN DE KOSTIAKOV

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Abstract

This report consisted of studying the effects caused by the soil physical characteristic, in the presence of wetness variations and structures-texture fluctuations, to the Kostiakov constants. The objectives were to investigate the effects of wetness, soil depth, and compaction on the Kostiakov constants "a", and "b". The experimental unit consisted of nine polyvinyl cylinders. Statistical analysis under a randomized block design with three replications and three factors: wetness with five levels, soil depth (0-15, 15-30 and 45-60) and compaction with three levels (0, 13 and 26 blows). The relation between the instantaneous infiltration versus compaction and bulk density were inversely proportional. The parameter "a" influenced infiltration more than "b". Soil texture and structure influenced "b" more than wetness. Wetness influenced "a" more than compaction and soil depth. Kostiakov parameters exposed physical relations to soil texture and structure.

Keywords: Surface response, proctor test, kostiakov equation theory analysis.

Resumen

Este reporte estudió los efectos causados por las características físicas del suelo, en presencia de las variaciones de la humedad y la textura-estructura fluctuante, a las constantes de Kostiakov. Los objetivos evaluaron los efectos de la humedad, profundidad y compactación sobre las constantes "a" y "b" de Kostiakov. La unidad experimental usó nueve cilindros. Análisis estadístico bajo diseño de bloques al azar con tres repeticiones y tres factores: humedad con cinco niveles, tres profundidades de suelo y compactación con tres niveles. Se concluyó que la relación entre la infiltración y compactación, infiltración y densidad aparente son inversamente proporcionales. El parámetro "a" influyó en la infiltración más que "b". La textura del suelo y la estructura influyeron en "b" más que la humedad. La humedad influyó más que la compactación y la profundidad del suelo en "a". Los parámetros mostraron relaciones físicas con la textura y estructura del suelo.

Palabras clave: Superficie de respuesta, método proctor, análisis teórico de la ecuación de kostiakov.

INTRODUCTION

This report considers to find out that the variance of soil physical and terra mechanics properties in the presence of soil wetness changes or drying and wetting conditions, may perturb Kostiakov parameters. According to Haghnazari *et al*. (2015) and Dingman, (2002) measurements must be collected during or close as possible to the irrigation event using a representative sample of the field area. Mara (2016) reported that pore diameter $\geq$ 30 microns (0.03 mm) hold no water due to the effect of the attractive force of gravity. Kostiakov (1932) indicated that the equation is no longer applicable once the characteristic steady infiltration rate has been attained. Infiltration variability poses a significant problem for the performance of surface irrigation systems. Not only it reduces the existing and potential irrigation performance, but it also limits the ability to specify improved irrigation strategies. The nature of soil properties does not facilitate direct measurement of the infiltration function. Hence,

there is a genuine need to estimate the parameters of the chosen infiltration function using measured field data. The objectives were to investigate the effects of wetness, soil depth and compaction on the constants "a" and "b" characteristic in the Kostiakov infiltration equation with a view of adapting this equation.

Theory

Poulovassilis *et al*., (1989) stated that many empirical or semi-empirical equations exist for describing the relationship between the cumulative infiltration and the infiltration time, during the process of vertical infiltration of water into the soil mass. Duru *et al*., (2005) suggested that Kostiakov was, apparently, the first to propose an empirical equation. One of the best-known models to assess the behavior of soil water infiltration is Kostiakov developed in 1932 (Kostiakov, 1932; Holzapfel and Matta, 2005; Forero, 2000; Weber and Apestegui, 2016). According to Ahuja *et al*., (2007) this equation applies only for early to intermediate infiltration times before gravity begins to dominate and the infiltration rate approaches a constant value. Kostiakov equation is valid when the infiltration rate is higher than the saturated hydraulic conductivity of the soil (Mazloom and Foladmand, 2013).

Kostiakov equation symbolized by Equation 1, "i" infiltration depth (cm) (also known as total infiltration depth, or infiltration rate, or cumulative infiltration, or cumulative infiltration depth, or cumulative infiltration rate, or infiltrated water since the beginning of infiltration, or steady-state infiltration rate or infiltration time) by length/hour, and the elapsed time (t) since the start of infiltration minute or hour, "a" and "b" are the fitting parameters (constant of empirical adjustment, a > 0 and 0 < b <1), "a" coefficient of infiltration rate, term that depends on the structure and soil conditions (a > 1); considered as an index of soil structure stability, "b" dimensionless parameter (0 - 1 agricultural soil), a time exponent and is a negative value; considered a measure of first-rate of infiltration and structural condition of the soil (Magnus and Adindu, 2014).

$$i = a*t^b \text{ (cm)} \qquad (1)$$

Kostiakov equation linearization is done by both equation sides logarithms application. The infiltration "i" is normally plotted versus time on a logarithm graph sheet (double-logarithmic scales) and the best-fit line obtained by the least-squares curve fitting technique. A plot of log(i) against log(t), gives a straight line whose slope gives the value of "b", while log(a) gives the intercept. The value of "a" is obtained from the anti-log(a) (Akinbile, 2010; Magnus and Adindu, 2014):

$$Log(i) = \log(a) + b*\log(t) \quad (2)$$

$$a = 10\log(a) \text{ equivalent to} = \log(10a) \text{ because } a = \text{antilog}(\log(a)) \quad (3)$$

According to Saito *et a*l., (2016) constant "b" has a negative and strong correlation. This constant does not have clear physical meaning, but when the "b" value is small, the infiltration rate rapidly decreases with time. Thus, "b" values were particularly small where there are horizons of low permeability. These "b" values enhanced the negative slope of the regression line. "a" measures infiltrability at the beginning of the infiltration process and results show that surface soil permeability was strongly correlated with the vegetation. Kincaid *et al*., (1969) found for three different soils (silt loam, sandy loam, and clay), that "a" ranged from 0.225 to 1.1 and "b" from 0.458 to 0.669. According to Adindu *et al.,* (2014); Al-Azawi (1985) and Moroke et al., (2009); "b" is accepted by most authors less than 1 (Al-Azawi, 1985; Moroke *et al.,* 2009; Adindu *et al*., 2014). Since the infiltration decreased with time, the exponent "b" considered negative; in this work varied -1 < b < 0. Analyzing Equation 1, when time tends to infinity, as "b" is negative, "i" would tend to zero instead of a constant value (different from zero). Fubara-Manuel and Otoko, (2015) found in loamy sandy soil in Nigeria, the values of "a", and "b", 0.62 and 0.01 correspondingly. Gosh, (1985) questioned, in the model, the value of "b" between zero and one. Mathematically, he proved that the value of "b" is greater than unity. Mbagwu, (1990) experimentally found that the value of "b" was consistently less than one. On real field plots, Roy and Gosh, (1982) reported that the infiltration rate was neither asymptotic with the time (t) axis, nor attained a zero value. Musa and Adeoye, (2010) found values of "b" that ranged from 0.37 to 1.79, and the infiltration equations obtained for the soils were: 0.41t1.38, 0.41t1.79, 0.50t0.37, 0.42t1.12 and 0.53t1.37, soil structure was not included. Soils that have a very stable structure have values of "b" greater than 0.6 and can reach 1.0 under conditions where gravity flow predominated (Rondón *et al.,* 1980).

Concurring, Swartzendruber, and Huberty (1958) defined "a" as a measure of the average infiltration rate for the first unit time interval and "b" as an indicator of the changes in the system of force with time; also, if "b" was close to 0.5, assumed that capillary forces were controlling infiltration, and that deviation of "b" from 0.5 was a measure of the relative importance of other forces and factors in controlling infiltration; similarly, gravity forces and hydraulic pressures, such as ponding, caused higher values for "b". Swartzendruber and Huberty, (1958) and Dixon, (1976) exhibited that "a" was storage during the first hour, and "b" the ratio which reflected the degree of storage abatement during the first hour, b = 1 indicated no abatement and b = 0 complete abatement; also manifested that the size of parameter "b" was inversely related to the number and intensity of active infiltration decay

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processes, and "a" was simply product of the first-hour time-weighted means for the hydraulic conductivity and the hydraulic gradient by Darcy's law at the soil surface.

The derivative of Equation 1 yields the instantaneous infiltration rate (I) indicating the infiltration depth per unit time t. "I" represents the rates of change. The second derivative produces the acceleration rate. The infiltration depth rate units are generally in cm•min-1, multiplied by 60 to convert to cm•h-1. The differential represents an infinitely small change in the variable i. It represents the relationship between a continuously varying quantity and its rate of change:

$$I = \frac{di}{dt} = b*a*t^{b-1} \quad \text{(cm·min-1) (4)}$$

$$di = (b*a*t^{b-1})dt \quad (5)$$

To test the Kostiakov model is necessary to study the basic speed of entry or basic infiltration (least value of f(t) in a finite time interval); defined as the value, when the rate of change of response for a standard period is 10% or less of its value; i.e., infiltration remains constant, after a certain period (Orjuela-Matta *et al.*, 2010; Rode, 1965; Holzapfel and Matta, 2005; Villalobos, 2008):

$$\frac{di}{dt} = -0.1*i \quad (6)$$

$$I = -0.1*a*t^b \quad \Rightarrow \quad (7)$$

$$a*b*t^{b-1} = -0.1*a*t^b \Rightarrow \quad t = -10*b \quad (8)$$

$$I_{BA} = a*(-10*b)^b \quad for \quad i = a*t^b \quad (9)$$

If basic infiltration IBA is in cm•min-1, multiplied by 60, IBA is obtained in cm•h-1. Equation 10 represents the time when the basic infiltration occurs.

$$I_{BA} = a*(-600*b)^b \quad \text{(cm·h-1) (10)}$$

Equation 11 represents the infiltration depth; named also, steady-state infiltration rate.

$$I_{INT} = i = a*t^b \quad \text{(cm)} \quad (11)$$

Equation 12 represents the total accumulated infiltration (IAC) when integrating i concerning the time

$$I_{AC} = \int_0^t i*dt = \int_0^t a*t^b dt \quad \text{An integral ponders an}$$

infinite sum of infinitesimal quantities.

$$I_{AC} = \frac{a}{(b+1)}*t^{b+1} \quad \text{cm·min-1}$$

$$I_{AC} = \frac{a}{60*(b+1)}*t^{b+1} \quad \text{(cm·h-1)} \quad (12)$$

Equation 13 represents the average o medium infiltration

$$I_{MED} = \frac{a*t^b}{(b+1)} \text{(cm)} \quad (13)$$

The parameters "a" and "b" are site-specific since they depend on texture, structure, vegetative cover, infiltrometer type, moisture condition, rainfall intensity, permeability, soil surface conditions and properties (Al-Azawi, 1985; Moroke *et al.,* 2009; Adindu *et al.*, 2014; Smith, 1972; Musa and Adeoye, 2010 Dixon, 1976; Swartzendruber and Huberly, 1958; Childs and Bybordi, 1969; Carvalho et al., 1999; Berndtsson and Larson, 1987; Kelishadi *et al.,* 2014; Dagadu and Nimbalkar, 2012). Giffobd, (1978) concluded, that it appeared that Kostiakov equation coefficients were related more to vegetation factors than to soil factors based on an analysis of data. Naeth *et al.*, (1991) established that the lower the value of "b", the flatter the slope and thus the lower the rate of decline of infiltration; and the greater the value of "a", the greater the first infiltration value. The equation has no physical basis and is non-homogeneous, but fits very well to the phenomenon of infiltration and has much use in irrigation. The model does not usually give good results for extended periods as observed in practice, which physically is not true and is at odds with the law of Darcy, for a longer time the ground would behave like a saturated medium and "i" should have values close to Kostiakov. A weakness of this model is that it does not predict a constant rate and last infiltration (Mbagwu, 1994). Fok, (1986) showed that the terms "a" and "b" had physical meanings although several authors have described it as empirical. Despite the weaknesses of the model, many researchers have used the model to study the infiltration processes in soils of the temperate and tropical regions (Bonell and Williams, 1986; Lai *et al.*, 1980; Mbagwu, 1987-1990). According to Rondón *et al.,* (1980-1985), the equation had been widely used in irrigation, mainly for its workability; now, several of the equations used in the design of surface irrigation method involve Kostiakov parameters. According to Sonaje, (2013), it describes the infiltration well at minor times but less right at large. No physical interpretation is possible of the constants "a", and "b" since they can only be obtained from field studies and curve-fitting. They cannot be derived from soil physical properties. This attributed to an empirical equation to implicitly account for the effects of factors not considered

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by physical equations. Fok, (1986) derived a set of infiltration equations of the form in which the constants related to the same soil parameters. Drawbacks to the equation are that the constants are dependent on first field conditions such as moisture content and crusting, and determined for each irrigation event. Also, the infiltration rate does not approach a constant value, at large times, which is a commonly accepted notion about infiltration behavior in infiltration practice (Roger, 1993).

MATERIALS AND METHODS

Sampling for the experimental analysis achieved on a sandy loam savanna soil in Monagas State, Venezuela, situated at a height of 147 meters and geographical coordinates of 9° 41' 33" north latitude and 63° 23' west longitude; with an annual rainfall of 1127 mm and a mean annual temperature of 27.5 ºC. Under typical savanna vegetation: *Curatella American (Dilleniaceae), Anacardium occidentale, Straw Hairy (Trachypogon and Axonopas sp), Byrsonima crassifolia Malpighiaceae, Hyptis suaveolens* Lamiaceae, Grasses and Cyperaceae among others. The soil area selected belongs to a Ultisol group of the family *Oxic Paleustults Isohipertérmic* in virgin soil conditions. Table 1 shows the physical characteristics and organic matter content. The particle size is in the range established by Rucks *et al*., (2004) and CIVIL2121 (2012). Figure 1 shows the sampling side position. These soils occupy a large Venezuelan agricultural area engaged in the exploitation of many items, with fertilization, such as maize, sorghum, cassava, and pasture. The lab study achieved in the Soil Physical and Mechanical Laboratory of the University of Oriente, Nucleus of Monagas, Juanico; campus located according to UTM E482908.31 N-1076748.00 and E-482924.24 N-1076752.51.

Table 1. Texture and organic matter analysis. Jusepín, Monagas State.

| Components | Horizons (cm) | | | |
	0-15	15-30	45-60	Diameter
	%	%	%	mm
Very coarse sand	1.01	1.31	0.20	1.41
Coarse sand	6.18	5.71	2.69	0.72
Medium sand	19.1	14.26	13.34	0.37
Fine sand	32.38	24.77	26.33	0.151
Very fine sand	15.0	13.11	15.81	0.07
Total sand	73.67	58.66	58.37	
Silt	16.13	17.14	29.43	0.053
Clay (kaolinite)	10.2	24.2	12.2	0.024
Organic matter	1.20	0.61	0.45	
Textural class	SCL	SCL	SCL	

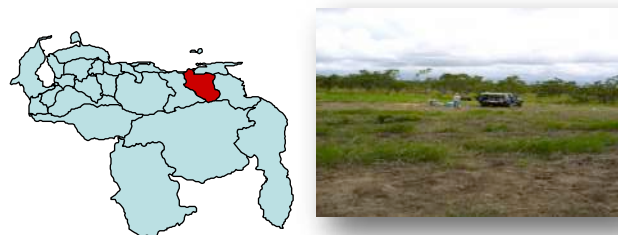Source: Labsea, Eudoca, 2010. UDO, Monagas
SCL sandy loam

Figure 1. Sampling side position

The experimental unit (Figure 2) consisted of 9 polyvinyl chlorinated cylinders, 15.24 cm diameter and 20 cm height. A soil volume of 2.50 kg/cylinder. Statistical analysis under a randomized block design with three replications; with two factors: humidity with five levels (3, 6, 9, 12 and 15%) and Proctor compaction with three levels (0, 13 and 26 blows). The shear tension measurement obtained with a manual in-situ vane shears tension tester (Leiva, 2011; Smith, 2011; Vásquez, 2011).
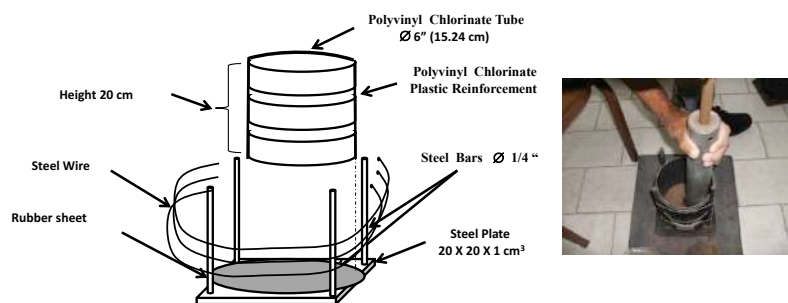

Figure 2. Experimental unit and Proctor tester

The Proctor compaction test is an experimental laboratory method for determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum bulk density. The original test, most commonly called the standard Proctor compaction test (ASTM, 2009).

A piece of tape, stuck on the cylinder wall, with millimeter-scale allowed assessments. The measurements consisted of finding the sheets of infiltrated water into the cylinders, with at least 10 readings per time intervals ranging between 1 and 60 minutes. The regression analyses curve fit and the multiple regression analysis with backward steps were used. The Durbin Watson statistic test autocorrelation always considered between 0 and 4. If the Durbin–Watson is substantially less than 2, there is evidence of positive correlation. As a rough rule of thumb; if Durbin–Watson is less than 1.0, there may be a cause for alarm. If > 2, successive error terms are negatively correlated (Montgomery *et al*., 2001). Table 2 shows the terminology employed.

Table 2. Terminology employed

a and b	Kostiakov's equation parameters
BL	Block
CO	Compaction blows
CV	Coefficient of variance
DF	Degree of freedom
F	*F*-statistical significance
i	*Infiltration depth*
I_{BA}	Basic infiltration cm·h^{-1}
MS	Mean sum of squares
P	*P*-value significance
PR	Soil profiles
SS	Sum of Square
w	Soil wetness
w_{op}	Optimal wetness
τ	Shear tension
τ_{op}	Optimal shear tension
ρ_S	Bulk density
ρ_{Sop}	Optimal bulk density

RESULTS AND DISCUSSIONS

Se presentarán en un solo capítulo, donde el lector debe
The savanna soil terramechanics characteristics, Figure 3,
disclose bulk density versus compaction blows, soil
wetness, and soil depth, and Figure 4 presents the soil
shear tension and bulk density versus soil wetness. This
recognizes the wetness influence upon the physical and
terramechanical characteristics triggering soil physical

variability. These factors affected infiltration. Observe in
Figure 4 that at low wetness, the shear tension and bulk
density practically did not exist, the soils crumble or
powder; the soil particle adhesion (due to water)
disappears. Capillary forces can exceed 10 kPa for
particles smaller than 0.02 mm and 1 MPa for particles
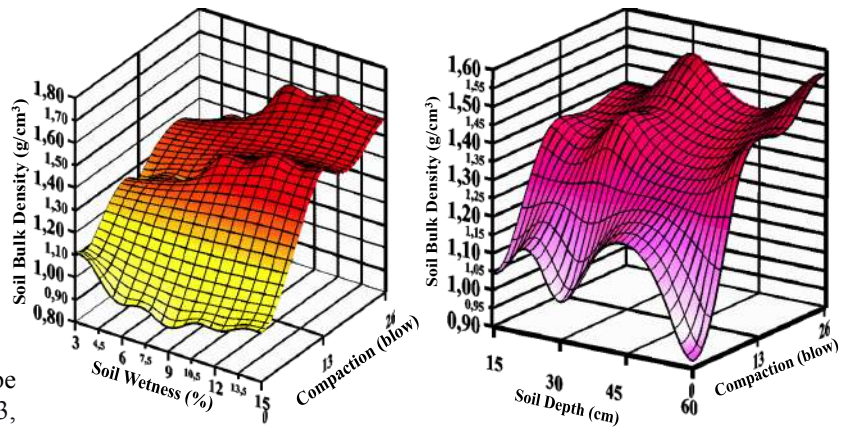<0.0002 mm (Santamarina, 2001).

Figure 3. Soil bulk density versus compaction blows,
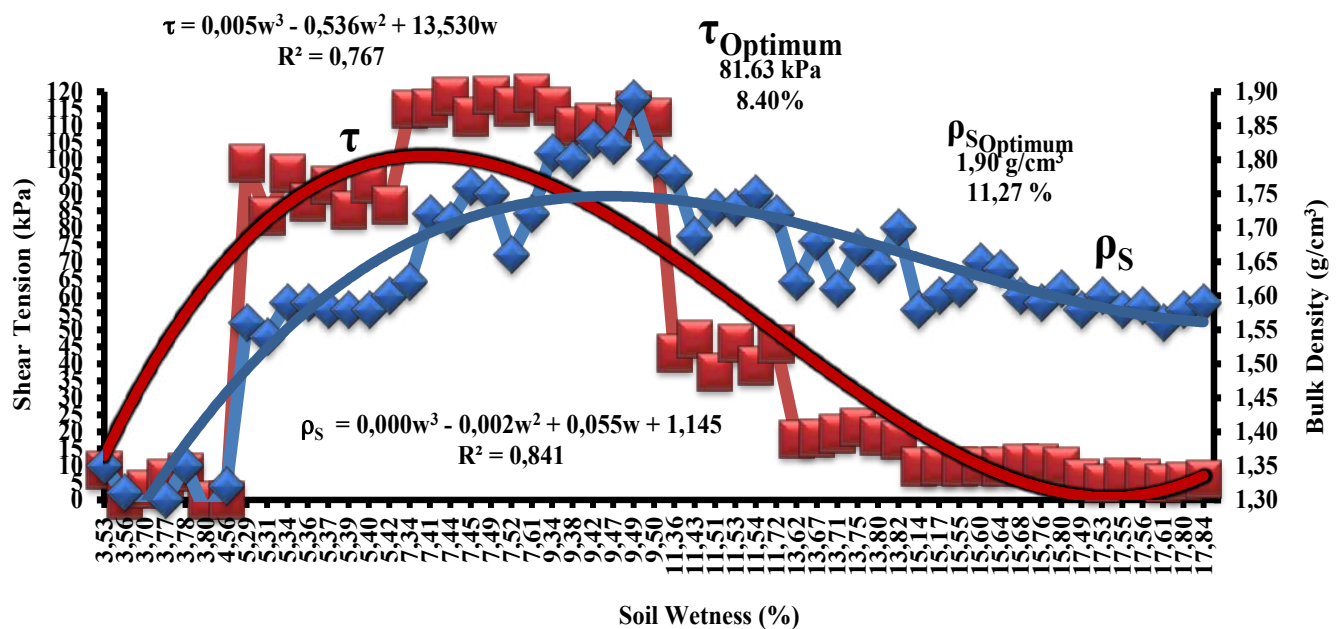soil wetness and soil depth

Figure 4. Shear tension and bulk density versus soil wetness for 15 cm soil profile

The τ and ρ_S versus w presented in Table 3 shows the statistical results where it could be observed effects on Kostikove due to soil structure variability.

Table 3. Regression analysis, with 55 total cases, of τ and ρ_S versus w

τ versus w	
$\tau = 19.428*w - 1.156*w^2$	
R^2 79%, adjusted R^2 78% Estimated without constant term	0.0000 ANOVA
Coefficients significance 0.000	
The optimum value of $\tau_{op} = 81.63$ kPa for $w_{op} = 8.40\%$.	
ρ_S versus w regression analysis curve fit	
$\rho_S = 0.338*w - 0.015*w^2$	
R^2 99%, adjusted R^2 89.9	0.000 ANOVA
0.000 significance for w and w^2 coefficients	
$\rho_{Sop} = 1.90$ g/cm^3 for $w_{op} = 11.27\%$	

Soil infiltration correlated to soil physical and texture exists acknowledged by many studies. Amin (2005) and Michael (2010) noted that the factors affecting infiltration rate (i) of a soil included, among others, the nature of the soil, humus content, soil surface roughness, moisture content, rainfall intensity, vegetation type, and cover, hydraulic characteristics, and permeability (related to soil texture and structure). Failure to consider adequate

infiltration process may result in non-uniform distribution of water in the field as well as excessive water loss due to deep percolation and runoff. The antecedent water content of the soil influences the sorptivity or capacity of a soil to absorb (suck up) water. According to Jagdale and Nimbalkar (2012), different soil conditions affect the soil infiltration rate. Compacted soils have a low infiltration rate which is prone to runoff.

The multiple regression analyses for I_{BA} and the independent fitting variables arrangements a, b, a*b, a^2, b^2 and a*b^2 results are presented in Table 4 showing influences on I_{BA}

Table 4. Dependent variable I_{BA} and the independent variable a, b, a*b, a^2, b^2 and a*b^2

$I_{BA} = 1,02596*a + 4,07465*a*b - 1,68532*b^2 + 4,47057*a*b^2$		
R^2 99.985, adjusted R^2 99.98%	0.0000 ANOVA	Durbin-Watson 1.43
Coefficients significance 0.000 for all		
Greater "a" influence. The "b" values kept practically steady for each value of "a"		

The parameters "a" and "b" variability effect on infiltration in a savanna soil, Figures 5, showed a greater "a" influence. The "b" values kept practically steady for each value of "a".
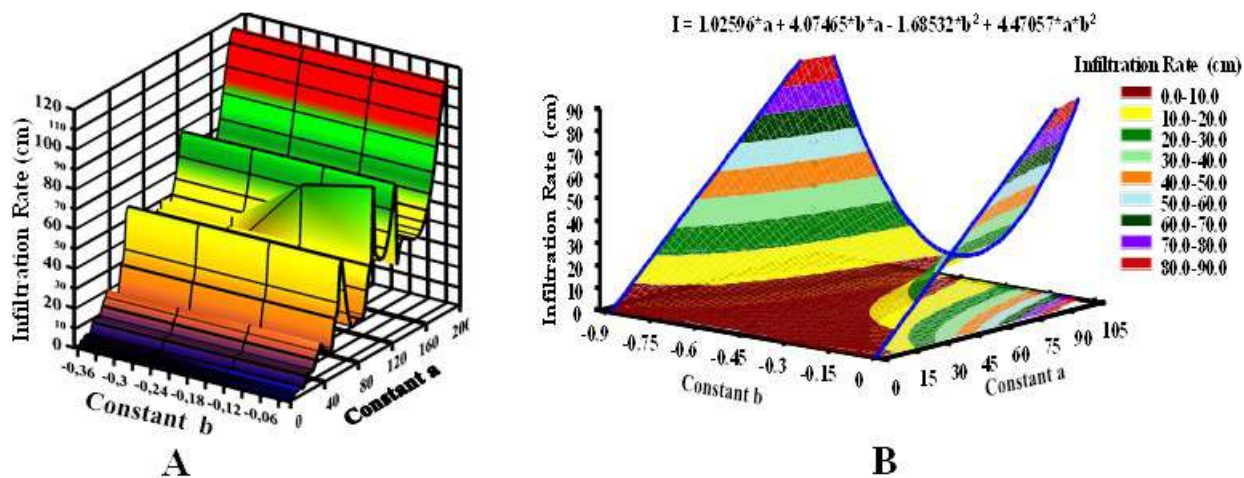

Figure 5. The infiltration rate against constants ¨a¨, and ¨b¨

Coefficients "a" and "b" fluctuations depend on many factors such as soil type, time, ancient moisture and soil hydraulic conductivity (Azad *et al*. 2016; Harteli, 1992). According to Weber and Apestegui (2016), if "b" increases, the initial infiltration rate decreases and basic infiltration rate increases; and if "a" increase, both the initial rate and the final infiltration increases. High value parameters models are probably due to high levels of sand

(75.7%). The large range of the variation of coefficient "a", demonstrated considerable spatial variability in the studied area (Azad *et al*. 2016; Duan *et al*. 2011; Zolfaghari *et al*. 2012; Mirzaee *et al*. 2014). Bresler *et al*. (1984) found that between 24-45% "a" variability could be related to sand content and 10-25% explained by the interaction between electrical conductivity and sand amount. Nestor (2006) found for parameter "a", a value of

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76.88 for sandy loam. Adindu *et al.* (2014) found for some sandy loam soils for "b" values of -0.48, -0.50, - 0.54, - 0.59, - 0.62 and - 0.84, indicating that the soils saturated at that time of the year (wet season); while the 'a' values ranged from 0.35 - 2.47. Girei *et al.* (2016) considered the values of "a", and "b" very high in almost across all the treatments. The higher the value of "b", the steeper the slope and the greater the rate of infiltration decline. The greater the value of "a", the greater the initial infiltration value (Naeth *et al.*, 1991; Turner, 2006). The value of "b" was consistently less than one. Mbagwu (1990) reported similar findings. Mbagwu (1994) found that the soil properties with the greatest influence over the "a" term are the effective porosity and bulk density. According to Kanya (2007) the value of "a" affects the value of "b" depending on the field data. In this work, "b" as a function of ¨a¨, resulted $b = 5E\text{-}07*a^3 - 0.0002*a^2 + 0.0143*a -$

0.3666 with $R^2 = 80.21\%$. Musa and Nosa (2003); Lili et al. (2008); Adindu *et al.* (2014); Azuka *et al.* (2013); Hunsaker *et al.* (1999); Zhuo *et al.* (2009); Mbagwu (1994); Saxton *et al.*, (1986); Michael, (1978); Kanya (2007); Maheshwari (1997); Mazloom and Foladmand (2013); Arab *et al.* (2014); Adindu *et al.* (2014); Al-Azawi (1985) noted that soil infiltrability influenced by soil structure, texture, moisture content, initial water content, structure and surface cover conditions, organic matter content, bulk density, clay and fine sand content (texture), wheel furrows, season period, hydraulic conductivity and microporosity contributed immensely to the variation in the infiltration characteristics of the soils.

The "b" ANOVA (Table 5), showed significance with respect to CO, w, PR, CO*w and w*PR

Table 5. Constant "b", analysis of variance for BL, CO, w, PR and the combined effects: BL*CO, BL*w, BL*PR, CO*w, CO*PR and w*PR of a savanna soil of Monagas State of Venezuela.

Sources	DF	SS	MS	F	P
Block (BL)	2	0.02376	0.01188	1.25	0.2922
Compaction (CO)	2	0.13147	0.06573	6.90	**0.0016**
SOIL WETNESS (w)	4	0.63076	0.15769	16.56	**0.0000**
SOIL DEPTH (PR)	2	0.20237	0.10118	10.63	**0.0001**
BL*CO	4	0.02206	0.00552	0.58	0.6785
BL*w	8	0.10931	0.01366	1.43	0.1933
BL*PR	4	0.02206	0.00552	0.58	0.6785
CO*w	8	0.75621	0.09453	9.93	**0.0000**
CO*PR	4	0.06578	0.01645	1.73	0.1512
w*PR	8	0.21516	0.02690	2.82	**0.0078**
Error	88	0.83802	0.00952		
Total	134	3.03128			
Mean			-0.2016		
CV	48.41		Alfa: 0.05		

The multiple regression analysis of CO*w effects on the dependent "b" and the independent variables CO, w, CO*w, CO^2, w^2, CO^2*w, $CO*w^2$, CO^2*w^2, Table 6 and Figure 6 shows that the greatest value for "b" happened for w and CO higher values, validated in Table 6.

Table 6. The multiple regression analysis of CO*w

The combined effect CO*w on the dependent variable "b"	
$b = -0.231256*CO + 0.0382744*CO^2 + 0.00017692*CO^2*w^2$	
R^2 92.2, adjusted R^2 90.79% without constant term	0.0000 ANOVA
Coefficients significance 0.000 significance for w and w^2	

In the response surface chart of Figure 6, "b" decreased with respect to compaction at low wetness; but, increased at higher wetness. "b" varied with soil compaction and soil wetness

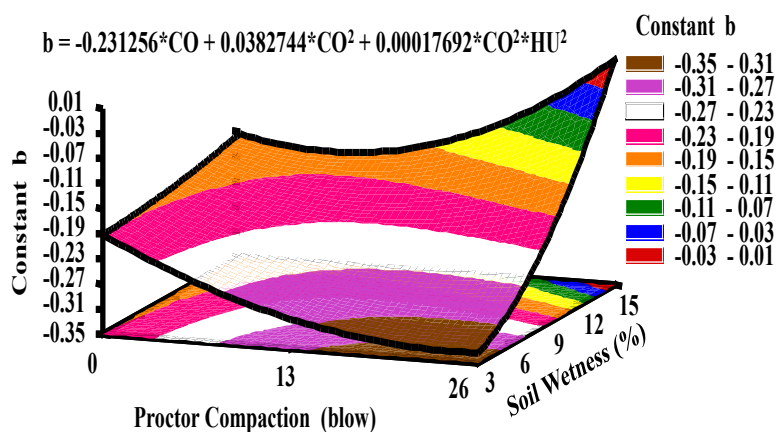According to Negro (1998) constant "b" gives an idea of the soil water content at the initial process

Figure 6. Surface response draft of empirical constant b versus CO and w

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The w*PR multiple regression analysis and results related with dependent variable "b" and the independent variables PR, w, PR*w, PR^2, w^2, PR^2*w, PR*w^2, PR^2*w^2 are presented in Table 7. Figure 7 shows that the greatest value for "b" happened for 15% wetness and 15 cm depth, validated in Table 7.

Table 7. The multiple regression analysis of w*PR

| The multiple regression analysis of w*PR versus "b"	
b = − 0.00868566*w - 0.0105247*PR + 0.000728146*w*PR	
R^2 94.72%, adjusted R^2 93.83% without constant term	0.0000 ANOVA
P significance of 0.0450, 0.0000 and 0.0005 respectively	
Durbin-Watson 2.29	
In the response surface chart of Figure 7, "b" with respect to w and PR, with the highest value at 15% water range for all soil depth. It could be supposed that constant "b" highest values indicated high soil wetness	
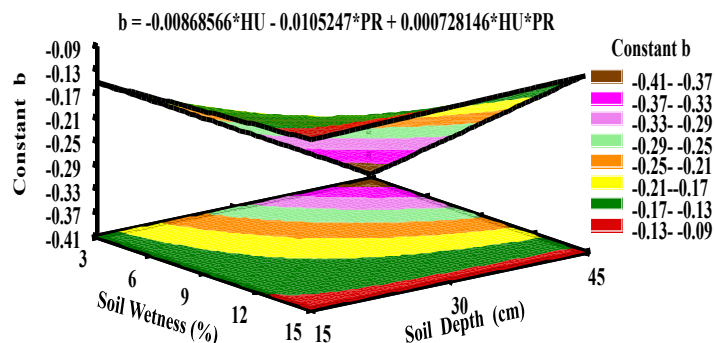
Figure 7. Surface response chart of constant "b" versus soil w and PR

The "b" indicates how the infiltration rate reduces with time; therefore, it depends on the soil structure changes, resulting from wetting. A small value of "b" indicates that the structure is not stable so the infiltration rate reduced due to structure changes.

The analysis of variance of "a" (Table 8), showed significance with respect to CO, w, PR, CO*PR, CO*w and w*PR.

Table 8. Constant "a", analysis of variance for BL, CO, w, PR and the combined effects: BL * CO, BL*w, BL*PR, CO *w, CO*PR and w*PR of a savanna soil of Monagas State of Venezuela.

Constant a					
Sources	**DF**	**SS**	**MS**	**F**	P
Block (BL)	2	185	92.5	0.44	0.6448
Compaction (CO)	2	51226	25613.1	122.11	**0.0000**
SOIL WETNESS (w)	4	8550	2137.4	10.19	**0.0000**
SOIL DEPTH (PR)	2	2771	1385.5	6.61	**0.0021**
BL*CO	4	365	91.4	0.44	0.7826
BL*w	8	633	79.1	0.38	0.9302
BL*PR	4	706	176.4	0.84	0.5029
CO*w	8	15120	1890.0	9.01	**0.0000**
CO*PR	4	9925	2481.2	11.83	**0.0000**
w*PR	8	5588	698.5	3.33	**0.0023**
Error	88	18459	209.8		
Total	134	113527			
Mean			21.931		
CV	66.04		Alfa: 0.05		

The multiple regression analysis of w*PR effects on the dependent variable "a" and the independent variable: w, PR, w*PR, w^2, PR^2, w^2*PR, w*PR^2, w^2*PR^2 is presented in Table 9. Figure 8 shows that the greatest value for "a" happened between 9-12% w and 15-30 cm PR, validated in Table 8.

Table 9. The multiple regression analysis of w*PR effects on "a"

The combined effect w*PR effects on the dependent variable "a"	
a = 28.2626*w - 1.47911*w*PR - 1.9994*w^2 + 0.0223972*w*PR^2 + 0.110408*w^2 *PR - 0.0016*w^2*PR^2	
R^2 97.08%, adjusted R^2 95.46% without constant term	0.0001 ANOVA
Coefficients significance 0.001, 0.0015, 0.0003, 0.0026, 0.0022, and 0.0035 respectively	
Durbin-Watson 1.89	
In the response surface chart, Figure 8, "a" varied with respect to w and slightly with PR, with the highest value around 15-30 cm and 9-12%	

$$a = 28.2626*HU - 1.47911*HU*PR - 1.9994*HU^2 + 0.0223972*HU*PR^2 + 0.110408*HU^2*PR - 0.0016*HU^2*PR^2$$
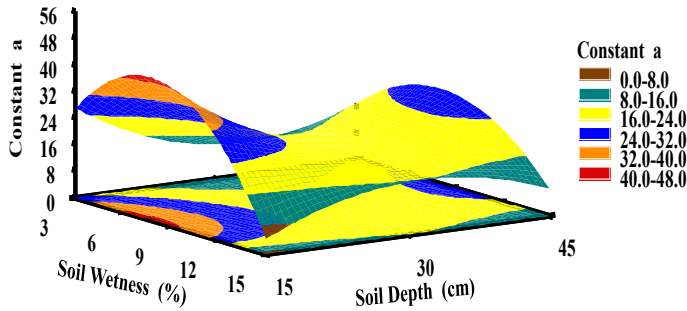

Figure 8. Surface response chart of constant "a" versus w and PR

The CO*PR multiple regression, along with the dependent variable "a", generated a model that included PR, CO^2*PR, $w*PR^2$ and w^2*PR^2 presented in Table 10. Figure 9 shows that the greatest value for "a" happened for 45 cm, and 0 soil CO; also, validated in Table 9.

Table 10. The multiple regression analysis of CO*PR related with "a"

Dependent variable "a" versus CO*PR	
$a = 1.03576*PR - 0.00103333*CO^2*PR - 0.00203549*CO*PR^2 + 0.000072063*CO^2*PR^2$	
R^2 99.82%, adjusted R^2 99.68% without constant term	0.0000 ANOVA
Coefficients significance 0.0000, 0.0021, 0.0001 and 0.0002 respectively	
Durbin-Watson 2.68	
In the response surface chart of Figure 9, "a" varies with respect to CO slightly compared to PR, with the highest value at 45 cm and 0 CO	

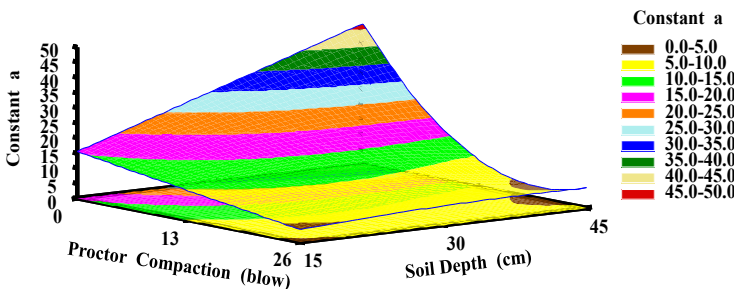$$a = 1.03576*PR - 0.00103333*CO^2*PR - 0.00203549*CO*PR^2 + 0.000072063*CO^2*PR^2$$

Figure 9. Surface response chart of constant ¨a¨ versus CO and PR

The multiple regression analysis of CO*w along with the dependent variable "a", generated the model a = 10.68*w − 1.50*C0*w − 0.45* presented in Table 11. Figure 10 shows that the greatest value for "a" happened for w between 6 and 9 %, and 0 CO, validated in Table 10.

Table11. The multiple regression analysis of CO*w along with "a"

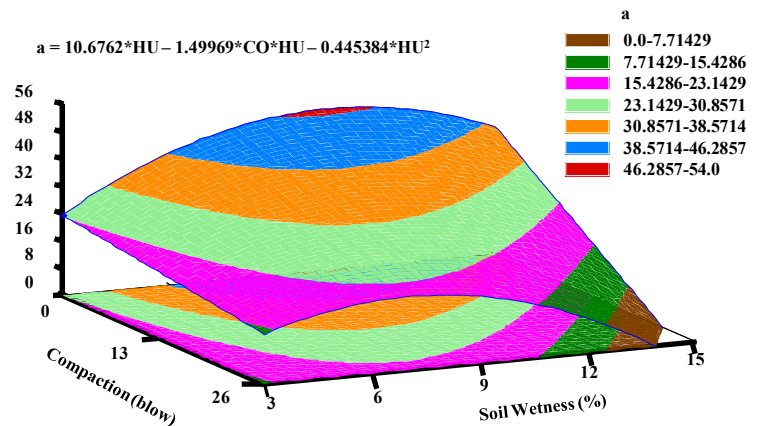| Model generated	
$a = 10.6762*w - 1.49969*CO*w - 0.445384*w^2$	
R^2 82.7%, adjusted R^2 79.55% without constant term	0.0001 ANOVA
Coefficients significance 0.0001, 0.0079 and 0.0036 respectively	
Durbin-Watson 2.15	
In the response surface chart of Figure 10, "a" varied with respect to CO slightly compared to w, with the highest value between 6 and 9 % and 0 CO	

$$a = 10.6762*HU - 1.49969*CO*HU - 0.445384*HU^2$$

Figure 10. Surface response chart of constant ¨a¨ versus CO and w

The results show that "a" and "b" Kostiakov terms disclosed physical meaning. Fok (1986) showed that the terms of the Kostiakov model have physical meanings even though several authors have described it as empirical. According to Adindu *et al.* (2014), the infiltration constants decay, including negative values obtained for saturated soils, happened when experiments was conducted under many rains. Do not use freely the equations forms adopted in this study in any soil unless the constants characteristic for that particular soil is first determined. The Durbin Watson statistic tests auto correlation considered, resulted suitable.

CONCLUSIONS

The parameter "a" showed greater infiltration influence than "b". The "b" values kept practically steady for each value of "a". The parameter "b" decreased with respect to compaction at low wetness; but, increased at higher wetness standards. The relation between the instantaneous infiltration and compaction, infiltration and bulk density were inversely proportional. Wetness influenced inversely shear tension. Compaction influenced "b" more than wetness. Depth influenced "b" more than wetness. Wetness influenced "a" more than depth. Depth

influenced "a" more than compaction. Wetness influenced "a" more than compaction. Soil texture and soil structure were the properties that most influenced. The greatest value for "b" happened for 15% wetness and 15 cm depth. The "a" analysis of variance, showed significance with respect to CO, w, PR, CO*PR, CO*w and w*PR. There are not studies deriving the Kostiakov constant from soils physical conditions, but they are influenced by its changes caused by wetness perturbation's.

ACKNOWLEDGMENT

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