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HYDRAULIC CONDUCTIVITY UNDER FORESTS
ONE KEY FOR WATER MANAGEMENT

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Abstract: Hydraulic conductivity under the soil of forests is related to sub-surface flows. It sought to know these behaviors and their differences, a fact that has great importance in the water management and sustainability of basins. Experimental one-hectare areas were characterized in forests of *Cupressus lusitanica, Eucalytus globulus and* natural forest in the San Cristobal River basin, Bogota, and fifty-four inverted blast hole well trials were conducted. Sand determined the characteristic curves of the infiltration velocity and according to them is calculated on the saturated hydraulic conductivity. The data obtained have the limitations of normal human errors in their obtaining, since these are tests carried out with very simple devices that do not represent a high degree of accuracy, a fact that is partly corrected by the significant number of tests carried out. No differences in saturation infiltration speeds were observed. It was verified that there were no significant differences in saturated hydraulic conductivity, with a probability of 0.01. It is apparent from this research that sub-surface root systems of undergrowth species can reduce hydraulic conductivity in the sub-soil by up to 71% on average by the effect of air entrapment that prevents total saturation of soil pores, a fact that could influence groundwater flow and erosion processes among others.

Keywords: Sub-surface flows under forests, infiltration, water management.

INTRODUCTION

JUSTIFICATION

Hydraulic conductivity is an indicator of the measurement of water mobility within the soil that serves in the knowledge of aquifer hydrodynamics for exploitation and management in the supply of drinking water or irrigation. It is useful to know about the interaction of surface water, groundwater, the assessment and estimation of the recharges and in groundwater quality studies. (Donado, 2004).

Knowledge of hydraulic conductivity provides in the study of precipitation-infiltration-recharge models, such as flows in the partially saturated area, and knowledge about their sub-surface flows is important in the dynamics of underground hydraulics and the transport of contaminants.

Given the implications of hydraulic conductivity in the process of sub-soil flows, it is necessary to specify what this behavior is like under each of the forest kinds under study, what differences there are between them, and how they would contribute to the water management of a basin.

OBJECTIVES

The objective was to study the behavior of hydraulic conductivity under the forests of *Cupressus lusitanica, Eucalytus globulus and* natural forest in the basin of the San Cristobal River and the variables that come to differentiate them and to find the main reasons that make this process different in each case, considering that this knowledge will allow further research to identify the relationship of hydraulic conductivity with water management that can be given to a basin.

THEORETICAL FRAMEWORK

This research is particularized in the sub-surface flows that occur under plant coverings, and which relate to hydraulic conductivity, which are affected, in addition to the type of soil, by the characteristics of sub-surface root systems, the content of organic matter in the field, the slope and the soil configuration among others. Also associated with the behavior of hydraulic conductivity aspects such as the transmission of water within soil, its storage capacity, the characteristics of the permeable medium and the flow of water through the soil profile (Philip, 2006); (Lal and Shukla, 2004) and (Terlien,1998).

Darcy formulated the physical law on the movement of water through the ground, where he says that the speed of the water "v" flowing in a porous medium is directly proportional to the hydraulic gradient "∇h". The water moving in a porous medium does so in the opposite direction to this gradient and at a speed "v" proportional to it. The proportionality factor is hydraulic conductivity "K", and depends on the nature of the medium and its degree of saturation (Lambe and Whitman, 1997)

$$v = -K\nabla h \qquad (1)$$

Water moves through the ground depending on the resistance of the soil matrix to the flow of water, and the forces of water on the ground; these factors are considered in Darcy's law. Flow occurs in saturation conditions if the matrix potential of the soil is zero, which corresponds to 95% of the pores filled with water and the rest with the air trapped.

In non-saturates soils, Darcy's law is complied with by considering that hydraulic conductivity is a function of the volumetric moisture content of the soil; Childs and Collis – George tested it experimentally. They are based on the consideration that fluid drag on the air-water interface is negligible, (Luna et al, 2005).

The general support of hydraulic conductivity was studied by Richards, Moore, Childs and Collis-George, (Luna et al, 2005). They determined that hydraulic conductivity decreases with soil moisture content based on:

The flow cross-section decreases with soil moisture.

Reducing soil moisture increases the size of large pores.

The hydraulic conductivity of the soil varies directly proportionally to the square of the radius of the ducts through which the water flows, and the soil moisture changes in direct proportion to the first power of that radius, and consequently the hydraulic conductivity will decrease faster than the decrease of soil moisture.

Regarding the speed of infiltration there are theoretical models with physical basis such as Philip's, which take into account Darcy's laws of mass and conservation of energy law; semi-empirical models such as Horton's, which use simple forms of the continuity equation and the accumulated infiltration-infiltration speed ratio hypothesis and empirical models that are based on field or laboratory measured data such as Those of Kostiakov and modified Kostiakov (Guevara and Marquez, 2010).

There is great uncertainty about the different methods of calculation and measurement of hydraulic conductivity (Donado, 2004). This can be determined in the field for the unsaturated area by means of the inverted sweeping well method, in which instead of measuring the recovery speed of the water table the rapid decrease of the water level in the well is measured (Luna et, 2005).

Unlike the infiltration capacity measured and evaluated in the field, the flow that is measured for hydraulic conductivity has no horizontal restriction, using the swept well, while for the infiltration capacity the descent of the sheet is measured, once the water enters the ground, but its internal flow is restrictive horizontally, using the concentric rings method.

Studies on hydraulic conductivity in Japan found that it gradually decreases as soil depth increases, and no significant correlations were found between hydraulic conductivity and maximum infiltration speed. The correlation value was low, and these same results were obtained in previous similar studies. This can be attributed to differences between species and site variability. This type of study allows to locate the sites where gravitational erosions can occur in mountain areas. (Morikawa-Sakura, Yoshitakaba, 2014).

HYPOTHESIS

This research is based on the hypothesis that hydraulic conductivity under the soil of forests is a process that is different under each type of forest and affects the dynamics of the waters in the sub-soil of a watershed.

METHODOLOGY

STUDY AREA

The San Cristóbal River basin is in the south east of the city of Bogotá over the eastern mountain range of the Andean system, within a rural area, established as a forest reserve with altitudes between 2850 and 3450 m.s.n.m. Figure 1. It is composed of three micro basins where in all there are forests of *C. lusitanica* (cypress), *E. globulus* (eucalyptus) and natural forest, which are in different percentages in each of them. For each tree species an experimental plot was established, and in total three, distributed in such a way that each micro basin corresponded to a plot of different species, but with similar characteristics of soils and climatological.

The average annual rainfall is 1220 mm. (El Delirio rainfall-pluviographic station at 3,000 m.s.n.m., period 1933-2017), with an average temperature of 13.3˚C (Vitelma weather station, at 2800 m.s.n.m., period 1981-2017). Both stations belong to the Bogota Aqueduct and Sewerage Company [10]. "EAAB" (EAAB, 2016).

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In the forest of *C. lusitanica* (ciprés), much of the area is free of undergrowth, but in return there is an important organic layer on the ground, with abundant contribution of acicles, since it is a very mature forest, planted without any design or subsequent management, but that is in good condition.

The forest with the cover of *E. globulus* (eucalyptus) is very populated by *Chusquea* sp. (chusque). It is a forest planted as old as *that of C. lusitanica* (cypress).

The natural forest has the greatest variety of species compared to the other forests and is of such density that between the chusque, which also predominates, and the other species, there are few free spaces left. The *Weinmannia tomentosa* (encenillo) was used as a reference tree. (Table 1).

Table 2 presents the most common species in undergrowth, which also details the total number of different species in each forest, and the number of plants in total per hectare of forest.

The area is made of sandstones and clays with varied compaction states. Geological formations in the study area belong to the upper Cretaceous age. They are the Guadalupe Formation with limestones and hard sandstones, the Guaduas Formation with clay and limolites, the Cacho Formation with sandstones and the Quaternary Formation that is of alluvial and fluvio-glacial accumulations (Van der Hammen, 1963).

The morphology and orientation of the rocky structures present in the Cerros Orientales de la sabana de Bogotá induce the recharge of groundwater, improving the sustainability of water flows in the savannah of Bogota. In the Eastern Hills an infiltration of 200 to 300 mm/year is estimated (Patiño and Osorio, 2011).

The soils have amorphous mineral materials from volcanic ash, in coluvial, alluvial and fluvioglacial accumulations (De

Micro basin	Species of reference	h (m)	Dap (m)	D cup (m)	Density (No./ha)	Main Undergrowth Species
Palo Blanco	*Cupressus lusitanica*	25-32	0.92	2.5	1166	*Chusquea* sp,
Osa	*Weinmannia tomentosa*	12-17	0.08-0.27	6.0	2672	*Chusquea* sp, *Myrcianthes leucoxyla (large arrayan), Myrsine sp. (hayuelo),* *Alnus acuminata (aliso)*
Upata	*Eucalyptus globulos*	20-30	0.70	3.0	1000	*Chusquea* sp

Table .1. Dimensions of reference tree species

Forest	Species in major No.	No. total species	No. total/Ha.
Cupressus lusitanica	*Pennisetum_sp.* *Elaphoglossum_sp.* *Syzygium_paniculatum_Gaertn.* *Geraniaceae_Juss.*	16	96667
Eucalytus globulus	*Munnozia_cf._Senecionidis_Benth.* *Drimys_granadensis_L.F.* *Begonia_sp.* *Chusquea_scandens_Kunth*	8	86667
Natural forest	*Polystichum_sp.* *Phenax_sp* *Peperomia_sp.* *Symplocos_sp.*	18	153333

Table .2. Undergrowth species

las Salas and García, 2000).

From the obtaining of nine cylindrical samples taken at 0.60 meters deep in each representative area of 254 m^2 for each type of forest, by reason of a sample for each point where the tests were carried out; the texture was evaluated, identifying these soils as sandy francs and francs, with permeability of 13 to 25 mm/h. Texture similarity could be found in experimental areas.

The relative density of soils under the plant cover in question is low, with values from 0.3 to 0.7 and their porosities range from 60 to 75 % with a vacuum volume of 55 to 65 %, according to measurements up to one meter deep (García, 2007).

On the soils under the plant coverings under study there is a thick organic layer that acts as a sponge that captures some of the water that reaches the soil, called the forest floor (Tobón et al, 2000).

According to the identified characteristics of soils in experimental areas, taxonomically classified, according to the United States Department of Agriculture -USDA, in the Order of the Inseptisoles, of recent volcanic origin, with undefined characteristics. They are soils of low temperatures that can develop in humid climates, with low rates of organic decomposition, have accumulations of aefatic clays and an acidic pH (De las Salas and García, 2000).

EXPERIMENTAL DESIGN

In this project the experimental areas were well defined and characterized but the results derived from this study cannot be generalized, given that variability can be presented in the behavior of hydraulic conductivity on larger surfaces, but an accuracy can be made on the differences that lie under the forests studied by the conditions of each species, and the similarity of the soils of the experimental areas.

In each type of forest, a representative tree was identified at a central site around which a circular plot of 9 meters in diameter was delimited. Radial lines were drawn every 120 degrees around each representative tree, and on them, the sites of the sweeping well tests were located, at distances of 3 meters, 6 meters and 9 meters from the representative tree. At each site, two replicates were made per trial, for ten and eight trials per forest, for a total of fifty-four experimental trials. (Figure 1).

Despite the reference of a representative tree, there is no orderly design of the forests there but the trees are randomly planted,

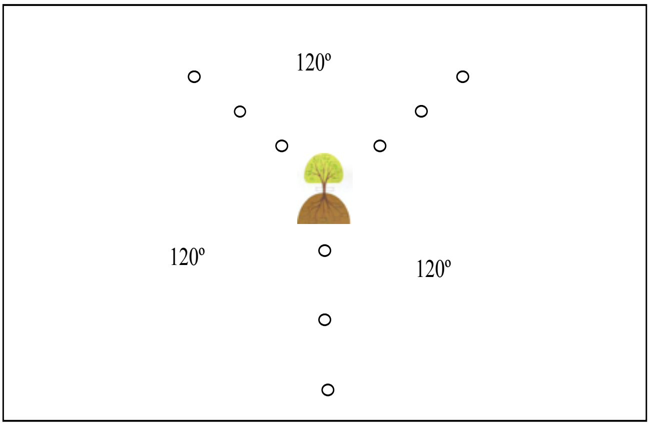

Figure 1. Disposition of the tests according to experimental design, in each forest.

so that there are various interferences that make it difficult to define trends about their affectation in the results, so an attempt was made to identify them according to various criteria that were: to take into account all the experiments in each forest around their representative tree , distance to the representative tree, line of each radiation from the representative tree and the initial moisture content of the soil.

EXPERIMENTATION

The initial soil moisture level of each test was established with the TDR-100 meter. The inverted sweeping well method was used, which was dug down with a bore to a depth of 0.50 meters and 0.15 meters in diameter at each of the sites, according to the experimental design, around the representative tree of each forest.

Each test was done in the unsaturated area of the soil, filling the open well with water, leaving a free edge of 0.10 meters, and by a system of a wooden ruler graduated in centimeters and supported at the bottom by a ball float, where this device floats over the well water, variations in reading the scale indicated by a needle were read at the top of the gap.

Variations in water levels and times were taken, recording every minute for the first five minutes, and then every 5 minutes to 30 minutes. Then every 15 minutes, up to 135 minutes, or more until the flow stabilized.

DETERMINATION OF INFILTRATION SPEED CURVES

From the field data obtained from the inverted well experiments, a pre-processing was first performed for data processing in order to obtain the infiltration rate at each of the time intervals of each test. Subsequently, processing was performed consisting of nonlinear regressions corresponding to different existing models that explain these phenomena. The processing of the data was carried out with MATLAB R2012b (Moler, 2012).

Pre-processing: Calculation of the infiltration rate for each time interval:

Data corresponding to water level were digitized in millimeters and time in minutes. The calculation of infiltration rate "f" was performed based on the definition of differentiation, being:

$$f[{}^{mm}/_{min}] = \frac{|sheet\ of\ water(t_{i+1}) - sheet\ of\ water(t_i)|}{t_{i+1} - t_i} \quad (1)$$

Processing: Calculation of parameters of the mathematical expressions chosen by nonlinear regression for the parameter adjustment of the equations.

The adjustment of the parameters was optimized by the least squares technique. However, the tool used in MATLAB is the nonlinearmodel.fit class which performs the adjustment using least squares unless instructed to do otherwise. The initial value assigned to the parameters was empirical, based on the shape of the curve obtained and the equation with which it is intended to represent.

To study the speed of infiltration, the mathematical expressions of Horton, Philip, Kostiakov and Kostiakov modified were considered to correspond to those that according to the field information obtained are the ones that best follow the observed behaviors, the formulas of which are presented below:

According to Horton:

$$f(t) = f_c + (f_o - f_c)e^{-kt} \quad (2)$$

According to Philip:

$$f(t) = st^{-0,5} + C \quad (3)$$

According to Kostiakov:

$$f(t) = abt^{b-1} \tag{4}$$

According to Kostiakov modified:

$$f(t) = \alpha t^{-\beta} \tag{5}$$

Where:
t - time spent from surface saturation of the ground, in minutes
k - constant decay
f(t) - speed of infiltration in time t, in mm/h
f_0- initial infiltration rate (t x 0), in mm/h
f_c - minimum infiltration rate, (asymptotic), in mm/h
sortivity in Philip's model, obtained by regression.
Transmissivity in Philip's model, obtained by regression.
a, b- Kostiakov model parameters, obtained by regression.
α, β- parameters of the modified Kostiakov model, obtained by regression.

The identification of characteristic curves for each tree species was made taking into account the initial moisture level criteria of the soil, which was defined as high (60 to 80%), mean (40 to 60%) low (20 to 40%) and the distance to the representative tree and based on the experimental curves of inverted well; they were first associated at the general level including all the trials of each species, and then according to the other criteria set out in the experimental design section.

DETERMINATION OF SATURATED HYDRAULIC CONDUCTIVITY

It has been filled from the characteristic curves identified under each type of forest according to the defined degrees of high, medium and low initial humidity.

The equation used was as follows: (Kessler, Oosterbaan, 1977); (Reynolds, 1983):

$$K_{is} = \frac{R}{2[t_2 - t_1]} Ln\left[\frac{2H_1 + R}{2H_2 + R}\right] \tag{6}$$

where
K_{is} saturated hydraulic conductivity, field conductivity (cm.s^{-1})
R well radius (cm)
H_1 height of the water column inside the well at time $t_{1,}$ in seconds.
H_2 height of the water column inside the well in time "t_2, in seconds.

RESULTS AND DISCUSSION

Table 3 presents the results of the degrees of adjustment to the infiltration speed equations according to the criteria set, according to the R^2 indicator.

According to Table 3, the criterion that allowed to find the characteristic curves of the infiltration rate according to the inverted well tests carried out, was that of the initial moisture content of the soil, using the Horton equation, where 87.5% of the experiments met a minimum adjustment of 76.2% of $R^{2,}$which was for the case of *C. lusitanica* when the initial soil moisture was 20 to 40%.

With respect to the distance to the representative tree, no defined trends could be identified, nor can it be identified according to the radiation line, since no defined effects of the trees adjacent to the experimentation sites were found.

The curves in Figures 2, 3 y 4 are those obtained at the experimental sites and mathematical expressions used, and Tables 3, 4 and 5 show the coefficients of the equations found and the R^2 achieved for initial soil moistures of 20 to 40 %.

From Tables 4, 5 and 6 it is found that the settings of Horton's equation are at least 76.2% except *for E. globulus,* in which case the other equations gave oden adjustments of 62%.

To have a complete comparative view of the

Description of modelling	species	R^2 best	model
General			
	E. globulus	0,3916	Kostiakov
	C. lusitanica	0,6058	Horton
	natural forest	0,5347	Horton
Depending on the line or radiation			
	E. globulus		
	Line 1	0,8349	Horton
	Line 2	0,2972	Kostiakov
	Line 3	0,2192	Horton
Depending on the distance to the tree			
Representative			
3 meters	*E. globulus*	0,4418	Philip
	C. lusitanica	0,8753	Horton
	natural forest	0,5641	Horton
6 meters	*E. globulus*	0,4529	Kostiakov Mod.
	C. lusitanica	0,4800	Horton
	natural forest	0,6578	Horton
The curves of the variation of hydraulic conductivity with the state of saturation of the soil, Figures 10, 11 and 12 show that the rates with which it increases are higher in all cases *for the C. lusitánica*, a species characterized by its low density of trees as well as species of its undergrowth, in addition to being last are of a very low size compared to the other undergrowths. It could be said that at a higher density of species in the undergrowth and high moisture content the hydraulic conductivity does not reach the state of complete saturation by effect of the air that is left under pressure between the pores of the soil. 9 meters	*E. globulus*	0,5063	Horton
	C. lusitanica	0,5533	Horton
	natural forest	0,7279	Horton
Depending on the initial humidity			
from the ground			
Low initial humidity	*E. globulus*	0,6230	Philip
	C. lusitanica	0,7622	Horton
	natural forest	0,7808	Horton
Average initial humidity	*E. globulus*	0,8096	Horton
	C. lusitanica	0,8915	Horton
High initial humidity	*E. globulus*	0,3398	Horton
	C. lusitanica	0,7677	Horton
	natural forest	0,7873	Horton

Table 3. Values of R^2 to equations deinfiltration speed, according to inverted well experiments under the experimental areas of the forests of the San Cristobal River basin.

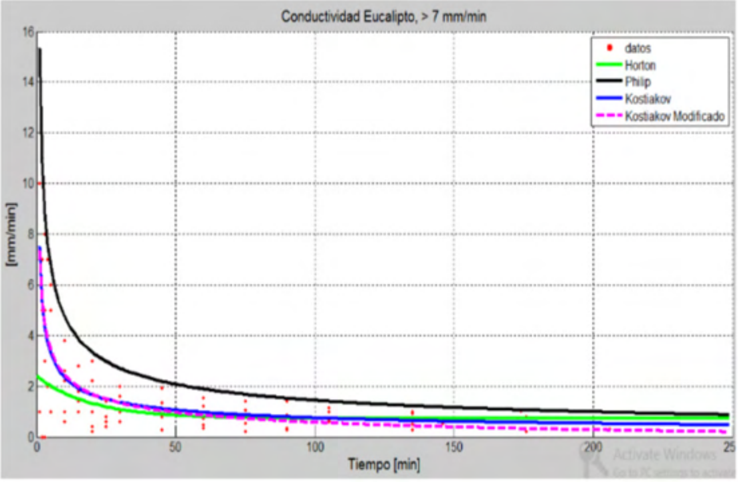

Figure 2. Infiltration speed curves under *E. globulus,* according to information from experiments with a low moisture content, between 20 and 40 %.

Model	Coeff. Dear			RMSE	R^2	R^2 Corrected
Horton	$f_c = 0.7139$	$f_o = 2.4016$	k = 0.0510	0.8224	0.3925	0.3771
Philip	s = 15.4489		C = -0.1138	1.4903	0.6277	0.6230
Kostiakov	a = 15.1513		b = 0.4965	1.4921	0.6267	0.6221
Kostiakov Modified	$f_c = -0.6332$	a = 7.9986	b = 0.4121	1.4939	0.6305	0.6212

Table 4. Results of adjustment to equations for infiltration speed using experimental curves under *E. globulus,* which correspond to tests with a moisture content, initial between 20 and 40 %.

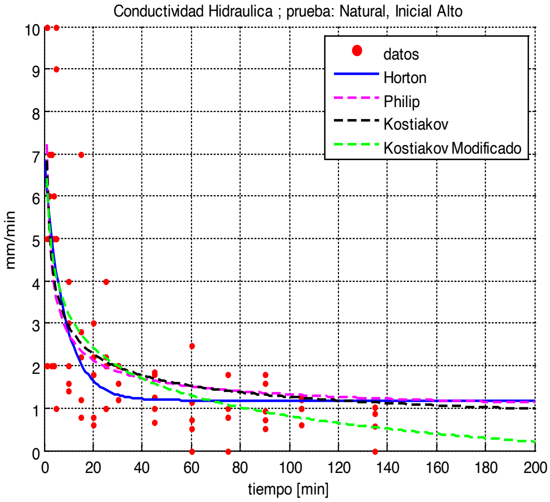

Figure 3. Infiltration speed curves, according to information from experiments with an initial moisture content of 20 to 40%.

Model	Coeff. Dear			RMSE	R^2	R^2 Fixed
Horton	f_c = 1.1810	f_o = 6.8570	k = 0.1247	1.1108	0.7866	0.7808
Philip	s = 13.1445		C = 0.6647	1.8023	0.4709	0.4639
K Kostiakov	a = 10.8252		b = 0.6331	1.7683	0.4907	0.4839
Modified Kostiakov	f_c = -6.7285	a = 13.1599	b = 0.1209	1.7480	0.5089	0.4957

Table 5. Results of the adjustment to the equations for the infiltration speed with the experimental curves under natural forest, which correspond to the initial moisture content of 20 to 40 %.

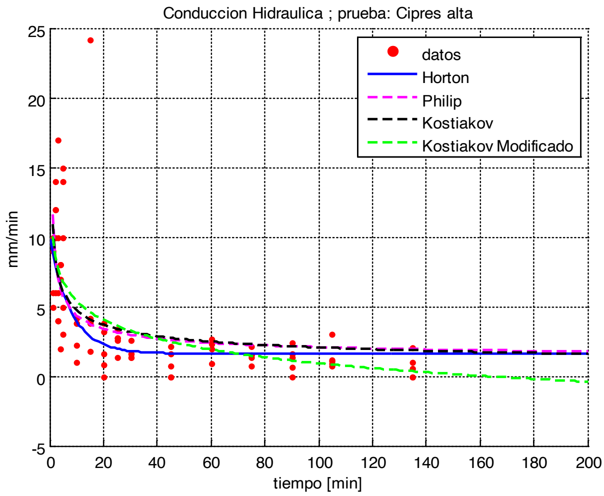

Figure 4. Infiltration speed curves, according to information from experiments with a low moisture content, from 20 to 40 %.

Model	Coeff. Dear			RMSE	R^2	R^2 Corrected
Horton	f_c = 1.6296	f_o = 9,8980	k = 0.1269	1.9193	0.7687	0.7622
Philip	s = 38.9682	C = -0.7824		3.6664	0.3628	0.3540
Kostiakov	a = 17.1179	b = 0.6385		3.6013	0.3853	0.3767
Modified Kostiakov	f_c = -141.4272	a = 151.4897	b = 0.0.135	3.5309	0.4173	0.4008

Table 6. Results of adjustment to equations for hydraulic conductivity with experimental curves in *C. lusitanica,* which correspond to moisture content, from 20 to 40 %.

infiltration speed behavior, the characteristic curves of Figures 7, 8 and 9 are presented, obtained by applying the coefficients found of Horton's equation, used to represent the infiltration rate according to inverted well tests, as it was the best fit according to the R^2 indicator

The infiltration rate represented by Horton for the three types of forests, according to inverted well experiments, grouped according to the initial moisture content of the soil, presented no differences to highlight, Figure 5, 6 and 7, so that taking into account a similarity in the soil characteristics of experimental areas, the differences between the root systems of forests and their undergrowth did not denote significant differences in the rate of infiltration, implying that the rate at which water moves in more horizontal flow paths, as is the case in the inverted well experiment is done in a similar way for cases in consideration.

Despite the above, if the initial moisture content in the soil is less than 40%,Figure 9, the rate of infiltration becomes higher under the natural forest and then under the forest of *E. globulus,* a fact that can be explained by the higher density and diversity of sub-surface root systems in the natural forest and more non-diversity abundance *in the forest of E. globulus,* which facilitate the flow of water in preferably horizontal trajectories, compared to undergrowth vegetation in the *C. lusitánica* (Tables 1 and 2).

In general, the values of infiltration rates according to the characteristic curves (Figure 6, 7 and 8) can be said that when the initial moisture content of the soil is less than 40% higher rates are achieved in the natural forest and in that of *E. globulus,* which are the coverages that present a higher density of undergrowth (Figure 9), *while under C. lusitánica,* where the vegetation that accompanies the forest is less, is less this infiltration rate value, a fact that shows an effect of these more superficial species. Finally, as time goes on, infiltration speeds are reduced to the ground saturation, and the differences in these rates become much smaller.

From the characteristic curves of the infiltration speed the hydraulic conductivity values and their characteristic curves were obtained for the three types of forests, with equation 6, which is applied for the method or the inverted well, Figures 8, 9 and 10. And Table 7 presents the values of saturated pseudo hydraulic conductivity, by the duration of the experiments.

The curves of the variation of hydraulic conductivity with the state of saturation of the soil, Figures 8, 9 and 10 show that the rates with which it increases are higher in all cases *for the C. lusitánica*, a species characterized by its low density of trees as well as species of its undergrowth, in addition to being last are of a very low size compared to the other undergrowths. It could be said that at a higher density of species in the undergrowth and high moisture content the hydraulic conductivity does not reach the state of complete saturation by effect of the air that is left under pressure between the pores of the soil.

Calculated saturated pseudo-hydraulic conductivity values are between 1 and 22 mm/h, with an average deviation of 7.4%, Table 7, can be considered representative of actual behavior. According to the Food and Agriculture Organization of the United Nations (FAO, 2016) for these sandy-free soils, arenose in experimental areas have hydraulic conductivity values of 25 to 50 mm/h, although hydraulic conductivity also depends among other factors in the soil structure. It is explained that for values in the field and with the presence of bushes and undergrowth the state of complete saturation by the air trapped between the pores of soil that oppose

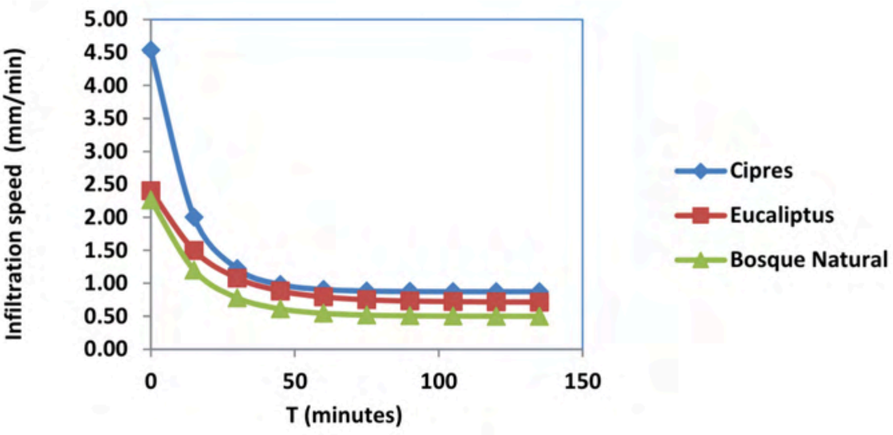

Figure 5. Characteristics curves of infiltration speed according to Horton, for inverted well tests that had a moisture content of 60 to 80%.

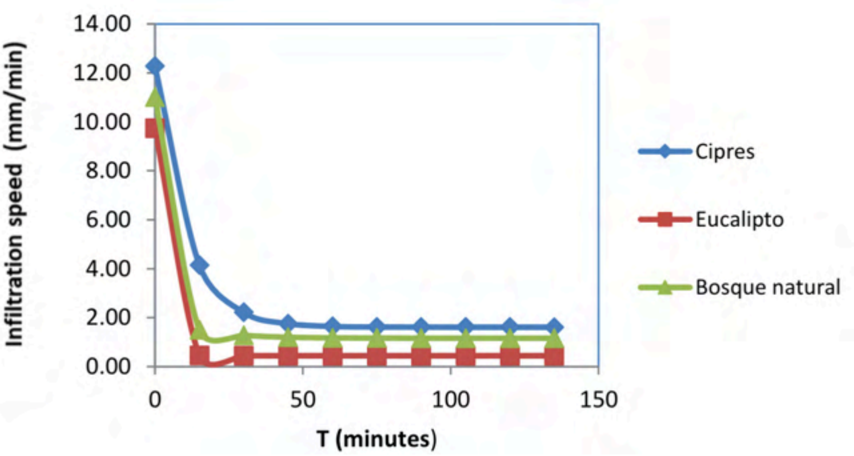

Figure 6. Characteristics curves of infiltration speed according to Horton, for inverted well tests that had a moisture content of 40 to 60 %.

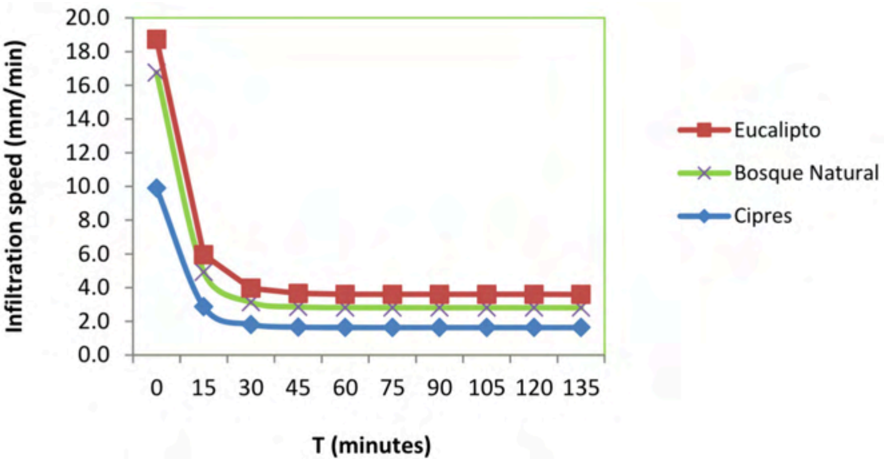

Figure 7. Characteristics curves of infiltration speed according to Horton, for inverted well tests that had a moisture content of 20 to 40 %.

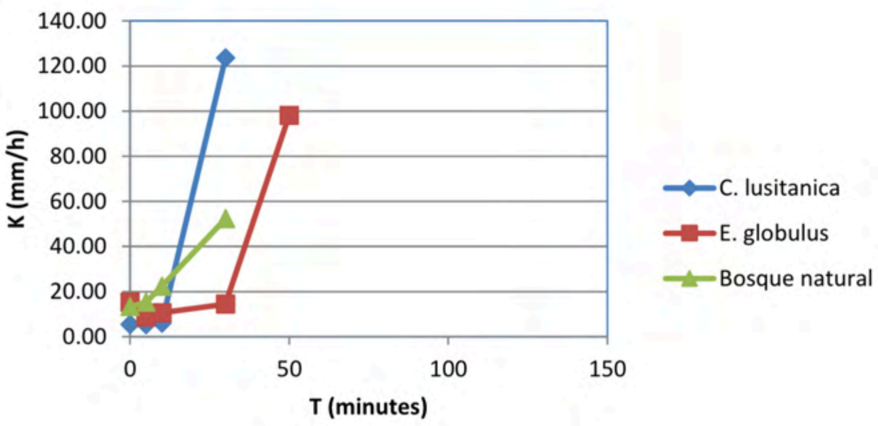

Figure 8. Behavior of hydraulic conductivity “k” from initial soil moistures of 20 to 40%, under the forests of *C. lusitanica, E. globulus* and natural forest in experimental areas of the San Cristóbal river basin, Bogotá.

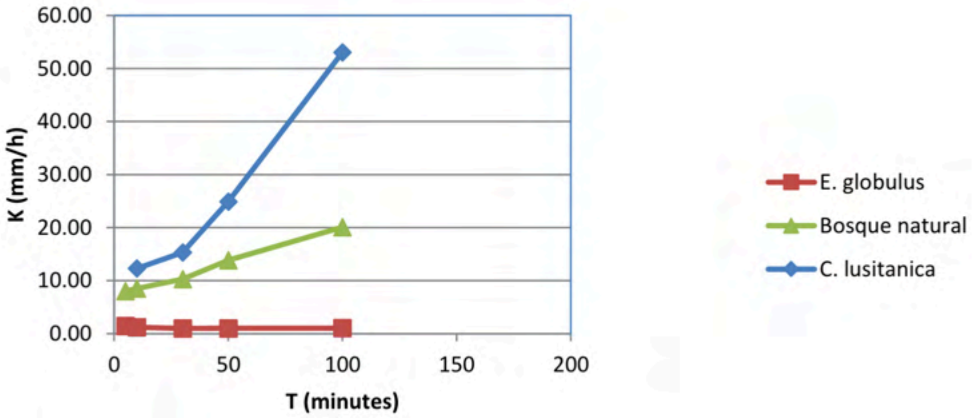

Figure 9. Behavior of hydraulic conductivity “k” from initial soil moistures of 40 to 60%, under the forests of *C. lusitanica,* E. *globulus* and natural forest in experimental areas of the San Cristóbal river basin, Bogota.

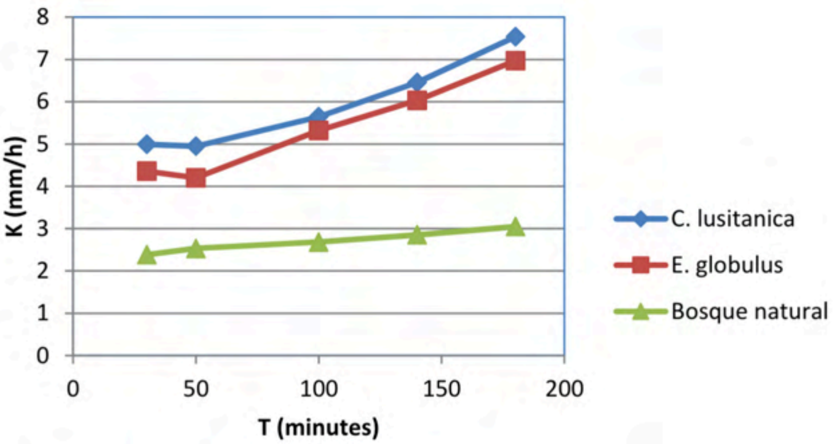

Figure 10. Behavior of hydraulic conductivity “k” from initial soil moistures of 60 to 80%, under the forests *of C. lusitanica,* E. *globulus* and natural forest in experimental areas of the San Cristóbal river basin, Bogotá.

No.	hi (20-40%)	hi (40-60%)	hi (60-80%)	Media	Standard Deviation
Natural forest	22.32	13.83	2.53	12.89	9.93
E. globulus	14.41	1.01	5.32	6.91	6.84
C. lusitanica	7.07	24.84	5.64	12.52	10.70

Table 7. Values, (mm./h), of saturated hydraulic conductivity for forests from the characteristic curves of the infiltration speed.

Source of variation	Sum Squares	Degrees of freedom	Medium square	F Ratio	Fo	P-value
treatment	67	2	34	0.39	Fo=3.463	<0,01
Error	520	6	87			
Total	587	8	73			

Table 8. Variance analysis for the results of saturated hydraulic conductivity (mm/h), under the *forests of E. globulus*, *C. lusitánica* and natural forest, in the San Cristobal River basin, Bogotá, D.C.

resistance to flow was not reached. (Luna et al, 2005).

According to the results of Table 7, the variance analysis was made to determine that the differences in saturated hydraulic conductivity are not significant, Table 8, and it could be established that under saturation conditions the forests under study together with their undergrowth do not generate significant differences in the behavior of saturated hydraulic conductivity.

CONCLUSIONS

In general, no significant differences in saturated hydraulic conductivity were found for *the forests of C. lusitánica, E. globulus* and natural forest, with a probability of 1%.

Despite the insignificant differences, found higher hydraulic conductivity rates under the C *forest. lusitanics,* which does not have a low density of undergrowth species.

The saturated hydraulic conductivity values found with the inverted well method under the forests and undergrowth under study turned out to be lower than those obtained in the laboratory, because of the trapped air left in the pores of the soil and which is facilitated by root systems, which offer resistance to flow, when water runs through the subfloor.

It is apparent from this research that sub-surface root systems of undergrowth species may decrease hydraulic conductivity in the sub-soil by the effect of air entrapment that prevents total saturation of soil pores, a fact that could influence groundwater flow and erosion processes among others.

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