A proposal of an infiltration function with ecological meaning

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Abstract:

In this work an infiltration function is proposed. This function gives a conceptual framework that may be useful to advance in soil/water/vegetation relationships. This function has fourteen adimensional coefficients (C_1,...., C_{14}). Some of these coefficients seem to be related with soil properties, that can be studied with the available infiltration models. Two additional coefficients (C_{15} and C_{16}) are also defined describing crust formation processes.

Keywords: infiltration, water resources, desertification, hydrological cycle

1. Introduction

Infiltration is –besides one of the principal components of hydrological cycle- the motor of life for the majority of organisms that inhabit a terrestrial ecosystem. Infiltration is the main way (for not saying the only) by wich the ecosystem keeps and collect the water coming from rain, snow or hail. Just a few organisms (for example: lichens) live outside the infiltration process. In exchange they must live a very slowed down life, because water is the main limiting factor for subsistence and growing of terrestrial life forms.

Being short the water resource in arid, semiarid and semimoist climates, it follows that infiltration results crucial. If soils are impoverished, (that is to say: if they have their infiltration capacity diminished) , they will lead to desertification. The main reason for desertification is an insufficient infiltration (Martínez de Azagra, 1996). Hydric erosion, biological, physic and chemical degradation of soil, botanic regression, etcetera, are mere effects of the main cause that originates them: we insist, a defficient infiltration. Consequently more attention has to be paid to infiltration, especially being a complex issue that has not been completely resolved. For the time being coexistence of more than twenty different models to estimate the infiltration capacity (Table 1) shows clearly this defficiency.

Table 1. More known infiltration models

Model name	Año	Type*	Model name	Year	Type*
Green – Ampt	1911	C	SCS (irrigations)	1974	E
Kostiakov	1932	E	Morel-Seytoux – Khanji	1974	C
Horton (Gardner – Widstoe)	1940	E	Parlange	1975	C
Mezencev (modified Kostiakov)	1948	E	Li – Stevens – Simons	1976	C
Hall	1955	C	Collis-George	1977	C
SCS (Curve number)	1956	E	Chu	1978	C
Philip	1957	C	Gill	1978	C
Holtan	1961	A	Hachum – Alfaro	1980	C
Overton	1964	AE	HEC	1981	E
Huggins – Monke	1966	A	Zhao	1981	A
Mein – Larson	1971	C	Ahuja	1983	C
Snyder	1971	E	Singh – Yu	1990	A
Smith	1972	C	Mishra – Singh	2003	E
Dooge	1973	A	Chu – Mariño	2005	C
* E = empirical model // A = analytical model // C = conceptual model					

The infiltration function that is proposed here may be useful to implement complete and accurate infiltration tests, to guide in the interpretation of their results, to select the appropriate infiltration models for each case, and to open and direct new lines of investigation and experimentation on this field that lead to a concrete and accurate infiltration equation that many researchers are on the search of. The analogy between this task with the search for the Hydraulics General Equation is clear. However, it faces a bigger difficulty - that is expected to have solution – as it deals with a far more complex problem than, for instance, water circulation through a rectilinear pipe (See on this issue the researchs and equations that determine the Darcy & Weisbach Friction Coefficient , due to Poiseuille, Blasius, Kármán & Prandtl and Colebrook & White, that are summed up in the well known Moody abacus) or the Hydraulics General Equation (Becerril (1960)).

In our opinion, to study deeper the Infiltration General Function is an essential step to understand the future Climate Change. Not all of this Climate Change is due to the Greenhouse Effect (that is produced mainly because of the use and abuse of fossil fuel energy production). To see it clearly we can expose this extreme case: If we think of covering all the planet surface with asphalt (which would be possible to do at our present time) we would change climate in a substantial and irreversible way. So inmmediatly arises the question: How much is the maximun of land surface that could be degraded and made waterproof ? How much could we alter the local hydrological cycle before having terrible consequences?

Definitively: to alter the local hydrological cycle is to alter microclimate, but extending this alteration to vast surfaces may affect mesoclimate and macroclimate of our planet Earth. So, the Infiltration Function that we propose in this communication is not out of bounds of this important meeting on Climate Change, forests and silviculture. Thereon, we will next develop and comment this Function.

2. Results and conclusions

2.1. Development of the function

2.1.1. Previous considerations

Infiltration depends on several physical magnitudes that will be concreted in this point. Once this magnitudes are fixed, we will be ready to establish a function on infiltration capacity, as a relationship (generic and , in the beginning, unknown) between these variables. A later dimensional analysis of this function permits definition of a series of adimensional coefficients that helps understanding the complex, diverse and crucial infiltration process.

We are going to define some previous fundamental or key concepts, before going into the physical-mathematical enunciation of the function. These concepts are: infiltration, infiltration velocity, accumulated infiltration, infiltration capacity, mean and minimum infiltration capacity, and maximum accumulated infiltration. It consists in related but different concepts that must be clearly distinguished in order not to be mistaken.

It's called *infiltration* to the process of entering of water in a soil through its surface, that means through the soil surface horizon (wether mineral horizon (A horizon)) or organic (O horizon)).

It's called *infiltration velocity* (also *infiltration rate*) ($v_i(t)$) to the quantity of water that enters the soil through its surface in a given time (t). The accumulated infiltration ($I(t)$) from the beginning of the shower (t=0) until a given instant (t) is calculated by the integral:

$$I(t) = \int_0^t v_i(t) \cdot dt \qquad \text{Eq. 1}$$

It's called *infiltration capacity* to the maximum quantity of water that can infilter through the soil by unit of time in a given instant. The maximum accumulated infiltration ($F(t)$) from the beggining of the infiltration test until a generic instant (t) is calculated by the integral:

$$F(t) = \int_0^t f(t) \cdot dt \,. \qquad \text{Eq. 2}$$

It's called *mean infiltration capacity* (f_m) to the average infiltration capacity for a given interval of time. For the interval [0,t] it is:

$$f_m = \frac{\int_0^t f(t) \cdot dt}{t} = \frac{F(t)}{t} \qquad \text{Eq. 3}$$

being t a generic instant in the infiltration test.

The *final infiltration capacity* (f_c) (also called minimum or basic) is defined by the next limit:

$$f_c = \lim_{t \to \infty} f(t) \qquad \text{Eq. 4}$$

It is a concept and a theorical limit, because soils seldom reach to this situation (but in extremely rainy climates). To obtain it by experimental means is very difficult. This is the reason for the infiltration tests being less exigent and being considered sufficient with a few hours of test.

Infiltration rate is always less or equal than infiltration capacity. It obeys that $0 \le v_i(t) \le f(t)$

Infiltration velocity (v_i) is affected by rain intensity ($i(t)$) and by infiltration capacity. Specifically:

- $v_i(t) \approx^* i(t)$ if soil is not covered with ponds (which is: if time of pond formation has not been reached: $t \leq t_p$)
- $v_i(t) = f(t)$ if soil is covered with ponds (si $t > t_p$)

* Notice that the symbol for "approximately equal to" has been included in the first case, given that is possible that may happen (and in fact it will probably happen) that a sort of surface water accumulation and a certain entering of rain water in the soil by effect of surface tension and the erratic trayectories followed by water drops in the porous edaphic mean. At least this effect can be noticed in the first periods resulting in forming of ponds $(t \leq t_p)$.

2.1.2. Obtaining the General Function

Phisycal magnitudes that intervene in the infiltration process can be grouped in five sets, that are detailed next.

1. Geometrical magnitudes of the porous rigid contour (soil) (See Fig. 1)

a, b, c_0, c_1, d_0, d_1, ξ_0, ξ_1

with: $(a \cdot b \cdot c_0)$ = volume of upper soil horizon $\{L^3\}$
$(a \cdot b \cdot c_1)$ = volume of second soil horizon $\{L^3\}$
d_0 = length of pores in the soil surface; characteristic diameter in the upper horizon (related with the soil superficial porosity) (sometimes also: pore diameter or characteristic particle diameter) $\{L\}$
d_1 = characteristic diameter of the second horizon (related with the soil general porosity) $\{L\}$
ξ_0 = tortuousity in the upper horizon (related with the conectivity of pores) $\{L\}$
ξ_1 = general tortuousity (related with connectivity in the second horizon) $\{L\}$

In a simplified analysis the study can me made with only one tortuosity (ξ) and one vertical characteristic length (c).

2. Geometric magnitudes of water inside the porous mean

a_h, b_h, c_h $\{L\}$

with:

$$\frac{a_h}{a} = \theta_x \quad \frac{b_h}{b} = \theta_y \quad \frac{c_h}{c} \approx \theta_z \text{ (contents of humidity of soil)} \qquad \text{Eq. 5}$$

3. Magnitudes associated to the intrinsic properties of flow

ρ, γ, μ, ε, σ, χ, d_h

with:

ρ = water absolute density $\{M \cdot L^{-3}\}$

γ = water specific weight $\{M \cdot L^{-2} \cdot T^{-2}\}$
μ = dynamic viscosity coefficient $\{M \cdot L^{-1} \cdot T^{-1}\}$
ε = volumetric elasticity module $\{M \cdot L^{-1} \cdot T^{-2}\}$
σ = surface tension coefficient $\{M \cdot T^{-2}\}$
χ = water thickness $\{M \cdot L^{-3}\}$
d_h = characteristic diameter of particles suspensión $\{L\}$

4. Magnitudes associates to the flow in the porous mean

k_0, k_1 $\{L \cdot T^{-1}\}$

with:

k_0 = superficial permeability (dead leaves, crusts, upper horizon)
k_1 = general permeability (or in the underlying horizon)

5. Specific movement magnitudes

f, ψ

with:

f = infiltration capacity $\{L \cdot T^{-1}\}$
ψ = hydric potential $\{M \cdot L^{-1} \cdot T^{-2}\}$

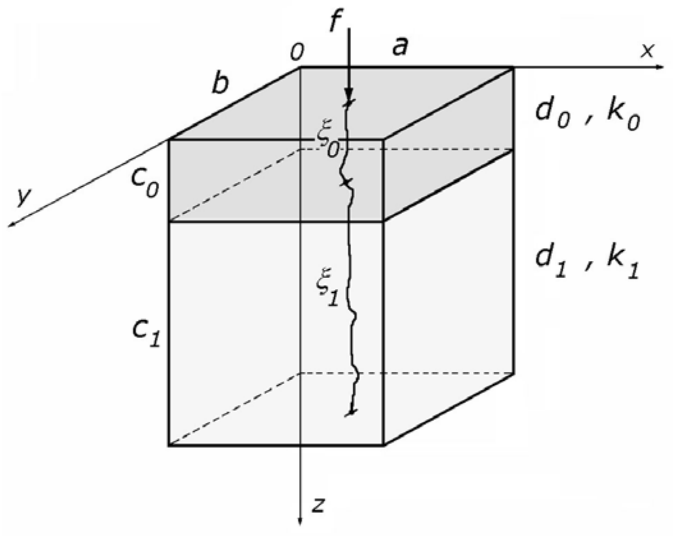

Fig. 1: Geometric magnitudes (a, b, c_j, ξ_j y d_j) and permeabilities (k_j) in the superficial horizon (j = 0) and in the underlying horizon (j = 1), ten of the physical magnitudes that intervene in the proposed infiltration function.

So, the infiltration function we search will adopt a similar form to the next one, being φ an unknown mathematical expresión but depending on the previously enumerated independent variables:

$$\varphi_1(a, b, c_0, c_1, d_0, d_1, \xi_0, \xi_1, a_h, b_h, c_h, \rho, \gamma, \mu, \varepsilon, \sigma, \chi, d_h, k_0, k_1, f, \psi) = 1 \qquad \text{Eq. 6}$$

2.1.3. Dimensional analysis of the infiltration function

In a simplified version, reducing the problem to a characteristic vertical length (*c*), a tortuosity (ξ) and doing without the infiltrating water thickness (χ and d_h having null value), we can write:

$$\varphi_2(a,b,c,d_0,d_1,\xi,a_h,b_h,c_h,\rho,\gamma,\mu,\varepsilon,\sigma,k_0,k_1,f,\psi)=1 \qquad \text{Eq. 7}$$

Although we can't apply directly the Buckingham π Theorem (1914), we can deduce by the dimensional analysis a list of adimensional coefficients, its interpretation having a clear practical interest. The total number of variables implied in the infiltration is reduced greatly by using this method. Initially we start with 18 variables (22 in the general version) that we can convert into a serires of adimensional hydrologic numbers (among them appear the hydraulic numbers of Froude, Euler, Weber and Cauchy).

The function can be simplified by stating a uniform humidity in the soil according to x and y axis. It leaves a physical relation with 16 independent variables:

$$\varphi_3(a,b,c,d_0,d_1,\xi,c_h,\rho,\gamma,\mu,\varepsilon,\sigma,k_0,k_1,f,\psi)=1 \qquad \text{Eq. 8}$$

Without needing to apply the Buckingham π Theorem but using its system to reduce the number of variables, we can obtain 13 independent adimensional coefficients (= total number of considered variables minus the number of fundamental dimensions of the problem: mass {M}, lenght {L} and time {T}). So the previous function (Eq. 8) can be transformed into the equivalent expression:

$$\phi(C_1,C_2,C_3,C_4,C_5,C_6,C_7,C_8,C_9,C_{10},C_{11},C_{12},C_{13})=1 \qquad \text{Eq. 9}$$

being C_i the thirteen adimensional coefficients that describe the infiltration process. The variable reduction that can be used to reach this adimensional coeficcients $(C_1,C_2,C_3,C_4,C_5,C_6,C_7,C_8,C_9,C_{10},C_{11},C_{12},C_{13})$ admits several solutions. The most interesting thing is to obtain coefficients having a clear physical interpretation (for example, the hydraulic numbers) and that establish a clear link between them, without remanining any of them aisolated from the rest of coefficients.

2.1.3 Infiltration adimensional coefficients and its interpretation

Among all the solutions (or combinations) possible and due to hydrologic considerations, we propose the next coeffcients:

$$C_1=\frac{a}{b} \qquad \text{Eq. 10}$$

$$C_2=\frac{a}{c} \qquad \text{Eq. 11}$$

$$C_3=\frac{d_0}{a}=p_e \qquad \text{Eq.12}$$

$$C_4=\frac{c_h}{c} \qquad \text{Eq. 13}$$

$$C_5 = \frac{\xi}{c} \qquad \text{Eq. 14}$$

$$C_6 = \frac{d_0}{d_1} \qquad \text{Eq. 15}$$

$$C_7 = \frac{k_0}{k_1} \qquad \text{Eq. 16}$$

$$C_8 = \frac{f}{k_1} = MA \qquad \text{Eq. 17}$$

$$C_9 = \frac{f}{\sqrt{g \cdot d_0}} = FR \qquad \text{Eq. 18}$$

$$C_{10} = \frac{\rho \cdot f \cdot d_0}{\mu} = RE \qquad \text{Eq. 19}$$

$$C_{11} = \frac{f}{\sqrt{\psi / \rho}} = EU \qquad \text{Eq. 20}$$

$$C_{12} = \frac{f}{\sqrt{\sigma / \rho \cdot d_0}} = WE \qquad \text{Eq. 21}$$

$$C_{13} = \frac{f}{\sqrt{\varepsilon / \rho}} = CA \qquad \text{Eq. 22}$$

Physical interpretation of the adimensional coefficients (or monomials) that appear in the equation is the following:

$C_1 = \frac{a}{b}$ and $C_2 = \frac{a}{c}$ define the general geometry of soil, in the surface and in depth.

$C_3 = \frac{d_0}{a}$ reflects the linear porosity of the soil surface (division between the length of empty spaces in a sufficiently long segment (*d_0*) divided by the total length of the segment (*a*). It can be considered equivalent to the volumetric porosity of the upper horizon or, preferred, to the mean effective porosity (*p_e*) to take account only the interconnected pores, through wich water can penetrate the soil.

$C_4 = \frac{c_h}{c}$ corresponds with the soil humidity content (θ). As the soil humidity content is uniform inside the planes that are parallel to the suface, only has to be analyzed humidity on the *z axis.* It can be admitted that:

$\frac{c_h}{c} \approx \frac{a_h \cdot b_h \cdot c_h}{a \cdot b \cdot c} = \theta$ (volumetric humidity content of soil)

The monomial C_4 can be interpreted as an absolute volumetric humidity, or as a difference of humidities between horizons.

$C_5 = \frac{\xi}{c} \geq 1$ is the relative tortuosity (ξ_r). The closer to one, the better the conectivity between pores, which will make easier infiltration

$C_6 = \frac{d_0}{d_1} \approx 1$, the relative porosity between horizons (d_r), it will be close to one (unless there are two very differenciated horizons in the soil: because of crust formation, or becuase it is an organic superficial horizon formed of dead leaves, pine needles or other vegetal rests). Mature and not perturbed soils present a superficial horizon (Ao) enriched in organic material, with a great relative porosity. In this type of horizons (and above all the organic horizons formed by superficial covers of dead leaves (O)) the characteristic diameter (d_0) cannot be estimated from the characteristic diameter of mineral particles. However this difficulty, the quotient $\frac{d_0}{d_1}$ will be far higher than one, which will make much easier the infiltration. On the contrary, naked soils, without organic covers (natural or artificial) that protect them, can worsen developing hard and compact superficial crusts, with reduced porosity ($d_0 << d_1$), scarce permeability and insufficient infiltration capacity (Mc Intyre, 1958 a, b; Miyazaki *et al.*, 1993; Regüés *et al.*, 2002). We will have a soil with a high probability to get desertificated. The quotient $\frac{d_0}{d_1}$ is a good measure of the risk of desertification of a soil.

$C_7 = \frac{k_0}{k_1}$, is the relative permeability between horizons (k_r). This adimensional number, being a quotient of hydraulic conductivities, can be more directly interpreted than the previous adimensional monomial. Its value is very decriptive if it's not close to one (whether it's much lesser than one (<< 1); or whether it's much bigger than one (>> 1)), for it reflects the hydrologic health of soil. In the first case: we have a degraded soil with regard to infiltration; in the second: we have a improved soil with regard to infiltration, that is the result of continous deposits of organic rests: being dead leaves, organic material or a combination of the two. It's crucial for plants in arid or semiarid zones to have a good infiltration, being necessary to condition their surrondings to obtain water, soil and nutrients harvests when it rains (Martínez de Azagra, Mongil & Rojo, 2004; also in <http:// www.oasificacion.com>).

Everytime that a marked difference exists between the characteristics of porosity and permeability of the two adjacent horizons (the superficial and the underlying one), favouring the upper horizon, in the soil will be produced hypodermic runoff during heavy rains through the horizons transition zone. But before the beginning of this subsuperficial runoff, the upper horizon will be able to infiltrate and accumulate an important volume of water, that will be proportional to its porosity (d_0) and depth (c_0). Besides, in evolutioned and not perturbed soils, transition between horizons is gradual and very sinuous, which makes easier the infiltration, accumulation and percolation of water in-situ (or slightly redistributed)

$C_8 = \frac{f}{k_1} = MA$, monomial that we call Martinez de Azagra's relation (*MA*). In dry soils that doesn't have crusts is greater than one. This adimensional coefficient decreases gradually its value as the soil gets humid, until it reaches a minimum constant value that –at least in soils with thick texture- uses to be less than one: $MA_{\min} = \dfrac{f_c}{k_1} < 1$ (close to 0,5 , according to Bouwer's relation (1966)). However, it's good to emphasize that the presence of organic material and vegetal rests in the upper horizon makes f_c and –of course- f much bigger than k_1 in healthy soils from the hydrologic point of view, which permits to make good use of rain water. It is much different the behaviour of a mineral soil that has developed a compact and waterproof crust, for this leads to desertification .

$C_9 = \dfrac{f}{\sqrt{g \cdot d_0}} = FR$, is the Froude number.

$C_{10} = \dfrac{\rho \cdot f \cdot d_0}{\mu} = RE$, is the Reynolds number.

$C_{11} = \dfrac{f}{\sqrt{\psi / \rho}} = EU$, is the Euler number.

$C_{12} = \dfrac{f}{\sqrt{\sigma / \rho \cdot d_0}} = WE$, is the Weber number.

$C_{13} = \dfrac{f}{\sqrt{\varepsilon / \rho}} = CA$, is the Cauchy number.

The last five monomials (C_9, C_{10}, C_{11}, C_{12}, y C_{13}) are well known in the field of Mechanics of Fluids. They are the hydraulic numbers, that characterize the movement of water (or, generally, of a fluid) from five different points of view. Froude number (*FR*) is interpreted as a relationship between inertial forces (= sum of external forces) and gravity forces. Reynolds number(*RE*) is related with the quotient between inertial forces and viscous forces. In a similar way, Euler number (*EU*) considers hydrostatic pressure forces (osmotic and capillary), Weber number (*WE*) considers surface tension forces and Cauchy number (*CA*) analyzes elastic forces.

Once we have expressed in concrete terms the monomials, we can write:

$$\phi(\frac{a}{b}, \frac{a}{c}, p_e, \theta, \frac{\xi}{c}, \frac{d_0}{d_1}, \frac{k_0}{k_1}, \frac{f}{k_1}, FR, RE, EU, WE, CA) = 1 \qquad \text{Eq. 23}$$

Finding the Euler number and then the infiltration capacity (f) from that number, the following equivalent expression remains:

$$f = \phi_1(\frac{a}{b}, \frac{a}{c}, p_e, \theta, \frac{\xi}{c}, \frac{d_0}{d_1}, \frac{k_0}{k_1}, \frac{f}{k_1}, FR, RE, WE, CA) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 24}$$

Weber and Cauchy hydraulic numbers don't seem to influence the process: Weber, because soil is covered with ponds during the infiltration test, so the surface tension membrane is located above the porous mean to be crossed, and because the possible effect of capillary suction inside soil is included in the hydric potential (ψ). Cauchy number is not interesting in this case because water that infilters doesn't suffer compressions or expansions.

For this reasons:

$$f = \phi_1 \left(\frac{a}{b}, \frac{a}{c}, p_e, \theta, \frac{\xi}{c}, \frac{d_0}{d_1}, \frac{k_0}{k_1}, \frac{f}{k_1}, FR, RE\right) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 25}$$

Froude number is neither relevant for the infiltration process. This claiming may surprise at first, but it becomes evident if we express more properly the question: Froude number relates to the infiltration capacity nearly in a same way in all kinds of soils, so it doesn't act as a variable of the process.

$$f = \phi_1 \left(\frac{a}{b}, \frac{a}{c}, p_e, \theta, \frac{\xi}{c}, \frac{d_0}{d_1}, \frac{k_0}{k_1}, \frac{f}{k_1}, RE\right) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 26}$$

Geometric general characteristics of the mean (*a/b* y *a/c*) neither have a noticeable efect in the process, therefore we reach the following general function:

$$f = \phi_1 \left(p_e, \theta, \frac{\xi}{c}, \frac{d_0}{d_1}, \frac{k_0}{k_1}, \frac{f}{k_1}, RE\right) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 27a}$$

Using the abbreviations for the adimensional coefficients that we defined, it results:

$$f = \phi_1 (p_e, \theta, \xi_r, d_r, k_r, MA, RE) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 27b}$$

which is the infiltration function that we propose.

Because the frecuent cultivation works, in agriculture soils exists a deep and homogeneus superficial horizon (ranging 20 to 40 cm deep, with symbol Aa in Fig. 2), which reduces general equation in two monomials:

$$f = \phi_1 (p_e, \theta, \xi_r, MA, RE) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 28}$$

Most infiltration tests have been carried out in agriculture soils. However, an increasing interest exists for the study of permeability and infiltration in degraded soils that are compacted or tending to form crusts (At horizon, according to Fig. 2). On the contrary, in evolved soils (not changed by humans) there is a lack of infiltration tests at the moment.

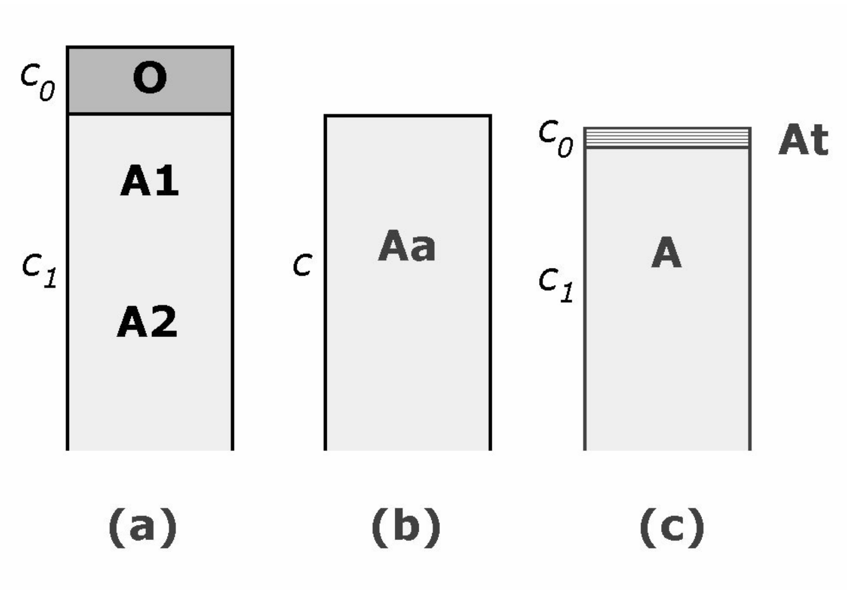

Fig. 2. Three different kinds of edaphic profiles for infiltration: Mature soil not perturbed with organic horizon O (a), Agriculture soil ploughed periodically with horizon Aa (b), and degraded soil with horizontal crust At (c).

It is remarkable that while is not used the Weber number for the calculation of infiltration capacity (*f*), for the reasons previously mentioned, it doesn't ocurr the same with infiltration velocity (v_i). In this velocity the surface tension plays a main role, as it does rain intensity. In addition, a second adimensional coefficient intervenes: the Del Rio coefficient (abbreviated by *DR*), that has an expression similar to the Strouhal number:

$$C_{14} = \frac{\xi \cdot v_i}{k_1 \cdot d_1} = DR \qquad \text{Eq.29}$$

being known all monomial factors.

It is convenient to observe that for obtaining the function for infiltration velocity, in each of the different adimensional coefficients must be substituted the infiltration capacity (*f*) by the infiltration velocity (v_i):

$$MA = \frac{v_i}{k_1} \quad , \quad FR = \frac{v_i}{\sqrt{g \cdot d_0}} \quad , \quad RE = \frac{\rho \cdot v_i \cdot d_0}{\mu} ,$$

$$EU = \frac{v_i}{\sqrt{\psi / \rho}} \quad , \quad WE = \frac{v_i}{\sqrt{\sigma / \rho \cdot d_0}} \quad \text{y} \quad \frac{v_i}{\sqrt{\varepsilon / \rho}} = CA .$$

Finally, we can write as a general function for the infiltration velocity the following:

$$v_i = \phi_2 (p_e, \theta, \xi_r, d_r, k_r, MA, RE, WE, DR) \cdot \sqrt{\psi / \rho} \approx i \qquad \text{Eq. 30}$$

A particular case of this expression (when time of ponds forming is reached: $t > t_p$) is the general function of infiltration capacity that we enunciated before:

$$f = \phi_1 (p_e, \theta, \xi_r, d_r, k_r, MA, RE) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 27b}$$

Time of ponds forming (t_p), its previous and later instants, are crucial moments for the terrestrial hydrologic cycle, in which Weber number (*WE*, because of surface tension of water in the soil surface, not completely covered with ponds) and Del Rio number (*DR*, due to a certain cadence in dripping because the more or less tortuous entering of water into the soil) have to be related in a direct form to the process. In this sense seem to indicate drip irrigation tests that study the wet bulb formed in the vertical of each dripping device, which shape changes notoriously depending on the soil texture (Rodrigo, Hernández, Pérez & González, 1992).

Time of ponds formation is a fundamental discontinuity that will be useful to study and define in the future. To express it clearly: t_p divides the ecosystem in two worlds. It is a sharp frontier between air world and underwater world. In t_p there is a very noticeable discontinuity (a sharp change in the contour condition). It is considered as a very significant moment in the hydrologic cycle. A lot of events ocurr a that time. For $t > t_p$ the coefficients *WE* y *DR* stop influencing and the water entering becames independent of rain intensity (*i*). Besides, the instant t_p can ocurr several times, repeatedly (even during the same shower it can ocurr a number of times and in different places in the basin and for different reasons: excess of rain intensity, emerging hypodermic flows or a combination of both of them). Time of ponds formation is an instant that needs to be studied calmly and deeply in the future.

To simplify the physical-mathematical discussion of t_p it is interesting to define it as the moment in which the superficial runoff starts (and not as the moment in which the first ponds are formed). Thus, we don't lose accuracy in the analysis, the instant t_p is more easily determined and a third question is resolved: the water stored in the microrelief is always accounted as in-situ infiltration, which is clearly a real fact).

We can claim that, for an aerial-terrestrial ecosystem (not underwater), the less times times of pond formation are reached the more stable the ecosystem is. On the contrary, the more times there is a forming of ponds and pools, the more risk exists for erosion (=degrading = desertification) or becoming a frequent flooded ecosystem.

There are interesting works that estimate the time of ponds formation in a soil, based on different infiltration models. Some of the more interesting and stimulating are due to a Mein & Larson (1971), Smith (1972), Chu (1978), Mls (1980), Kutilek (1980), Verma (1982), Kutílek & Nielsen (1994), Chow, Maidment & Mays (1988), Martínez de Azagra (1995, 1998), Chu & Mariño (2005), etcetera. However, this approximations don't use neither the Weber number (*WE*) nor the Del Rio coefficient (*DR*), and therefore we find convenient to carry on investigating this interesting question, until fully satisfying results and models are reached.

As a concrete first general equation for infiltration and emulating the Universal Soil Loss Equation (USLE), we could work with the product of coefficients previously defined. However that would result in a only qualitative equation. Anyway, in conclusion, we can claim that infiltration capacity is related (symbol: $\succ\!\prec$) with the product of the following terms:

$$f \succ\!\prec p_e \theta \cdot \xi_r \cdot d_r \cdot k_r \cdot MA \cdot RE \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 27c}$$

2.2 Particular cases

All physical or analytical infiltration models suits the proposed general function. (See Table 1). Thus, Green & Ampt equations (and related), Hall and Philip models, and –of course- the Darcy's law (1856) or the Richards differencial equation (1931) have this magnitudes intervening. In general, they are functions that use much less physical magnitudes than the general function. For example, Green & Ampt equations (and related: Gill, Ahuja, Chu & Mariño, etc.) are of this type:

$$f \approx \phi_3(\theta, MA) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 31}$$

Or, for example, the analytic models of Holtan, Overton, Huggins & Monke, Zhao, Singh & Yu, etc. are of this type:

$$f \approx \phi_4(p_e, \theta) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 32}$$

On the other hand, in a first interpretation, the empiric infiltration models (Kostiakov, Horton, Mezencev, SCS (curve number and irrigations), HEC, Mishra & Singh, etc.) don't have a clear connection with the proposed function, but it is not strange.

For making a example and trying no to be too extensive, we are going to link three of the more used models in Hydrology with the proposed general function. They are the Green & Ampt, Philip and Holtan models.

Initial equation of the conceptual Green & Ampt model (1911) is wrote as:

$$f = k_s \cdot \frac{L + S}{L} \qquad \text{Eq. 33}$$

Combining the previous equation with the soil continuity equation (*F(t)* = $\eta \cdot L(t)$), the authors (op. cit) obtain the operative expression for their model:

$$F(t) = k_s \cdot t + \eta \cdot S \cdot \ln\left(\frac{\eta \cdot S + F(t)}{\eta \cdot S}\right) \quad \text{Eq. 34}$$

with: *f* (t) = infiltration capacity of the soil at instant *t* (= $\frac{dF}{dt}$)

k_s = Green & Ampt hydraulic conductivity {$L \cdot T^{-1}$}

L = *L*(*t*) = vertical distance between the soil surface and the wet front {L}

S = capillary suction {L}

F = accumulated infiltration (= volume of water infiltered during the test by surface unit) {L}

$\eta = \theta_s - \theta_i$ = humidity deficiency = difference of content of humidity between the saturated zone (θ_s) and the initially dry soil (θ_i) {adimensional}

Simple considerations show that the Green & Ampt equation constitutes a particular case of our general function. Effectively: when analyzing the model paramenters and interpreting its physical meaning, it can be noticed that both the initial equation [Eq. 32] and the operative expression [Eq. 33] are functions on permeability (k_s), on hydric potencial between the soil surface and the humid front ($L + S = \psi$) and on the humidity content of soil (η, expressed in this model as difference in relation to the maximum value). It results, consequently, a simple function of the type $f = \phi_4(k_s, \psi, \eta)$, that constitutes a particular case of the expression:

$$f \approx \phi_3(\theta, MA) \cdot \sqrt{\psi / \rho} \quad \text{Eq. 31}$$

Models made later than Green & Ampt's and inspired by its approach (Gill, Hachum & Alfaro, Ahuja, Chu & Mariño, etc.), include in the analysis several horizons inside the edaphic profile so to extend the validity of the original model. With similar reasonings it can be shown that they are models that can be considered into the general infiltration function. From a practical point of view it must be noticed that subdividing the profile in several horizons can lead to develop models that are conceptually attractive but lacking of effectiveness.

In the Philip's binomial (1957) intervenes sorptivity (*s*), that is an interesting parameter that depends on the soil humidity characteristic curves and different analytic solutions exist for it. (see Parlange (1975), etc). Philip's binomial is written: $f(t) = \frac{1}{2} \cdot s \cdot t^{-1/2} + f_c$

As sorptivity {$L \cdot T^{-0,5}$} depends on the soil humidity characteristic curves, this parameter is function of permeability, hydric potential and humidity content that exists in the soil: $s = \phi_5(k_s, \psi, \theta)$, For this reason we can conclude that Philip's binomial is also a particular case of Eq. 31.

Holtan equation (1961; the first analytical model on infiltration) is written as:

$$f(t) = A \cdot [S(t)]^n + f_c \quad \text{Eq. 35}$$

Combining the Holtan model initial equation with the continuity equation, and using the model explicit solution (obtained by Singh & Yu in 1990), we reach to a very operative expression to estimate the accumulated infiltration (Martínez de Azagra & Pando, 2006):

$$F(t) = f_c \cdot t + M - \left(M^{1-n} - A \cdot (1-n) \cdot t\right)^{1/1-n} \quad \text{Eq. 36}$$

where:

f(t) = soil infiltration capacity $\{L \cdot T^{-1}\}$

f_c = final (or minimum) infiltration capacity $\{L \cdot T^{-1}\}$

A = infiltration rate $\{L^{(1-n)} \cdot T^{-1}\}$ for each milimeter raised to a power *n* of volume of available pores (constant value for a given soil and vegetation)

S(t)= volume of non saturated pores existing in the soil (expressed in volume by surface unit) that are available to store water that infiltrates at a generic instant *t* {L}

n = exponent (constant value for a given soil and vegetation) {adimensional}

M = initial volume of non saturated pores = *S*(0) {L}

It can be observed that in the Holtan equation intervene, through the *S(t)* parameter, two soil physical magnitudes: porosity and humidity content, so: $f(t) - f_c = \phi_6(p_e, \theta)$. This equation constitutes a particular case of the general function that we have enuntiated:

$$f \approx \phi_4(p_e, \theta) \cdot \sqrt{\psi / \rho} \qquad \text{Eq. 32}$$

Later analytic proposals, as for example the interesting model by Singh & Yu (1990), can also be easily included into our infiltration general function.

2.3 Monomials describing the crust formation process

Crust formation in a mineral soil is ruled by two processes: surface sealing and soil compactation, as it is described by many researchers in a clear and attractive way (FAO, 1979, 1983; Porta, López-Acevedo & Roquero, 1994). Both processes are interrelated through precipitation, infiltration and erosion, in a way that makes difficult to study them separately.

By dimensional analysis and with a bit of physical intuition it is possible to define two adimensional numbers that, separately and together, help to understand and interprete the surface crusts formation phenomenon. These numbers are: the Reynolds number for turbid waters infiltration (that we abbreviate by *PA* or Pando number) and the Euler number for rain (or hail) (of which the inverse we abbreviate by *NA* or Navarro number).

We define, for describing the first phenomenon, the monomial C_{15} by the following relationship:

$$C_{15} = PA = \frac{\chi \cdot v_i \cdot (d_h - d_0)}{\mu} \qquad \text{Eq. 37}$$

where, (according to the notation throughout our development):

χ = water turbidity $\{M \cdot L^{-3}\}$

$v_i = v_i(t)$ = infiltration velocity $\{L \cdot T^{-1}\}$

d_h = characteristic diameter of suspended particles {L}

d_0 = characteristic diameter of soil superficial pores {L}

μ = dynamic viscosity coefficient $\{M \cdot L^{-1} \cdot T^{-1}\}$

with an aditional condition, that helps to understand the meaning of the monomial:

$PA = 0 \quad if \quad d_0 \geq d_h$, in which case crusting by sealing will not be produced (because soil characteristic pore (d_0) is bigger than the sediment or particle that could seal it (d_h)).

This coefficient or adimensional monomial is consistent with the process and relates to rain intensity (by means of v_i) and to the erosive processes in the considered areas (by means of water turbidity (χ)).

In the supposition that the soil is covered with ponds or flooded, the characteristic velocity is no more the rain intensity but the infiltration capacity, so that:

$$\text{if } t \leq t_p: \quad PA \approx \frac{\chi \cdot i \cdot (d_h - d_0)}{\mu} \qquad \text{Eq. 37a}$$

$$\text{if } t > t_p: \quad PA = \frac{\chi \cdot f \cdot (d_h - d_0)}{\mu} \qquad \text{Eq. 37b}$$

Relationship between d_0 y d_h is hard to predict if we don't know the soil properties (in particular: its particle size distribution and its structure). But in any case and given that the more easily eroded type of particles are silts (Weesies, 1998), it's very likely that d_h tends towards that diameters, if that type of soil is well represented in the granulometric composition of soils feeding the turbidity (this is: soils being eroded in an upper height than the infiltration place). On the other hand, d_0 will be as big as good is the soil structure (= contains more organic material and the texture is gross). In this sense, it's understandable that is the clay type soils without organic material the ones that form crusts by sealing. In this direction seem to point data and experimental indexes, as for example the index propose by FAO (1979, 1983).

Elevated Pando numbers imply a well developed turbulent hydraulic regime, that favours turbidity (and the transporting of suspended particles) and, consequently, the sealing of pores (d_0), if $d_h > d_0$.

The Euler number for rain (or hail) is defined by the expression $\dfrac{v_c}{\sqrt{\dfrac{p_d - p_c}{\rho_c - \rho}}}$. Its inverse value has a more inmediate physical meaning and we term it de Navarro's relationship. It is:

$$C_{16} = NA = \frac{\sqrt{\dfrac{p_d - p_c}{\rho_c - \rho}}}{v_c} \qquad \text{Eq. 38}$$

where:

p_d = hydrodynamic pressure that exerts the hydrometeor upon the soil (hydrodynamic pressure of the rain)

p_c = soil resistance to compression (or compactation)

ρ_c = characteristic denity of the superficial soil horizon. This characteristic density can be made equal to the superficial horizon bulk density (ρ_a). Sometimes can also be made equal to the absolute density (ρ_s) of the soil mineral particles.

ρ = water absolute density (or hail bulk density, or granulated snow density, etc.)

v_c = characteristic velocity of arrival of the meteor to the soil (rain characteristic velocity). This velocity corresponds with the limit velocity of falling rain drops or hailstones (in naked soils), but it's different (usually slower) if the soil is covered with vegetation. And the characteristic velocity is null if the soil is covered with a sort of amortiguation layer due to vegetal rests.

Limit velocity of a particle falling (v_∞) depends on the diameter and density of the particle (wether a rain drop ,hail stone, or snow granule, etc). It can be determined "a priori", because formules and abacus exist that permit to estimate its value: They are graphics and expressions that calculate the falling velocity of a particle inside a viscous fluid (in this case: air) for action of gravity (Laws & Parsons, 1943; Torri, Sfalanga & Chisci, 1987).

Hydrodynamic pressure (p_d) can be estimated from the rain (or hail) intensity. Effectively: the expression that calculates the hydrodynamic thrust (E_d) that a water (or ice) flow exerts on a wall when colliding (without return) is written as: $E_d = \rho \cdot Q \cdot v_c$, being known all factors but Q, that represents the volumetric flow that collides on the wall. If we call *S* the area being collided, the hydrodynamic pressure values: $p_d = \frac{\rho \cdot Q \cdot v_c}{S}$.

To resolve the question in our case, it is enough to consider that the volumetric water (or ice) flow equals the rain characteristic intensity (i_c) multiplied by the soil surface area (*S*), resulting: $p_d = \rho \cdot i_c \cdot v_c$

It's interesting here to comment briefly the importance of the difference between rain and hail in this process: the hydrodynamic pressure for hail is much greater when characteristic intensity is equal (it can double its value if the collision is perfectly elastic: rain soaks you, but hail can hurt!), because of the ice grains rebounding on the ground. So, to be strict, for the hail: $p_d = \rho \cdot i_c \cdot (v_c - v_{rb})$, being v_{rb} the rebound velocity after the collision with the ground (it has negative sign and therefore it sums in the previous expression).

At this time, as a conceptual curiosity, we can define the individual flow (or unitary flow, *q*) originated by an isolated rain drop when trying to enter the ground. Its expression is:

$$q = v_c \cdot \pi \cdot \frac{D^2}{4} \qquad \text{Eq. 39}$$

being: v_c , characteristic arrival velocity of the drop on the ground
D, diameter of the drop

This drop, when arrives the ground, expands, gets fractionated and in the end penetrates the porous mean or slips superficially, or follows both ways.

As for the resistance to compaction of the ground (p_c), it depends on a characteristic diameter of the soil and its humidity at the moment of the collision. At this respect we can consider a 'Proctor Natural' compaction test, acting in this case the rain drops or hail stones or the snow grains like a rammer. Magnitude p_c can be obtained directly for a certain soil by a physical test of simple compression of the soil superficial horizon for different humidity contents. A general formule to estimate this physical magnitude (p_c) can resemble the "total normal pressure", which is a concept developed in the batters estability analysis (Ayala, 1991). This resistance (p_c) can be clasified in six great groups according to the values on Table 2, that is due to Lambe and Whitman (1988), but that we present here in the modified version by Navarro (2002).

Table 2: Resistance of cohesive soils to penetrability (simple compression test) (by Lambe and Whitman (1998); modified by Navarro (2002))

Resistance to simple compression (kp/cm^2)	**Consistency**
< 0,25	Very soft
0,25 – 0,5	Soft
0,5 – 1,0	Medium
1,0 – 2,0	Semitough
2,0 – 4,0	Tough
> 4,0	Rigid

The Navarro number (*NA*) for a rain (reduced by vegetation on arrival to the soil) can be greater or equal than zero. For this reason we must establish a similar restriction than that of Pando number (*PA*). In this case, the restriction is:

$$NA = 0 \quad if \quad p_c \geq p_d$$

Finally, we can claim that the process of crust formation is ruled by a certain law or function that involves this two monomials. Consequently, the risk of superficial crusts formation (*Rt*) in a mineral soil can be defined by the following expression:

$$Rt = \varphi_4(NA, PA) \quad \text{Eq. 40}$$

This expression can be an orientation in the study of crust formation process, that is a serious problem and one of the main causes of desertification of agriculture soils in the world. The generic index that we propose can be related to several models on erosion existing at present time (USLE, RUSLE, WEPP, EUROSEM, etc). But this will be matter of a future work.

The problem of crust formation was and is very well known by farmers, who combat its formation by using different labours, year after year (even month after month), for reducing its negative effects. This is visible, for example, in the traditional dry farming practiced in Spain since immemorial time, in the system termed “year and turn” (before the arrival of fertilizers).

2.4 Final considerations

Can forests reduce the Greenhouse Effect, the effects of our consumism excess on Planet Earth, by getting as input carbon dioxide CO_2 and transforming it into carbohydrates? we think that partially yes, but it would be difficult if we keep on reducing the forest surface. This extreme paradox can clarify the answer: With our *progress* we can think of the next situation, as eloquent as a joke: will the last surviving tree from our consumist madness fix the problem we are generating with our unsustainable development? Answer is clearly no!.

Consequently, a crucial question to make is: How much coal and fuel can be burned in a sustainable manner?. To this question we don’t have the answer, not even vaguely.

But other question related and – in part – equivalent is: How much degraded surface (with little or null vegetation) can we have in our continents?. For the Climate Change is referred among other things to the natural water cycle and this is being altered substantially with our unsustainable development (and we insist: without looking at the indiscriminated burning of fossil fuels).

We think that the alterations that we are generating with the masssive burning of fossil resources must be compensated by capturing the CO_2 excess by means of vegetation, that will need more water for executing this task. It implies: that we must favour the infiltration in emerged lands of our planet if we want to attenuate the Greenhouse Effect. We remark that this is only a reasonable supposition that many scientists consider at present time.

Without doubt, it’s urgent to study deeper this issue. The infiltration function that we propose can help in the progress of finding a right solution to the big problem we have ahead. The task ahead is beautiful and hard at the same time; it constitutes a technical and intelectual challenge.

An important alteration of hydrological cycle at a local level leads to a different microclimate, much more arid than the original. This alteration implies a reduction of the infiltration, an increase of superficial runoff and of hydric erosion, altogether with other noticeable changes (as for example the reduction of primary production in that place, the fertility loss of the soil, the decreasing of density and height of vegetation in the ecosystem (see Martínez de Azagra, Mongil & Rojo, 2004)). By reducing (or even blocking) the infiltration in a certain place, there is a progress towards desert in that place and the surroundings. The area is desertificating.

The proposed infiltration function can be useful (once is concreted) to determine the grade of alteration of hydrological cycle in a certain place, without perturbing the ecosystem as a whole in an irreversible way.

Alteration of hydrological cycle (= of infiltration) that humans are generating cannot be considered only as local and sporadic, but rather general and global, which can be inducing changes not only in microclimate but also in Earth mesoclimate and macroclimate.

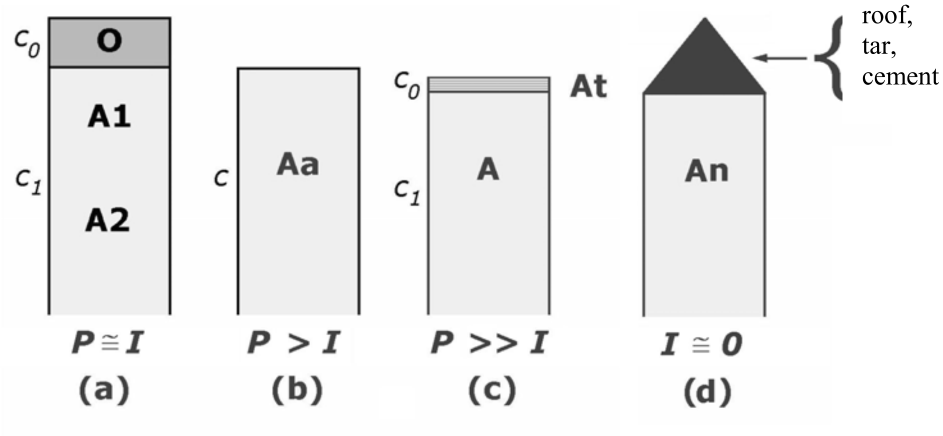

Fig. 3. Edaphogic simplified classification distinguishing four big groups of soils: natural soils (a), agriculture (b), strongly desertificated (not compatible with agriculture) (c) , and completely anthropic soils (anthroposoils) (d). (P= precipitation in a year; I= infiltration in a year)

How much surface in situation (c) and (d) can we have as maximum in the planet, without being in danger our life and our planet?. Developing functions as the one here proposed can give answers in a close future (and in time) to a such a crucial question. Soils of type (b) and (d) are necessary, essential to Humans. However, soils of type (c) must be reduced to a minimum. They must be transformed into soils of type (a) or (b) in order to compensate our effect on Earth, due to present overpopulation in many regions of our planet, which is not sustainable. Equally, for the rational planning of the territory, it seems more and more essential to plan for urban use (soils of type (d)) basically the non-fertile soils, and to reserve for agriculture use (soils of type (b)) the fertile soils and river margins.

As basic previous works to study deeper infiltration, we must define a complete, clear and unique protocol to make infiltration tests reliable and comparable for all kinds of soils and with a reasonable testing time (less than a working shift).

A lot of infiltration tests must be made, interpreted and compared.

The value of the main adimensional coefficients (MA, RE, PA, NA, etc) must be obtained for the different texture classes defined by the USDA. In this sense Rawls, Brakensiek and Miller (1983) have started this task for the parameters of the Green & Ampt model, which is a remarkable work that we think must be followed with the parameters and monomials of the infiltration function that we propose.

Symbols meaning

The notation used in this communication and the meaning of each symbol is resumed in the following table.

Table 3. Meaning of symbols used in this work.

a	Soil characteristic length according to horizontal x axis {L}
a_h	Linear humidity length according to horizontal x axis {L}
A	Name of a parameter of Holtan model {$L^{(1-n)}\cdot T^{-1}$}
An	Anthropic horizon
Ao	Mineral horizon with much not decomposed vegetal rests
A1	Upper mineral horizon
Aa	Often ploughed upper horizon
At	Superficial crust
b	Soil characteristic length according to y axis {L}
b_h	Linear humidity length according y axis {L}
B	Mineral horizon formed in the soil inner side
c	Soil characteristic length according vertical z axis {L}
c_h	Linear humidity length according vertical z axis {L}
c_0	Upper horizon depth {L}
c_1	Underlying horizon depth {L}
C_i	Generic adimensional coefficient (=π_i)
CA	Cauchy number {adim}
d_0	Characteristic pores length in the superficial horizon, (superficial horizon characteristic diameter) {L}
d_1	Characteristic pores length in the second horizon, (underlying horizon characteristic diameter) {L}
d_h	characteristic diameter of suspended particles in the water {L}
D	Rain drop diameter {L}
DR	Del Río number {adim}
E_d	Hydrodynamic thrust {$M\cdot L\cdot T^{-2}$}
EU	Euler number {adim}
f, $f(t)$	Soil infiltration capacity at instant $t = \dfrac{dF}{dt}$ {$L\cdot T^{-1}$}
f_c	Final infiltration capacity {$L\cdot T^{-1}$}
F, $F(t)$	Accumulated infiltration at instant t {L}
FR	Froude number {adim}
g	Gravity acceleration {$L\cdot T^{-2}$}
i, $i(t)$	Rain intensity {$L\cdot T^{-1}$}
i_c	Rain characteristic intensity {$L\cdot T^{-1}$}
k_s	Permeability or hydraulic conductivity in saturated porous mean {$L\cdot T^{-1}$}
k_0	Superficial horizon permeabilty {$L\cdot T^{-1}$}
k_1	Underlying horizon permeability {$L\cdot T^{-1}$}
L, $L(t)$	Length; difference of height between soil surface and humid front (Green & Ampt model) {L}
M	Name of a parameter in the Holtan model; initial volume of non saturated pores = $S(0)$ {L}
MA	Martínez de Azagra number {adim}
n	Name of a parameter in the Holtan model {adim}

NA	Navarro number {adim}
O	Organic horizon
PA	Pando number {adim}
p_c	Soil resistance to compacting (or compression) $\{M \cdot L^{-1} \cdot T^{-2}\}$
p_d	Hydrodynamic pressure of rain on the soil $\{M \cdot L^{-1} \cdot T^{-2}\}$
p_e	Effective porosity {adim}
q	Individual (or unitarian) flow of an isolated rain drop $\{L^3 \cdot T^{-1}\}$
Q	Volumetric water flow (also ice or snow flow) that impacts on the soil during a rain $\{L^3 \cdot T^{-1}\}$
RE	Reynolds number {adim}
R_t	Crust formation risk {adim}
s	Sorptivity (Philip model) $\{L \cdot T^{-0,5}\}$
S	Capilary suction (Green & Ampt model) {L}; Area supporting the impact (in factor C_{16}) $\{L^2\}$
$S(t)$	Volume of non saturated pores available in soil for storing water at instant t (modelo de Holtan) {L}
SR	Strouhal number {adim}
t	Time {T}
t_p	Ponding time {T}
v_c	Characteristic velocity of arrival of a meteor to the soil; characteristic velocity of arrival of a drop to the soil $\{L \cdot T^{-1}\}$
$v_i(t)$	Infiltration velocity at instant t $\{L \cdot T^{-1}\}$
v_{rb}	Rebound velocity after impact of hail stone or granulated snow against the soil $\{L \cdot T^{-1}\}$
v_∞	Limit velocity of a particle falling into a viscous fluid (in this case: air) $\{L \cdot T^{-1}\}$
WE	Weber number {adim}
χ	Water turbidity $\{M \cdot L^{-3}\}$
ε	Volumetric elasticity module $\{M \cdot L^{-1} \cdot T^{-2}\}$
ϕ, ϕ_i	A generic function
γ	Water specific weight $\{M \cdot L^{-2} \cdot T^{-2}\}$
η	Humidity defficiency = $\theta_s - \theta_i$ (Green & Ampt model) {adim}
φ, φ_i	A generic function
μ	Dynamic viscosity coefficient $\{M \cdot L^{-1} \cdot T^{-1}\}$
π_i	Generic monomial {adim}
θ	Volumetric humidity {adim}
θ_i	Initial volumetric humidity of soil {adim}
θ_s	Volumetric humidity in the saturated area of the soil {adim}
ρ	Absolute density of water or hail, or apparent density of granulated snow $\{M \cdot L^{-3}\}$
ρ_a	Apparent density of the soil superficial horizon $\{M \cdot L^{-3}\}$
ρ_c	Characteristic density of the soil superficial horizon $\{M \cdot L^{-3}\}$
ρ_s	Absolute density of the soil mineral particles $\{M \cdot L^{-3}\}$
σ	Surface tension coefficient $\{M \cdot T^{-2}\}$
ξ	Tortuosidad del flujo del agua infiltrada en el suelo {L}
ξ_0	Pores tortuousity in the superficial profile {L}
ξ_1	Pores tortuousity in the underlying profile {L}
ψ	Hydric potential $\{M \cdot L^{-1} \cdot T^{-2}\}$

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