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"A Routine Laboratory Index to Predict the Effects of Soil Sealing on Soil and Water Conservation"

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ASSESSMENT OF SOIL SURFACE SEALING AND CRUSTING

Proceedings of the Symposium held in Ghent, Belgium, 1985

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CONSERVATION

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A ROUTINE LABORATORY INDEX TO PREDICT THE EFFECTS OF SOIL SEALING ON SOIL AND WATER CONSERVATION.

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ABSTRACT

A simple method that measures both the aggregate stability of surface soil to raindrop impact, and the changes in saturated hydraulic conductivity of the seal formed in the upper part of the soil in introduced. Drops of distilled water formed by a constant head system are applied 2,5 m. above a layer of soil aggregates in a rotating sieve, at a constant selected rate. The water percolating through the layer of soil aggregates is collected and measured at short intervals. Hydraulic conductivity values calculated for each time interval are plotted versus cumulative kinetic energy of the water drops reaching the soil surface. The index of sealing is based on the minimum constant value of hidraulic conductivity, and the cumulative kinetic energy of falling water drops required to reach such value. Measurements, during the last fourteen years in very different natural and treated soils in Venezuela, have shown very good qualitative correspondences of the index with field and laboratory observations and measurements related to soil and water conservation under natural and simulated rainfall. Very good correlations are shown between this index and soil particle size distribution, specially with the clay, and the silt + very fine sand + fine sand, fractions. It is recommended as a laboratory routine method of characterization of the soil physical properties more related to problems of soil and water conservation problems in tropical rainfed agricultural lands.

INTRODUCTION

Sealing on the surface soil generally is the result of the disintegration of the original aggregation by impact of water drops during rainfall. This happens when the soil is unprotected, after tillage operations previous to planting, or in the early stages of crop growth. In the formed seal, the different sized paticles are oriented and stratified, and as a consequence the large pores are fewer and the bulk density is higher than in the soil below. Therefore, the saturated hydraulic conductivity of this surface layer is generally low, limiting infiltration. The reduction in water intake may reach one or two orders of magnitude, being the prime factor causing flooding, water runoff, and erosion. The amount of soil removed by runoff water also depends mainly on the destruction of aggregates by raindrop impact. In many cases, as the surface seal dries becomes a crust hard enough to interfere with the emergence of seedlings.

The interactions among rainfall characteristics, the original conditions on the soil surface, and the soil characteristics cause the correlation between rainfall and infiltration to vary widely. When the raindrops are larger the formed seal is thicker because the original structure is destroyed to a greater depth. If rainfall exceeds intake rate, soil particles going into suspension in the ponded water tend to segregate with the finer ones left on top. Due to rainfall and soil characteristics in most of the rainfed agricultural areas of Venezuela (Pla et al, 1979; Pla, 1981), and in many other tropical and subtropical areas of the world, the sealing of the soil surface is the main factor directly responsable of runoff and erosion. The resultant irregular water regime is the main cause of the very erratic and defficient agricultural production based on seasonal rainfed crops in the tropics (Pla et al, 1974, 1981). Appropiate utilization of the soils and management practices to prevent these problems have been proposed, but the required practices will vary with each particular combination of rainfall and soils. With the high variability of the surface soils even in a same climatic area, it becomes very important to preview, through a simple laboratory test, the variable response of each soil to the rainfall action, mainly in relation to seal formation.

In the past several laboratory methods have been developed, both for measuring the ability of soil aggregates to resist the disruptive forces of raindrop impact (Mc Calla, 1944, Bruce-Okine and Lal, 1975), the sealing effects of rainfall on the soil surface (Pereira, 1956; Mc Intyre, 1958), and both the rain infiltration and soils losses (Moldenhauer and Long, 1964) or soil detachment (Romkens et al, 1975). Different systems of raindrops formation and application to soil samples ranging from a single soil aggregate to indisturbed soil cores, have been used. Common to all of them is the use of small laboratory samples and simulated rainfall with uniform raindrop distribution at a known and constant intensity. Indices for erosion risk assessment, based on the results of direct measurements of aggregate stability to rainfall impact (Bruce-Okine and Lal, 1975) and for indirect assessment of the "crustability" of top soils through consistency values (De Ploey, 1981) have also been proposed.

Taking into consideration the above referred experiences and based on the very good correspondence with field and laboratory observations and measurements in very different natural and treated soils in Venezuela (Pla, 1975, 1981; Pla et al, 1974, 1979, 1981), there is proposed a new index to be used routinely for prognosis of sealing effects on soil and water conservation.

MATERIAL AND METHODS

Figure 1 shows the laboratory assembly for measuring what we call "sealing index". With the soil sample and measuring assembly for percolating water at bench level, distilled water drops of 4,5 mm. diameter from three droppers 2,5 m. above the soil surface are continuously applied for 60', at a constant calibrated intensity of about 90 mm/hour. This approximately corresponds to the energy of impact of the average 60 mm/hour for 30-60', natural rainfall in rainfed agricultural areas of Venezuela (Pla, 1981; Pla et al, 1981).

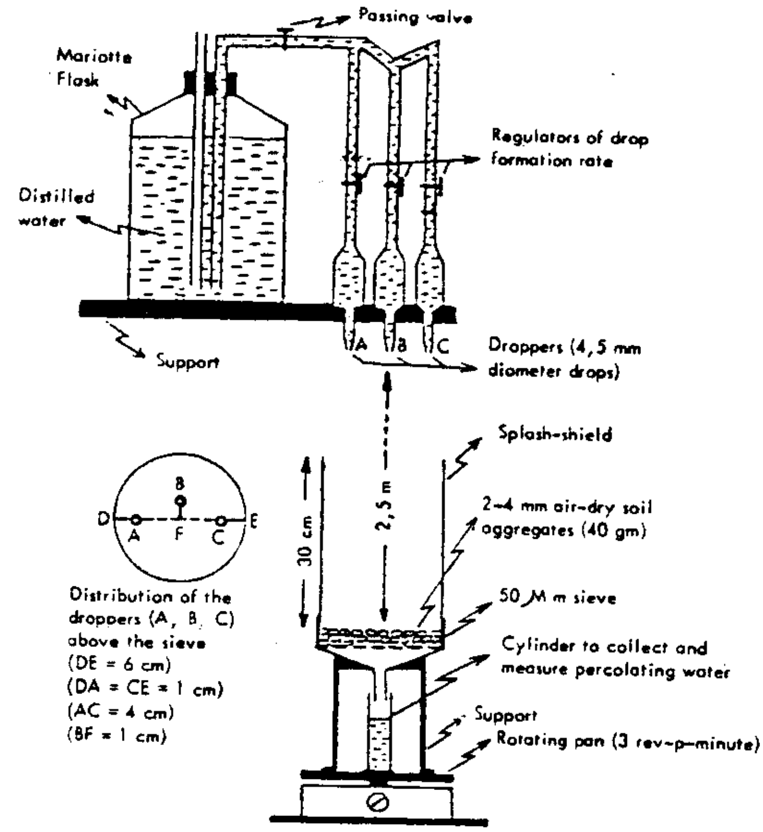

Figure 1.- Laboratory system to measure the "sealing index".

Uniform raindrop impact distribution is assured through the distribution of the droppers above the soil and by a continuous rotation of the sample assembly during the test. The soil samples consist on 40 gm. of sieved air-dry aggregates 2-4 mm. in diameter, in order to assure a more uniform original material. Larger aggregates are crushed to that size. When more than 50% of the original soil material is not aggregated or in aggregates less than 2 mm., common in sandy soils, a sample of the whole soil is used. The sample is uniformly distributed on the net of a 50 μm mesh sieve of about 6 cm. diameter. This results on a layer of soil about 1 cm. thick when wet. A cylinder 30 cm. high is mounted on the upper side of the sieve to form a splash-shield; therefore, all splash returs to the soil surface.

Once the falling water starts percolating through the layer of soil, it is collected and measured at 1-2 minutes intervals. Values of saturated hydraulic conductivity (K) are calculated for each time interval, using the corresponding volumes of percolating water, and hydraulic gradients. These gradients are calculated assuming that the soil is essentially saturated with water and 1 cm. thick when percolation occurs, and taking for each interval the resulting average hidraulic head from the cumulative depth values of rainfall over percolation.

Plotting K values versus cumulative time, or versus cumulative impact kinetic energy, the resulting decrease in K is associated with the degree of seal formation (Figs. 2 and 4). After a certain time or cumulative kinetic energy a minimum constant value of K is reached, which we call "sealing index".

- RESULTS AND DISCUSSION

In order to demostrate the usefullness and universal application of the method of measurement and the "sealing index" derived from it, size very diverse surface agricultural soils were tested. (Table 1, and Fig. 2).

Table 1.- Measured and calculated —best fit equations*— values of "sealing" (Y_1: minimum value of hydraulic conductivity in the "seal" formed on the soil surface) and "wet sieving" (Y_2: water-stable aggregates larger than 2 mm. given as % of dry weight soil) indexes for different agricultural soils in Venezuela. (X_1: silt + very fine sand + fine sand given in % of dry weight soil; X_2: clay, given in % of dry weight soil).

SOIL	ORDER	X_1 (%) (2-250 μ)	X_2 (%) (< 2 μ)	"SEALING INDEX" Y_1 (mm/hour) Measured	Calculated	"WET SIEVING INDEX" Y_2 (%) Measured	Calculated
GUANIPA	Ultisol	77	10	25	20	11	15
CHAGUARAMAS	Alfisol	73	17	10	12	7	15
BARINAS	Alfisol	37	19	30	24	37	21
FANFURRIA	Entisol	75	25	2	4	9	15
GUANAGUANARE	Inceptisol	54	42	2	3	38	18
RICOA	Vertisol	14	86	7	6	4	29
CHAGUARAMAS I	Alfisol	77	15	11	13	18	15
CHAGUARAMAS II	Alfisol	79	19	7	8	16	15
CHAGUARAMAS III	Alfisol	75	20	9	8	6	15
CHAGUARAMAS IV	Alfisol	73	23	5	7	7	15
CHAGUARAMAS V	Alfisol	[illegible]	28	3	5	18	16
CHAGUARAMAS VI	Alfisol	71	28	3	4	7	16

* $Y_1 = 91,82 - 0,39 X_1 - 18,1 \ln X_2$ ($R^2 = 0,82$)

* $Y_2 = 53,13 - 8,84 \ln X_1$ ($R^2 = 0,17$)

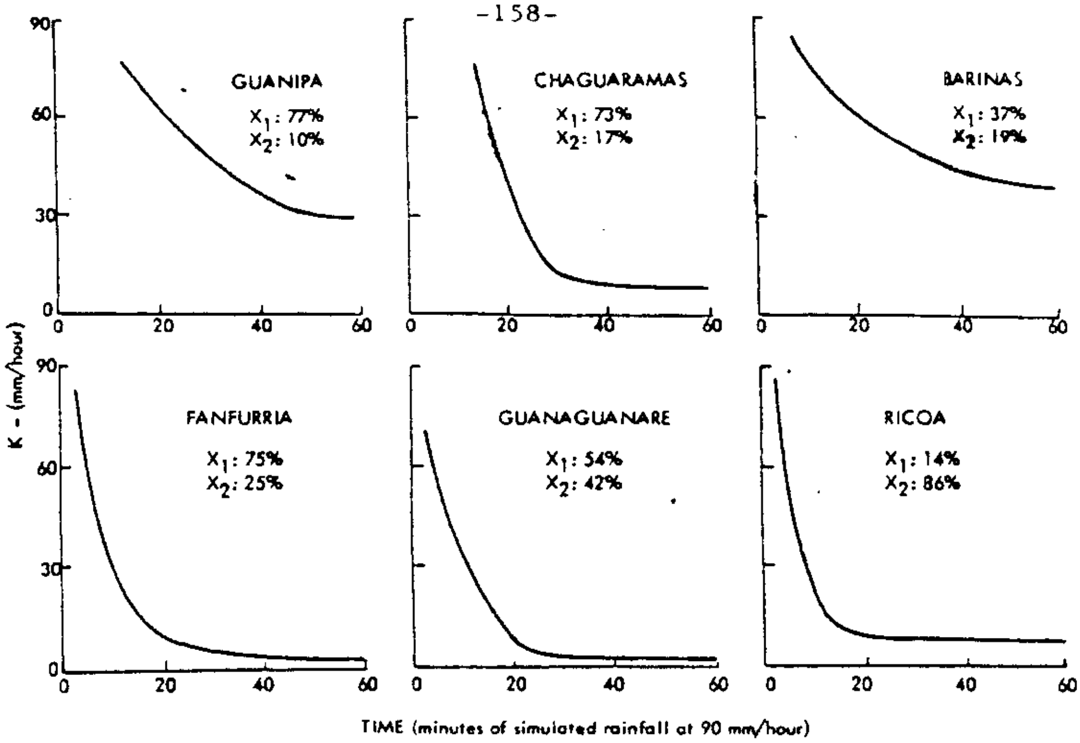

FIGURE 2.- Hydraulic conductivity (K) of the seal vs time of laboratory simulated rainfall at 90 mm/hour using the system of figure 1, in six different agricultural soils of Venezuela (see table 1).

Besides, "wet-sieving index" (Y_2) values (water-stable aggregates larger than 2 mm) for the same soils are given to check their correlation with the "sealing index" (Y_1). With Y_1 and Y_2 as the dependent variables, stepwise multiple regression were run with the different particle size fractions and combination of them as independent variables. The best fit equations selected to predict Y_1 and Y_2, were:

$$Y_1 = 91,82 - 0,39X_1 - 18,1 \ln X_2 \quad (R^2 = 0,82)$$

$$Y_2 = 53,13 - 8,84 \ln X_1 \quad (R^2 = 0,17)$$

The highest correlation for "sealing index" (Y_1) was obtained using the clay (X_2) and the silt + very fine sand + fine sand (X_1) fractions as the independent variables. No satisfactory correlation was obtained among the "wet-sieving index" (Y_2) and any of the particle size fractions. Figure 3 shows the graphical relations among Y_1, and the X_1 and X_2 particle size fractions.

An independent testing of the best-fit equations in six different textured Chaguaramas soils (Table 1), shows similar correlations.

Figure 4, presents the graphical results of the "sealing index" test on those soils.

As a demonstration of the very good qualitative correspondence of the "sealing index" with field measurements under simulated rainfall, figure 5 shows the runoff, soil losses, and waterlogging results for six of the soils included in table 1.

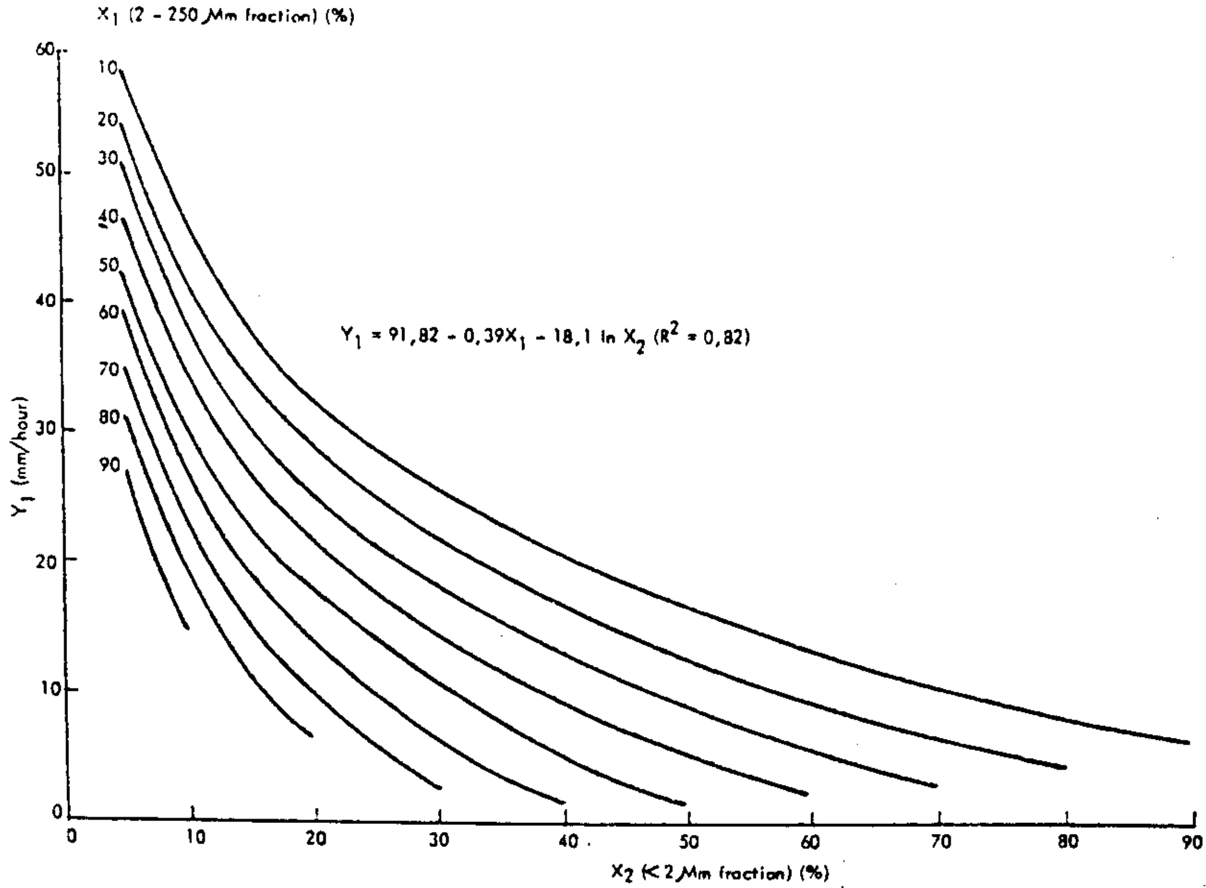

FIGURE 3.- Graphical representation of the relationships - best fit equation-between the "sealing index" (Y_1) or minimum value of K in mm/hour, and the clay (X_2) and silt + very fine sand + fine sand (X_1) fractions in % of dry weight soil.

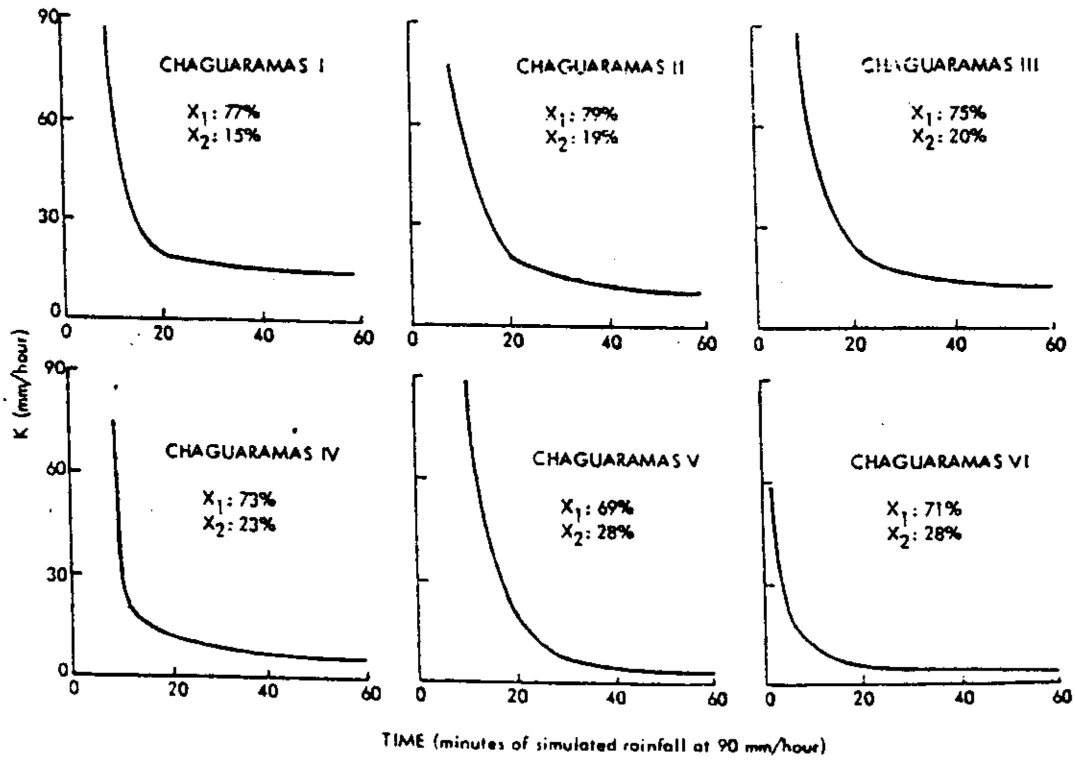

FIGURE 4.- Hydraulic conductivity (K) of the seal vs time of laboratory simulated rainfall at 90 mm/hour using the measurement system of figure 1, in Chaguaramas surface soil with six different particle size distributions. (See table 1).

The measurements were made in 3 x 1 m. plots, along the slope, with air dry surface soil tilled for planting. Although the infiltration rates reached at the end of the 60' text period are generally higher thatn the minimum constant values of K ("sealing indices"), their values are probably influenced by the higher hydraulic gradient between the surface of the seal and the air dry soil inmediately below, and by the larger-up to 5 cm - original soil aggregates in some of the soils.

FIGURE 5.- Cumulative infiltration and soil erosion losses of simulated rainfall (100 mm/hour) tests under field conditions in six agricultural soils (see table 1) with different "sealing indexes" (Y_1).

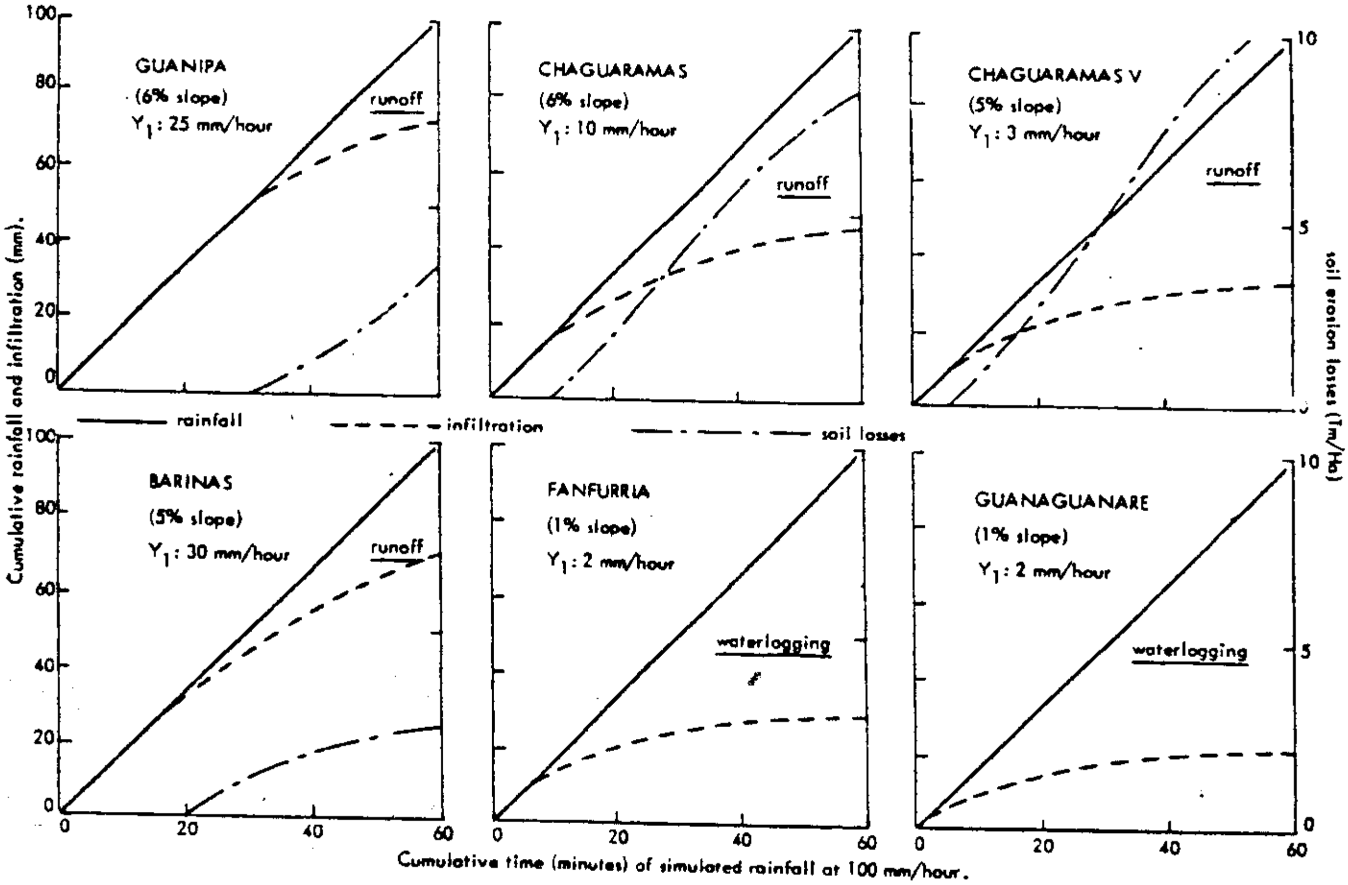

TABLE 2.- Proposed —1st approximation— "sealing index" (Y_2) evaluation for rainfed agricultural soils in Venezuela.

SLOPE (% in the field)	Y_1 (K: mm/hour)	TIME* (minutes)	KINETIC ENERGY** (Kgm/m^2)	PROBABILITY OF: (in bare soil)
				Waterlogging
0-2%	< 5	30-45	60-90	Very high
	5-10	"	"	High
	> 10	"	"	Low
				Runoff and erosion
2-5%	< 10	30-45	60-90	Very high
	10-25	"	"	High
	> 25	"	"	Low
				Runoff and erosion
> 5%	< 25	30-45	60-90	Very high
	25-50	"	"	High
	> 50	"	"	Low

* Time required to reach the Y_1 values with simulated rainfall at 90 mm/hour.

** Approximate cumulative kinetic energy of the simulated rainfall when the Y_1 values are reached.

CONCLUSION

The proposed method is well adapted ro become a laboratory routine determination, simple, rapid and inexpensive, for measuring in a continuos manner the most important sealing effects of falling drops on the soil surface. Although the conditions of formation of surface seals are not the same as field conditions, where varying weather produce a wide range in the actual size and energy of raindrops, and the limitations on the area of the samples, it appears that the resulting seals have similar properties, at least qualitatively, in both cases. As a single value, the introduced "sealing index" appears to be a good approach for the physical routine characterization of the surface soil in relation to potential problems of soil and water conservation, particularly in the tropics.

The very low correlation of the "wet-sieving index" with particle size distribution demonstrate once more that the mechanisms and factors responsible for the destruction of aggregates are different according to the process involved. In the case of sealing by waterdrop impact, the presence of soil particles not very large, with platty shapes and low cohesion among them (silt, very fine sand, fine sand) favors such sealing effects upon orientation on the soil surface. The clay fraction helps to reduce even more the saturated hydraulic conductivity of the seal, and increases the cohesion of particles and hardness of the crust when the seal dries out.

Further applications of the proposed method are possible through the measurement and evaluation of the silt + clay fractions moving with the percolating water, and of the modulus of rupture of the surface crust resulting from the seal formed during the test when it dries out.

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