A RAIN SIMULATOR FOR QUICK FIELD TESTS OF INFILTRATION AND SOIL LOSS EVALUATION

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The evaluation of certain soil features, such as erodibility and infiltration, is of primary importance in planning farming activities which these soils are able to support.

In order to get quick, even if short-term, evaluations on these soil features, we set up and used a small portable rain simulator which was very reliable.

The data obtained with this simulator will serve in comparison with the result obtained on the same soils with a larger simulator (**Zanchi, 1983**); this so as to utilize the portable simulator expeditiously for quick erodibility estimates.

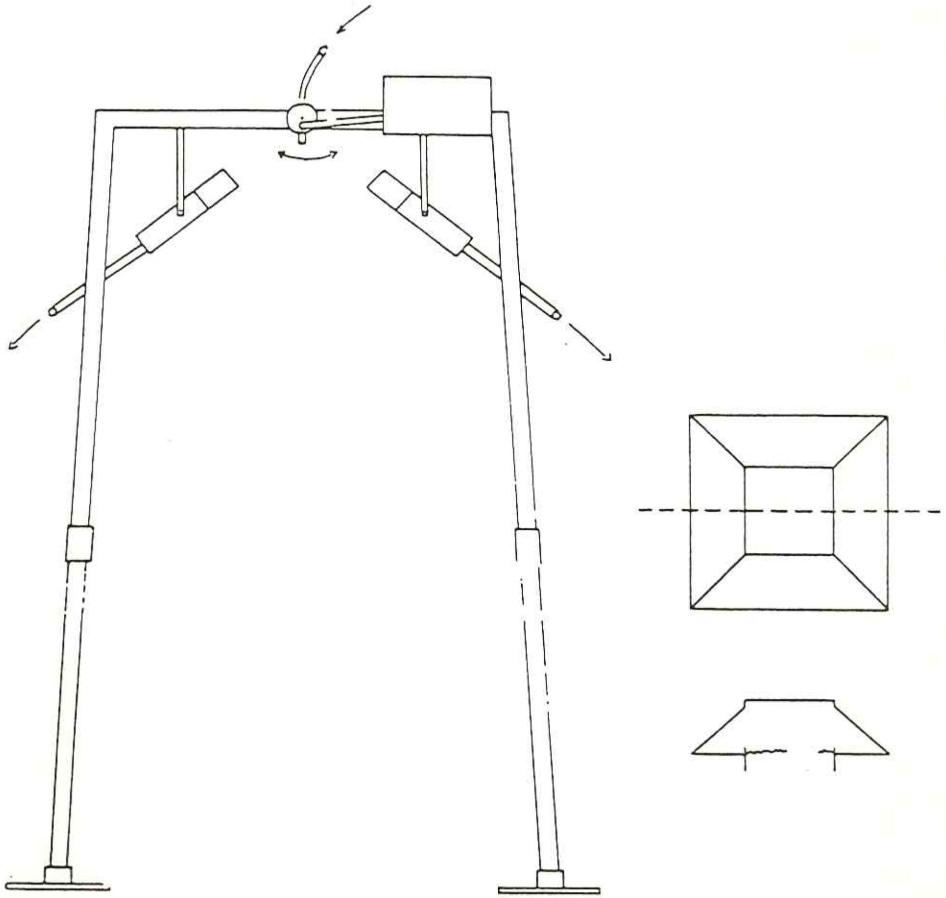
The experimental results herein reported were obtained on three types of soils, with different textural classes, spread out over an extensive area (the Mugello Valley in Tuscany, Italy) chosen as a representative study area under the auspices of the P.F. - I.P.R.A. (Finalized Project - Agricultural Resources Productivity Increment) of the Italian National Research Council, who financed the project.

DESCRIPTION OF THE RAIN SIMULATOR

The simulator used was made up of an alluminum mount with four collapsible legs which enabled it to adapt to the terrain surface, and to direct the rainfall vertically with respect to the horizontal plane. The four legs support a small electric motor powered by a small generator which, through a connecting rod and cam, causes the bar on which the nozzle is mounted to oscillate perpendicularly to the longer axis of the wetted ellipse as well as perpendicularly to the slope (**Figure 1**).

Oscillation speed can be varied by intervals of between 60 and 300 oscillation per minute, by changing the rotation speed of the electric motor. This variation may be done from the electronical control board without interrupting the rain simulation. This feature greatly improves the quality of the simulation, since increase in movement speed at the same rain intensity considerably reduces the non-spraying time on the plot.

Figure 1



The intensity of the simulated rain may be regulated, besides by varying the oscillation speed, by the use of a timer which, with microswitches, determines a delay in one of the two sides of the nozzle. During this delay the nozzle sprays into funnels placed on either side of the nozzle, to avoid watering the ground. in this way it is possible to simulate low intensity rainfall with intermittent periods (non-spraying on plot area) reduced to a minimum.

The water intercepted by the funnels is conveyed through tubes to a tank, from which it is returned to the nozzle by means of a lift and force pump.

To facilitate transportation, the tank is composed of five separate alluminum walls which may be rapidly assembled by means of connecting plugs which act as supports for a rubber-sheeted sack with a capacity of about 220 liters.

The nozzle used, a veejet 80100, produces a broad flat fan-like spray which diminishes in intensity the farther the sprayed area of the ellipse gets from its center, that is, on its longer axis.

In order to obtaina uniform distribution of simulated rainfall, the size of the test site was fixed at 0.60 x 0.60 m (0.36 m^2).

The nozzle at a working pressure of 0.41 kg/cm^2 (corresponding to a discharge of 14.3 l/min) makes it possible to obtain an impact speed, a drop pattern and a kinetic energy (**Zanchi et al., 1983**) similar to those of natural rainfalls.

The plot delimiter employed, to permit an easy collection of splashed material and of material transported by inter-rill erosion, is made up of a gabled structure (**Figure 2**); three metal sheets soldered together under the roof around three of the four sides of the delimiter are sunk a few centimeters into the ground so as to isolate the plot hydraulically from the rest ot the soil. The splashed material from the plot is then swept toward the two discharge mouths one on each side, where it is gathered into specia containers. The roof, placed above the four side of the delimiter, prevents the simulated rain from agai "Splashing" into the plot any material previously carrie away from it.

The particles carried away by inter-rill erosio are swept to the measuring station by way of a smal through placed on the lower side of the plot.

EXPERIMENTAL PLAN

The simulator was used during this first phas of research at 9% slope to evaluate the erodibilit and infiltration of three bare fallow soils of differen textural classes with three different rain intensitie (23.7; 60.5; 103.3 mm/h). The soil examined are:

- Eutric Cambisols (Sprocco area);
- Calcaric Regosols (Crocioni area);
- Mixture of Eutric and Calcaric Regosols (Fagn. area).

The features of these three types of soils ar shown in **table 1**.

Table 1.

Skeleton	Clay	Silt	Sand	pH	$CaCO_3$	Organic matter	Soil
%	%	%	%		%	%	
0	52.0	35.0	13.0	7.8	14	2.0	Calc. Reg.
4	20.9	25.8	53.3	7.6	/	2.6	Mixture
0	4.0	5.5	90.5	6.8	/	2.0	Eutr. Camb.

The rain intensities were chosen on the basis o the representativeness of their recurrences; it wa noted in fact that the 23.7 mm/h intensity was represen tative of the maximum precipitations over a 24-hour period at a recurrence time of 1 year; a 60.5 one represents a maximum 24-hour precipitation with a recurrence time of 5 years, and a 103.3 mm/h one represents the maximum precipitations with a recurrence time of 10 years.

In order to verify the influence, in the comparisons of the splash and of inter-rill erosion of differing intensities within the time-span of the same simulated event (1 hour), the possible successions, each having a 20-minute duration, of the three above-mentioned intensities, were executed (see **table 5**).

All the tests, aside from having been repeated twice, were executed on wet soil obtained after one hour of simulated rain and with a brief interval before the start of the test.

The sampling was made at five minute intervals, with alternating measurement of runoff discharge and of those for the runoff collecting, which were afterwards analysed in the laboratory. We naturally made sure to crowd in the measurements both at the beginning and at the end of the tests, in order to obtain information on the runoff pattern and on the trend of soil concentration.

EXPERIMENTAL RESULTS

Splash, inter-rill erosion

The following **figures 3a, b, c,** show the results obtained from the simulation tests and indicate that at a 23.7 mm/h intensity no substantial differences are noticed in the inter-rill erosion of the three types of soil. With an increase in rain intensity the Eutric Cambisols turn out to be more subject to erosion than the Calcaric Regosols and the combination of Eutric and Calcaric Regosols which are characterized by a higher clay content (**Figure 3a**).

As for splash erosion, the results show that the Eutric Cambisols, as compared with the two other types of soil, are more subject to the action of rain-drop splash. In the case of the Eutric Cambisols the amount of splashed soil notably increases with an increase in rain intensity. The Calcaric Regosols, with their higher clay content, are less subject to splash action, particularly at the 23.7 mm/h and the 60.5 mm/h intensities, while no substantial differences are noted between these and the association of Eutric and Calcaric Regosols at the highest intensity (103.3 mm/h).

As a general trend it was observed that with the Eutric Cambisols the amount of soil splashed increase considerably with the increase in rain intensity; this increase is far less marked in the Crocioni area soils. As for the Calcaric Regosols, the amount of splashed soil, on the contrary, did not increase with the incres in intensity (**Figure 3b**).

The values of splash, inter-rill erodibility show in the **figure 3c**, make clear the greater susceptivit of the Eutric Cambisols, characterized by a highe sand an silt content, as compared with the two othe types of soil.

Erodibility values decrease noticeably with a increase in intensity from 23.7 to 60.5 mm/h. At intensities greater than 60.5 mm/h the splash-inter-ril erodibility of the Calcaric Regosols and of the combination of Eutric and Calcaric Regosols remains nearl constant; with the Eutric Cambisols, however, it continues to decrease in a fairly noticeable manner (**Tabl** 2).

This might indicate a lack of correspondence wit the methodology used by **Wischmeier and Smith** (197 for erodibility evaluation. Since notably greater eros vity values (R) correspond to lower increments of soi loss (splash and inter-rill) with an increase in rai intensity.

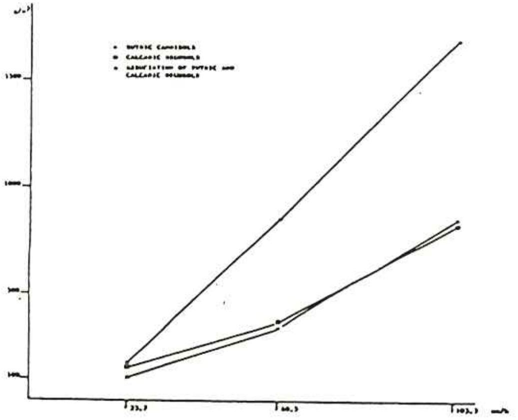


Fig. 3a

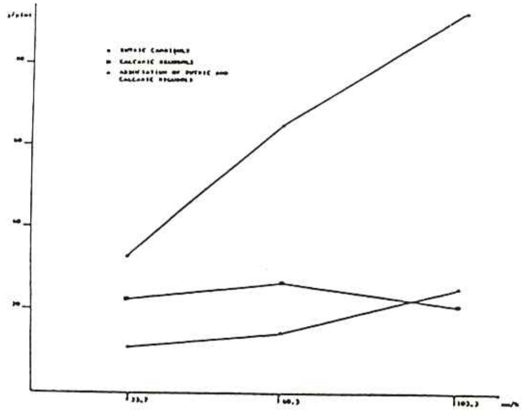


Fig. 3b

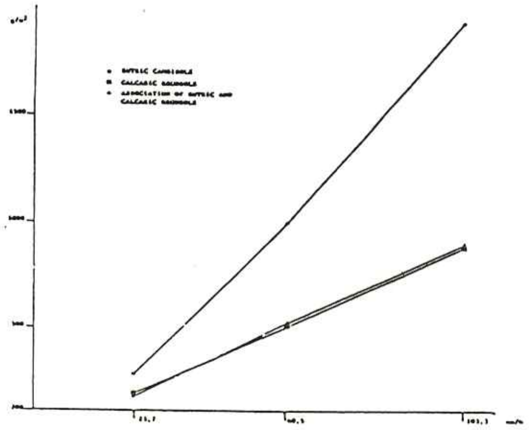


Fig. 3c

Table 2.

Intensity	Eutric Camb.	Calcaric Reg.	Mixture
23.7	0.020	0.014	0.012
60.5	0.010	0.004	0.004
89.0	0.009 0.007 0.008	0.003 0.002 0.002	0.002 0.002 0.002
103.3	0.006	0.003	0.003

Infiltration

Infiltration was determined as the difference between the amount of rainfall and the measured amount of runoff.

The infiltration rate values during each rain simulation test made possible a more exhaustive study of their feature's pattern, For each rain simulation event, simple regressions of the accumulated rainfall and of progressive time from the beginning of the rain were done with the least square method, and were considered as independent variables, as opposed to the corresponding infiltration rate, considered as dependent variables.

The regression analysis of the progressive time (t) as compared to the infiltration rate (Ir), presented in **table 3**, and the accumulated rainfall (q) as opposed to the infiltration rate, presented in **table 4**, show that these equations:

$$Ir = A + B/t \quad (1) \qquad \text{and} \qquad Ir = A + B/q \quad (2)$$

Table 3.

Soils	Intensity	Equation	A	B	R^2	Steady Infiltration rate
EUTRIC CAMBISOLS	23.67	Y = A + B/X	0.023	0.014	0.949	0.03
	60.5	Y = A + B/X	0.0696	0.0017	0.889	0.08
	103.3	Y = A + B/X	0.154	0.015	0.945	0.17
CALCARIC REGOSOLS	23.7	Y = A + B/X	0.0588	0.0025	0.987	0.06
	60.5	Y = A + B/X	0.095	0.030	0.928	0.08
	103.3	Y = A + B/X	0.191	0.034	0.969	0.19
ASSOCIATION OF EUTRIC AND CALCARIC REGOSOLS	23.7	Y = A + B/X	0.0698	0.0025	0.970	0.07
	60.5	Y = A + B/X	0.1556	0.0088	0.926	0.14
		$Y = A . X^{B}$	0.3788	-0.1836	0.939	0.22
	103.3	Y = A + B/X	0.2276	0.1084	0.842	

Table 4.

Soils	Intensity	Equation	A	B	R^2	Steady Infiltration rate
EUTRIC CAMBISOLS	23.7	Y = A + B/X	0.0223	0.1015	0.9343	0.03
	60.5	Y = A + B/X	0.0703	0.0068	0.8551	0.08
	103.3	Y = A + B/X	0.1530	0.0259	0.9380	0.17
CALCARIC REGOSOLS	23.7	Y = A + B/X	0.0589	0.0173	0.9874	0.06
	60.5	Y = A + B/X	0.0952	0.0845	0.9285	0.08
	103.3	Y = A + B/X	0.1909	0.0555	0.9690	0.19
ASSOCIATION OF EUTRIC AND CALCARIC REGOSOLS	23.7	Y = A + B/X	0.0697	0.0184	0.9725	0.07
	60.5	Y = A + B/X	0.1556	0.0250	0.9274	0.14
		$Y = A . X^B$	0.4055	-0.1816	0.9465	0.22
	103.3	Y = A + B/X	0.2175	0.1796	0.9018	

have the maximum R-square and the minimum-maximum absolute residuals.

Only for the tests on the combination of Eutric and Calcaric Regosols, at a 103.3 mm/h intensity the best fit was obtained with an equation of the type:

$$Ir = At^B \qquad \text{and} \qquad Ir = Aq^B$$

even if equations (1) and (2) have a high determination coefficient (R-square of 0.90 and 0.84, respectively).

The coefficient values A and B given in **tables 3** and **4** indicate that their value varies as a function of soil type, and rainfall intensity. In particular, infiltration speed decreases rapidly with time (**Figures 4a, b, c**) untill it becomes stabilized.

As an example, for tests at 23.7 mm/h a steady infiltration is reached after about 10 minutes, for those at 60.5 mm/ha after about 8 minutes, and for those at 103.3 mm/h after about 7 minutes from the beginning of the test; an exception was evidenced in the test at 103.3 mm/h intensity on the association of Eutric and Calcaric Regosols, where stabilization occurred after more than 40 minutes from the start of the test. An analysis of the results show that the infiltration rate increases considerably with increasing rain intensity (**Figure 5**).

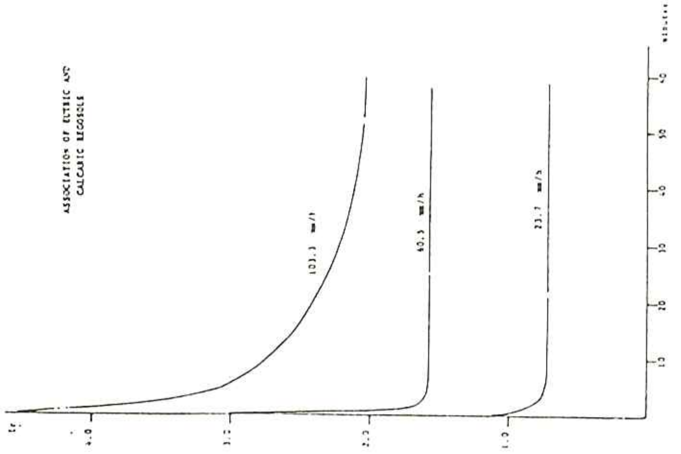


Figure 4c

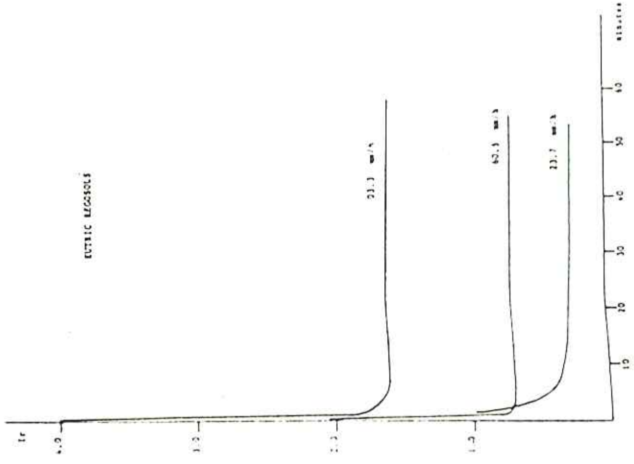


Figure 4b

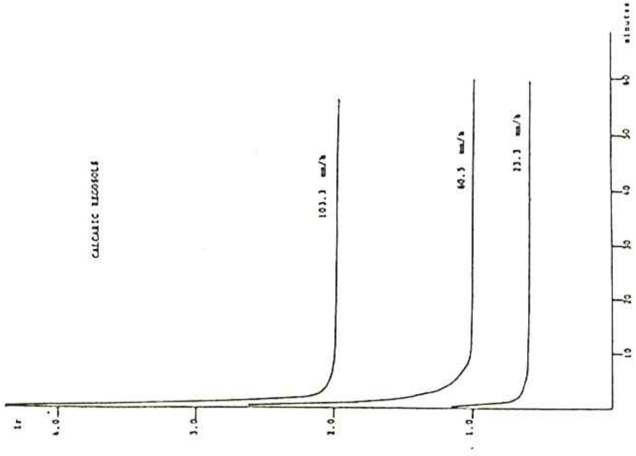


Figure 4a

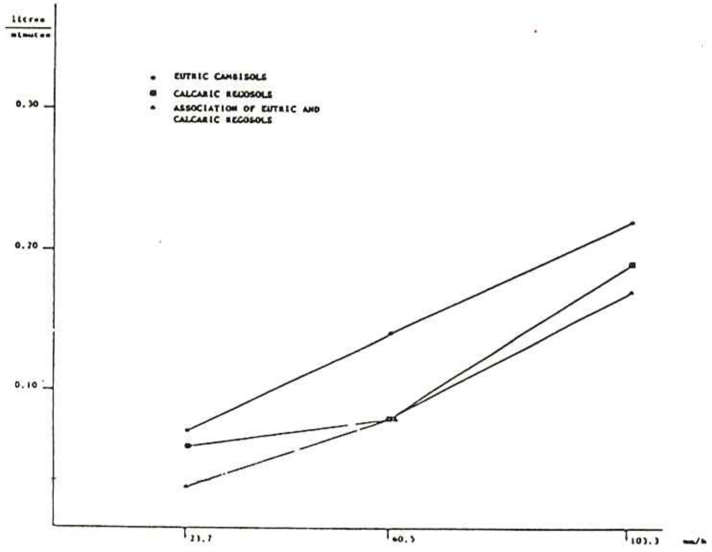


Figure 5

CONCLUSIONS

Following the analysis of the simulation test results, it was possible to determine the capacity of the "little" field rain simulator to duplicate with optimal approximation the intensities to be simulated. Moreover, a reduced difference was noted between replications at the same intensity for high values of this (103.3 mm/h). This confirms the usefulness of the instrument because of its simplicity and easiness of handling and the accuracy of its data for estimation of erodibility, besides the possibility of seeking correlations with simulators of larger size, or with fixed plots, wherever present.

As for infiltration data, it was observed a fair correlation between simulation repetitions at the same rain intensity. A more exhaustive analysis of infiltration characteristics, however, will require knowing other parameters, such as indicated in the Green-Ampt equation (1911), like, hydraulic conductivity, effective soil-water pressure, initial soil water content, etc.

At any rate, it seems that empirical equatio of the type:

$$Ir = A + B/t \quad \text{and} \quad Ir = A + B/q$$

may be used with a fair degree of confidence to predi the infiltration pattern in different types of soil.

Table 5.

Soils	Intensity	Erosion	Conc.	Splash	Infiltration	
EUTRIC CAMBISOLS	23.7	36.2	6.6	65.5	0.03	20 minutes
	60.5	239.9	14.9		0.05	
	103.3	765.4	19.9		0.11	
	60.5	143.6	10.3	59.0	0.08	20 minutes
	103.3	383.3	16.6		0.17	
	23.7	244.7	8.6		0.04	
	103.3	304.8	11.3	53.2	0.12*	20 minutes
	23.7	32.2	7.5		0.04*	
	60.5	447.8	13.7		0.06*	
CALCARIC REGOSOLS	23.7	20.4	7.1	11.7	0.05	20 minutes
	60.5	151.4	10.0		0.09	
	103.3	316.6	22.2		0.17	
	60.5	78.3	7.5	8.8	0.05	20 minutes
	103.3	207.2	10.0		0.21	
	23.7	17.7	5.2		0.06	
	103.3	244.1	10.4	13.6	0.17	20 minutes
	23.7	17.7	5.4		0.06	
	60.5	78.7	7.5		0.11	
ASSOCIATION OF EUTRIC AND CALCARIC REGOSOLS	23.7	1.7	2.7	21.7	0.13	20 minutes
	103.3	37.3	4.4		0.40	
	60.5	29.2	3.8		0.19	
	60.5	43.6	4.1	32.4	0.13	20 minutes
	23.7	6.4	3.3		0.07*	
	103.3	122.0	6.7		0.20	
	103.3	127.3	6.6	21.2	0.24*	20 minutes
	60.5	57.2	5.9		0.17*	
	23.7	6.0	3.9		0.12	

* Not steady

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