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On involving hydrological research in land use improvement

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ABSTRACT The optimum use of land resources is a current problem of major importance. Essential to the solution of this problem is a knowledge of the water resources and hydrological research is, therefore, aimed at obtaining an understanding of the characteristics of water resources and the interdependence between the use of water resources and land use. For typical climatic, geomorphological and soil conditions the research should identify the specific hydrological parameters which are modified by land use change. This paper describes some case studies concerned with research on these relationships between hydrology and land use improvement.

Sur l'introduction de recherches hydrologiques dans l'amélioration de l'utilisation des sols

RESUME L'utilisation optimale des ressources en terres cultivables pose un problème courant mais de grande importance. La connaissance des ressources en eau est essentielle pour trouver une solution à ce problème, et la recherche hydrologique doit par conséquent tendre à déterminer les caractéristiques des ressources en eau liées à l'utilisation des sols. Pour des conditions typiques climatiques, géomorphologiques et pédologiques, la recherche devrait identifier les paramètres hydrologiques spécifiques qui sont modifiés par le changement d'utilisation des sols. Cette communication décrit certains cas d'études comportant des recherches de ce genre sur les relations entre l'hydrologie et l'amélioration de l'utilisation des sols.

THE CORRELATION BETWEEN LAND USE AND HYDROLOGICAL ACTIVITIES

The rapid growth of population together with the generally higher living standard raises problems for land use-hydrology-water resources relations.

At present attention is mainly focussed on raising the fertile potential of land under extensive use and on reclamation works aimed at meeting the water demand for crops to guarantee maximum yields.

From the standpoint of water resources, the existing hydraulic structures and those being designed in Romania are concerned with:

(a) preventing damage being brought about by water;

(b) providing the quality and quantity of water needed for agriculture both from surface and groundwater resources;

(c) maintaining a safe level of salinity;

(d) compensating for water deficit and eliminating water excess in the soil, according to crop/water requirements.

Hydrological research is differentiated according to the type of structure, to the agricultural procedures and to the natural conditions pertaining. For example, methods of preventing damage due to excess of water include: stream regulation, dyke building, and drainage.

Such works require hydrological data on floods, such as the precipitation regime of the site, and the probability curve of the maximum discharges at the river stations of interest. The main source of these data is long-term records at permanent gauging stations. Similarly research on the other three areas requires data and the derivation of parameters which may not always be available. The remainder of this paper now deals with several experiments in which some of these data were obtained.

SOME HYDROLOGICAL PARAMETERS USED IN THE DESIGN AND OPERATION OF LAND RECLAMATION WORKS

Hydrological parameters are used initially in planning the basis of land reclamation projects aimed at the optimum use of water resources. This paper presents some of the hydrological parameters required and how such parameters can be derived. The main criterion used is scale, as the parameters are derived for:

(a) very small areas - 0.50 m^2;

(b) experimental plots - hundreds of m^2;

(c) complete basins, using mathematical models.

An experimental determination of the relationship: "rainfall-infiltration-runoff" over small surfaces (both for water and sediments)

A mobile device for producing artificial rain was employed to provide a uniform wetting over a circular surface of 0.5 m^2. The intensity of the experimental rainfall is adjustable and may be kept constant during the experiment. The intensities used were: 0.50, 1.00, 1.50, 2.00 and 2.50 mm min^{-1}. The intensities of the experimental rainfall and of the runoff (either solid or liquid) are rigorously controlled.

This device may be used over terrain of various slopes and assures protection against wind due to its design. Losses through evaporation are also avoided. The experiments continue under given conditions of rainfall intensity, soil, slope, vegetation, etc. until the runoff reaches a steady state over an interval of some tens of minutes. Accurate knowledge of the variation in time both of the rainfall depth and of the runoff depth allows the determination of the infiltration loss from the moment the rainfall starts to the moment the runoff ceases. The variation in sediment runoff over the experiment may be determined through turbidity analysis on the samples collected from the runoff at pre-selected time intervals.

The results of these studies emphasize the influence of the various factors (initial soil moisture, slope, type of soil, extent of vegetation cover) on the infiltration and runoff processes.

In Fig.1 the relationship between rainfall intensity i_p and runoff depth $i_s(c)$ is presented for various soil moisture conditions (W%) and slopes (p%).

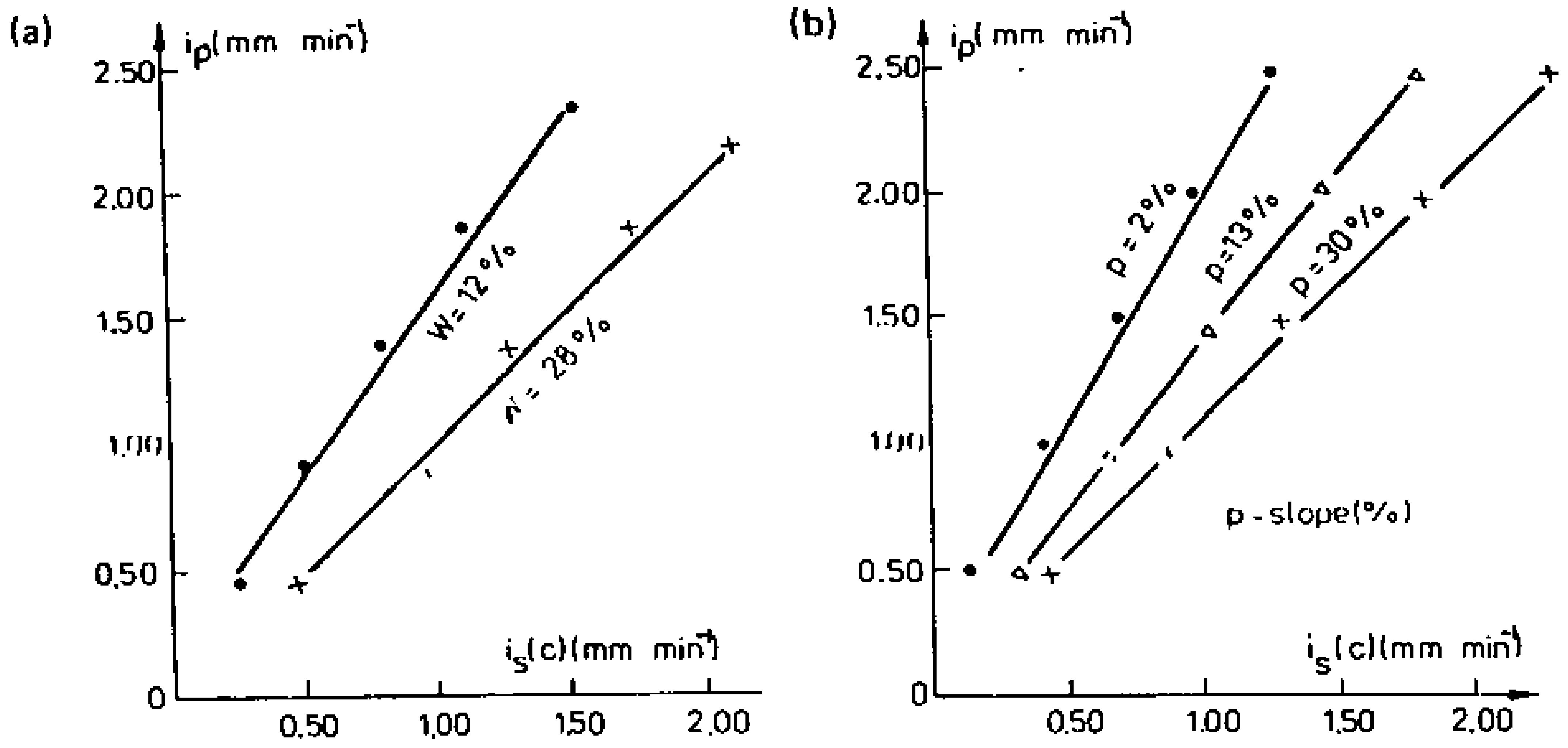

FIG.1 (a) Relationships between rainfall intensity and runoff intensity for different soil moisture values. (b) Relationship between $i_s(c)$ and i_p for different slopes.

Under similar conditions of soil-type, slope and rainfall intensity, the type of agriculture strongly influences the infiltration intensity (i_{fc}). For instance, on pasture with slopes of 12%, on the same type of soils and the same rainfall intensity (2.50 mm min^{-1}), the steady infiltration intensity is 0.55 mm min^{-1}, while under tilled land the steady infiltration is 0.97 mm min^{-1} (Table 1). This table shows the values of the maximum runoff coefficient (α_{max}) for the given conditions.

The overland solid transport, expressed in terms of turbidity S_a (g l^{-1}) was analysed as a first stage in relation to the experimental rainfall intensity, the slope of the land and the extent of vegetation cover. All sets of experiments resulted in an increased turbidity with increased intensities of rainfall. For example, with the first set of experiments, the maximum turbidity increased from 8 g l^{-1} under a rainfall intensity of 1.0 mm min^{-1} to 23 g l^{-1} with a rainfall intensity of 3.5 mm min^{-1} (Table 1).

Under similar conditions of soil, vegetation cover and rainfall intensity, turbidity increases with slope. A comparison between the experiments with slopes of 12% and 21% respectively shows a difference of almost double the value in maximum turbidity under rainfall of constant intensity (Fig.2(a)).

With similar soil conditions and slope (i_t = 12%) and the same rainfall intensity, the value of the maximum turbidity depends on the condition of the soil surface.

TABLE 1

No.	Land use	p_t (%)	$i_p(c)$	$i_s(c)$ (mm min^{-1})	$i_f(c)$	α_{max}	$S_a max.$ (g l^{-1})
1	Pasture	12	1.00	0.61	0.39	0.61	8
2	Pasture	12	1.50	1.04	0.46	0.69	11
3	Pasture	12	2.00	1.50	0.50	0.75	17
4	Pasture	12	2.50	1.95	0.55	0.78	23
5	Pasture	21	1.00	0.72	0.28	0.72	25
6	Pasture	21	1.50	1.17	0.33	0.78	29
7	Pasture	21	2.00	1.65	0.35	0.82	37
8	Pasture	21	2.50	2.12	0.38	0.85	41
9	Tilled	12	1.00	0.28	0.72	0.28	22
10	Tilled	12	1.50	0.58	0.92	0.39	28
11	Tilled	12	2.00	1.14	0.86	0.57	34
12	Tilled	12	2.50	1.53	0.97	0.61	41

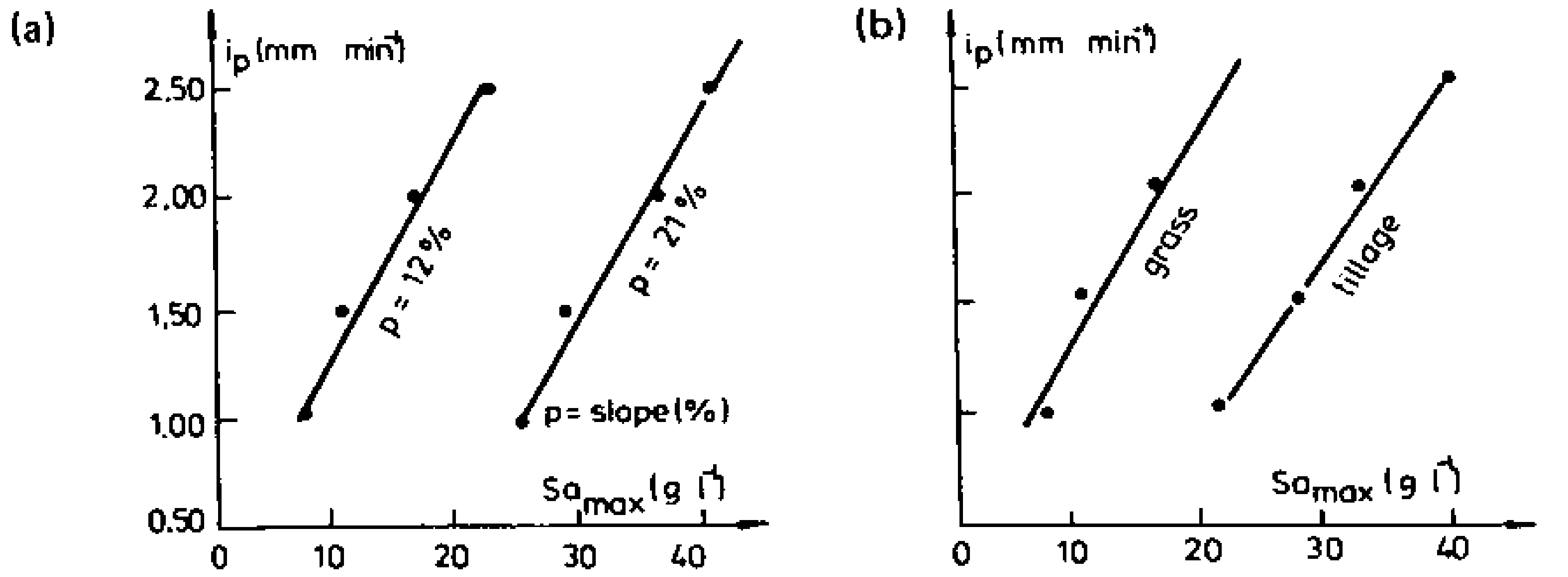

FIG.2 Relationship between rainfall intensity i_p and turbidity S_a for different slopes and land use.

A comparison of maximum turbidity values in the first set of experiments (pasture) and the third (tilled land) will show increased maximum turbidities for the tilled land by 78-180% (Fig.2(b)).

The relationship of the overland solid transport (S_a) to the maximum runoff intensity, the land slope and the type of vegetation is given in Fig.3. The experimental procedure described here allows the hydrological mapping of runoff parameters and implicitly, of soil erodibility in basins with agricultural crops. These parameters are very useful in designing and controlling land reclamation and soil conservation systems. The results of such studies may also be used as input parameters for various rainfall-runoff models.

The correlation between natural rainfall and surface and groundwater flow derived from experimental plots

Two 300 m^2 plots were used for the study of the water balance, while

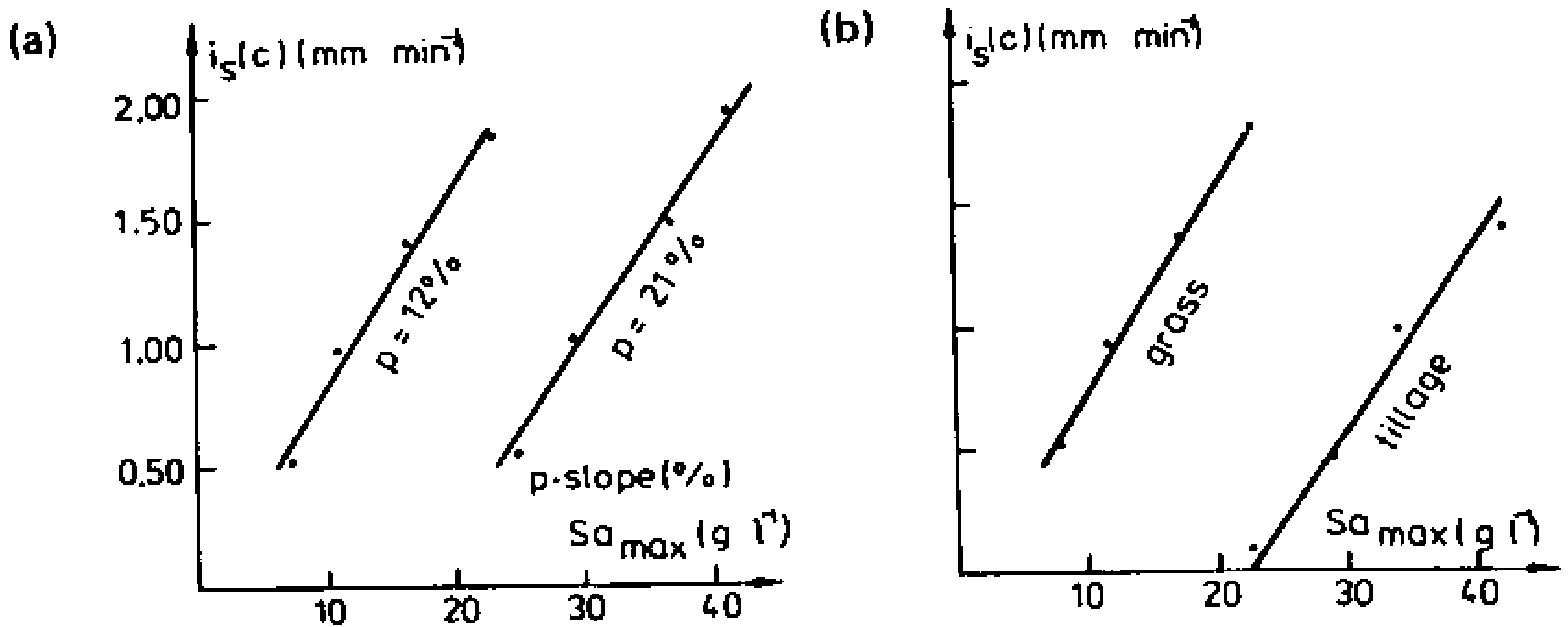

FIG.3 Relationship between runoff intensity $i_S(c)$ and turbidity S_a for different slopes and land use.

two 600 m^2 plots and one of 900 m^2 were employed for the study of runoff origination. The surface runoff, subsurface flow and groundwater flow were recorded on the water balance plots while on the runoff plots only the surface flow was recorded. The slope of the four experimental plots was 13% while the slope of the impervious layer (clay marl) of the two plots for water balance was 10.5%. The rainfall was recorded by a recording raingauge situated in the vicinity of the experimental plots. The results of these studies are presented in Table 2.

TABLE 2

No.	*H* (mm)	$I_{max\ p}$ (mm min^{-1})	$\alpha_{max\ 1}$	$\alpha_{max\ 2}$	$\alpha_{max\ 3}$	$\alpha_{max\ 4}$
1	29.6	0.55	0.39	0.30	0.26	0.21
2	30.6	1.60	0.44	0.30	0.32	0.21
3	16.3	0.80	0.30	0.19	0.15	0.17
4	24.9	1.77	0.29	0.22	0.21	0.16
5	49.1	1.24	0.55	0.41	0.47	0.41
6	17.7	0.74	0.31	0.19	0.17	0.21
7	17.9	0.64	0.38	0.26	0.29	0.29
8	19.5	0.80	0.25	0.19	0.19	0.17
9	81.2	0.98	0.29	0.24	0.17	0.21
10	26.4	0.41	0.35	0.27	0.27	0.27
11	47.8	1.32	0.59	0.44	0.51	0.43
12	20.2	1.07	0.25	0.88	0.20	0.17
13	69.7	1.03	0.72	0.63	0.66	0.55
14	44.7	0.42	0.50	0.41	0.43	0.38
15	36.4	1.11	0.39	0.29	0.33	0.30
16	54.2	0.86	0.59	0.53	0.54	0.47
17	64.4	0.67	0.75	0.59	0.63	0.54
18	66.6	1.50	0.66	0.52	0.64	0.61
19	55.3	1.62	0.62	0.44	0.53	0.45
20	16.0	0.58	0.26	0.18	0.14	0.12
21	43.0	1.55	0.55	0.50	0.42	0.35
22	21.3	0.79	0.32	0.24	0.20	0.18

where

h = depth of the rainfall (mm);

$I_{max\ p}$ = the maximum rainfall intensity (mm min^{-1});

α_1 = the maximum runoff coefficient on the 300 m^2 plot of untilled land;

α_2 = the maximum runoff coefficient on the 300 m^2 plot of tilled land;

α_3 = the maximum runoff coefficient on the 600 m^2 plot of untilled land;

α_4 = the maximum runoff coefficient on the 900 m^2 plot of untilled land.

The data recorded on the two water balance plots were used in order to emphasize the type of agriculture (tillage) and the groundwater flow. The surface of the first plot was grass, in a natural state, while the soil of the second plot was tilled to a depth of 0.30 m and seeded with grass.

In order to assess the influence of rainfall expressed by depth (h) and maximum intensity (I_{max}) on groundwater flow, a groundwater analysis was effected for plot 1.

Thirteen events of differing rainfall depths and intensities were selected. These depths were correlated with the ratios Q_1/Q_0, where Q_1 is the maximum groundwater discharge due to the rainfall event, and Q_0 is the basic groundwater discharge before the rainfall event.

In Fig.4 a satisfactory relationship is shown between h and Q_1/Q_0, for different I_{max}.

The infiltration capacity of the second plot was increased by working the surface soil layer and this contributed to the increased groundwater flow.

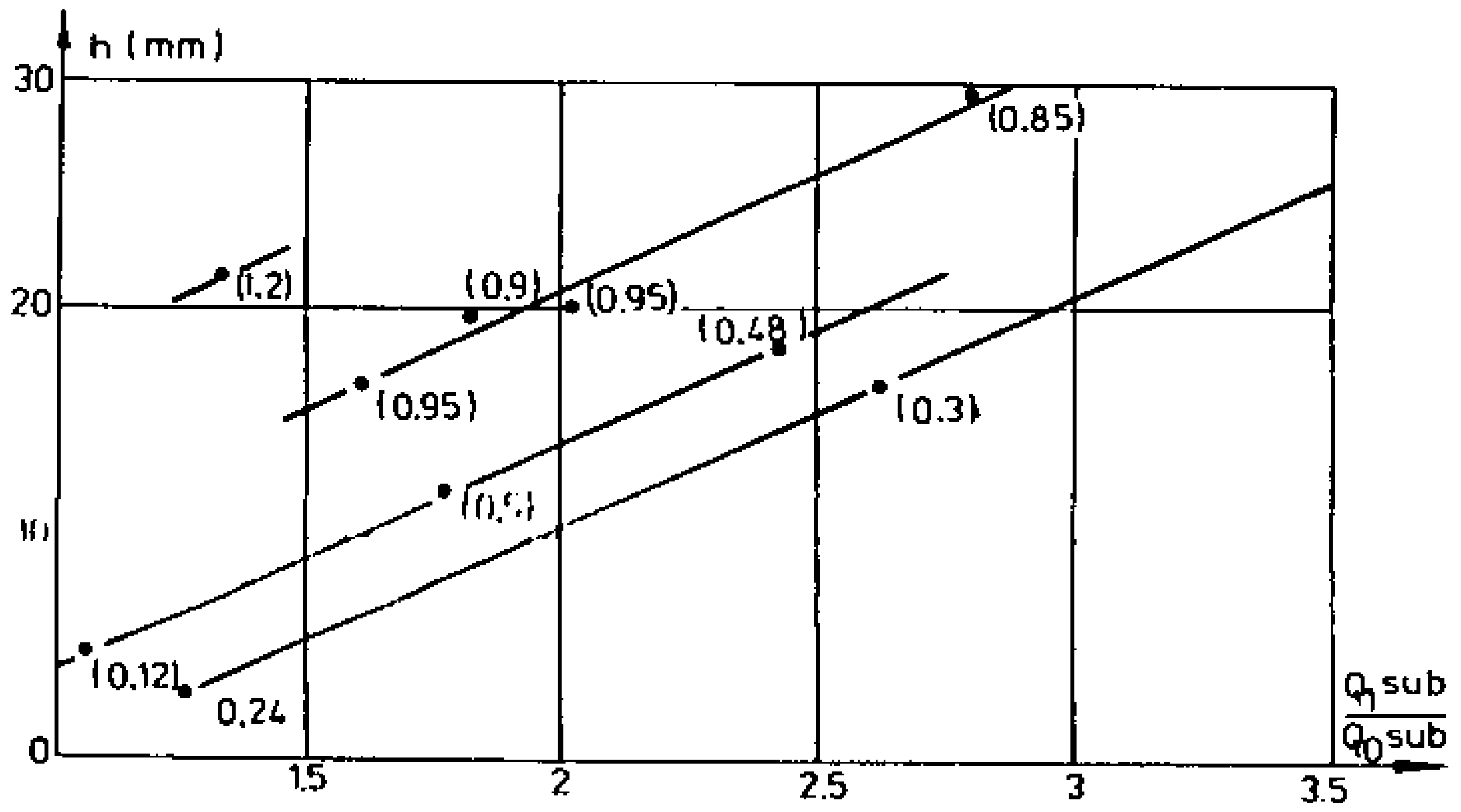

FIG.4 Relationship between rainfall depth h and groundwater discharge for various rainfall intensities.

Figure 5 shows the relation between the groundwater flow on plots 1 and 2 (Q_1 and Q_2 respectively). The relationship shows the particular importance of the state of the land in "rainfall-infiltration-groundwater flow" processes.

The influence of agricultural practice (tillage) on the "rainfall-surface runoff" process is shown by the relationships estab-

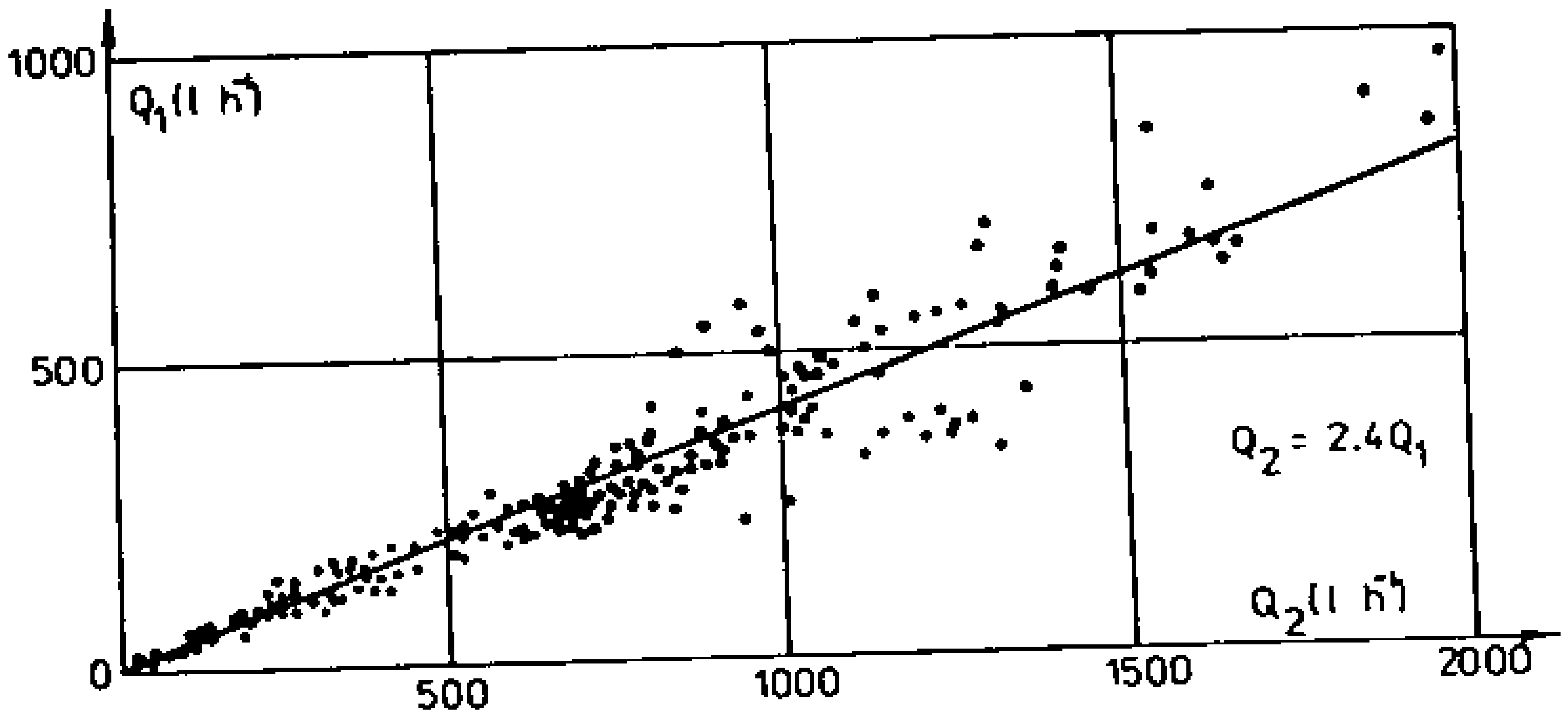

FIG.5 Relationship between groundwater discharges for two experimental plots.

lished between the rainfall depths (h) and the maximum runoff coefficients ($\alpha_{max\ 1}$ and $\alpha_{max\ 2}$ respectively), in Fig.6(a), (b).

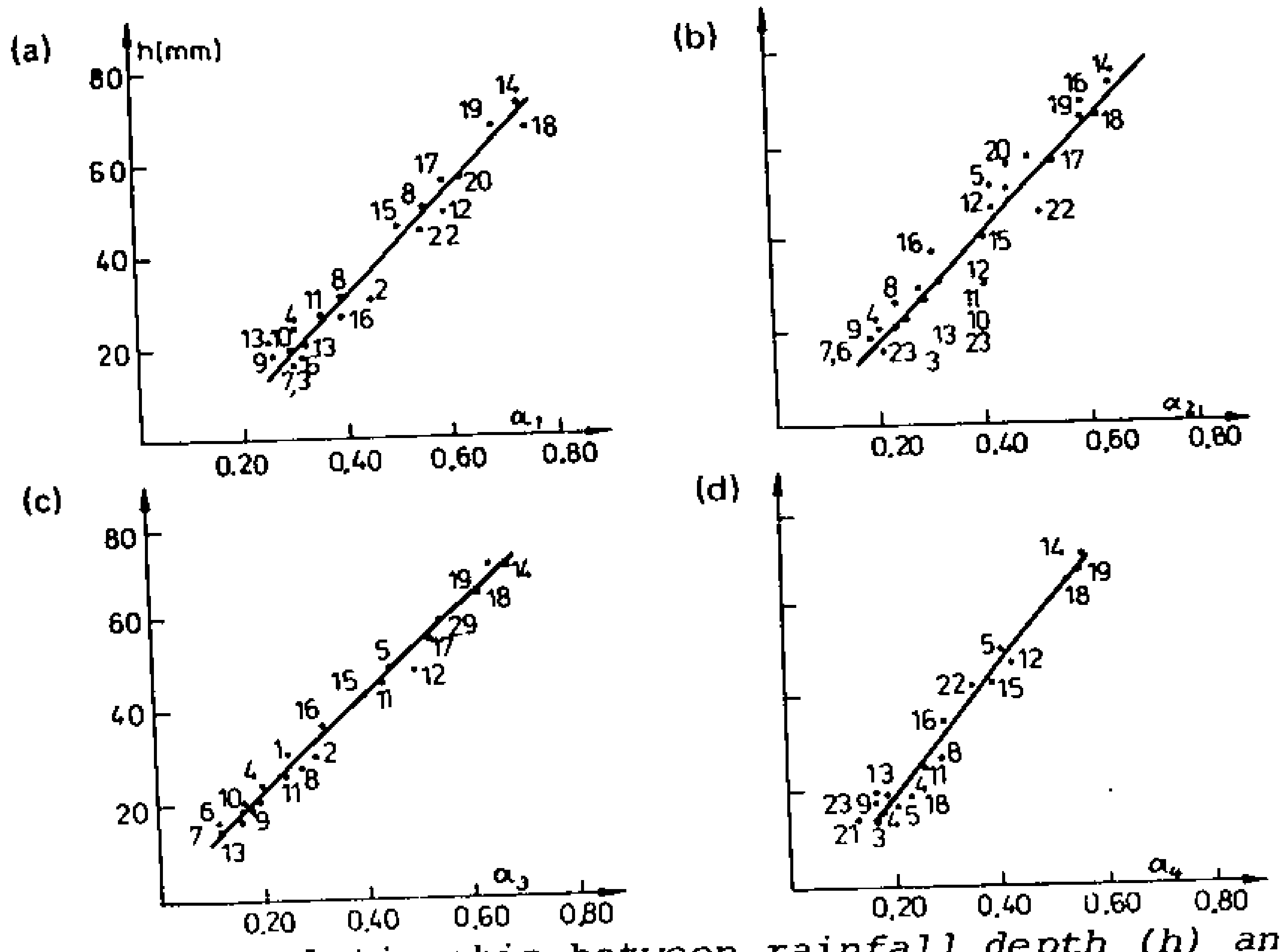

FIG.6 Relationship between rainfall depth (h) and maximum runoff coefficients (α_{max}) for four experimental plots.

In order to demonstrate the role of the slope length in runoff dynamics, an analysis was performed on the maximum runoff coefficients ($\alpha_{max\ 1}$, $\alpha_{max\ 3}$ and $\alpha_{max\ 4}$) for the three experimental plots with different slope lengths (30, 60 and 90 m) (Fig.6).

The value of the maximum runoff coefficient decreases with increasing slope length under the same rainfall conditions, with the same land inclination (p = 13%), vegetation cover and initial soil moisture. This effect is more noticeable with lower antecedent soil moisture conditions.

The application of this methodology and of the results obtained is really useful in the design and operation of the irrigation, drainage and soil conservation systems.

The use of rainfall-runoff models in analysing the hydrological effects of hydraulic structures

The application of statistical methods for the computation of hydrological parameters for slopes, or small basins is difficult due to the lack of long data series and to the rapid changes in the areas under consideration.

The development of computers with high computational speeds has made possible the development of models integrating the relationships between components of the runoff process at a sequence of points within the basin being investigated - distributed models. From the multitude of existing mathematical models, a physiographic type of model was adopted, which allows the hydrological effects of the hydraulic structures in a given basin (Blidaru *et al.*, 1980, 1982) to be quantified.

Figure 7 shows the concepts employed in the model. For application of the model the basin is divided into a finite number of units (Fig.8). The size of each unit was set so that the major hydrologi-

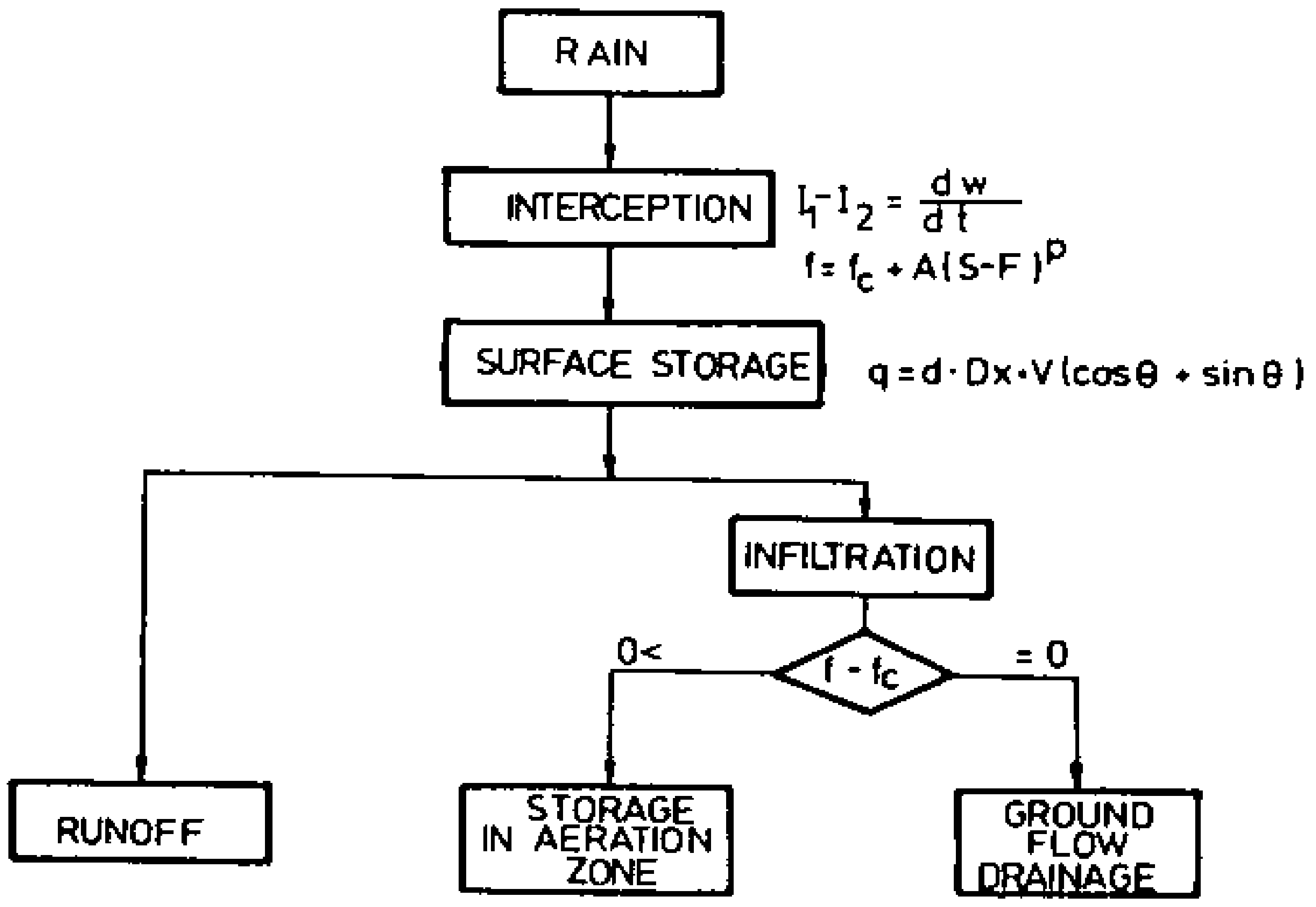

FIG.7 The model.

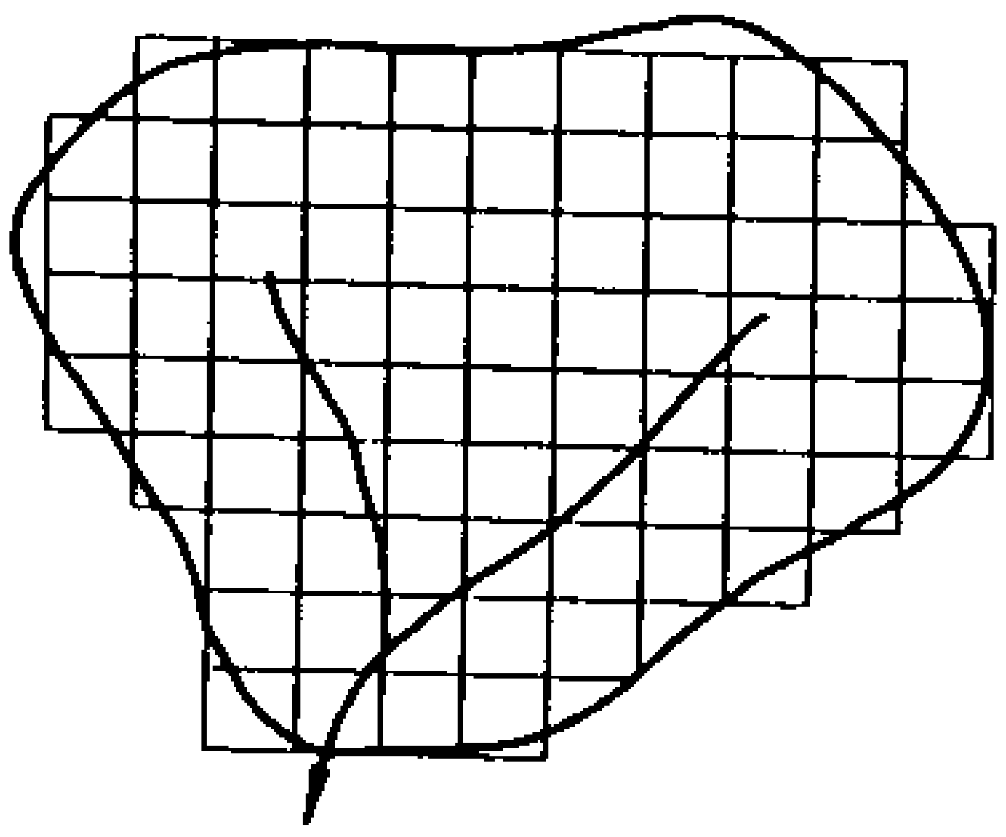

FIG.8 A division of the basin into a finite number of surface units.

cal parameters (rainfall, infiltration intensity, slope and direction, as well as the vegetation cover) would be constant within the same unit. The procedure involved the determination of a runoff hydrograph for each surface unit and the integration of all the resulting hydrographs for the entire basin.

The distribution runoff in time is determined by combining the relationship established between the water balance components with the continuity equation. The total runoff hydrograph for the entire basin to be computed may be obtained by starting from the given initial conditions and integrating the equation of continuity over the entire basin. The conceptual surface runoff model within a given unit of the basin under study is based on the division of the runoff cycle into several components. Each of these components may be independently incorporated into the general model. Water balance components employed in the mathematical model were generally determined by experimental means.

The major advantage of this model lies in its responsiveness to the modifications introduced by the parameters of hydraulic structures in the basin. The analysis revealed the fact that, excepting the rainfall, the most significant influence on runoff generation is the infiltration, which is itself a function of the initial soil moisture. Other significant contributing factors are the roughness coefficient, surface storage and interception (Fig.9).

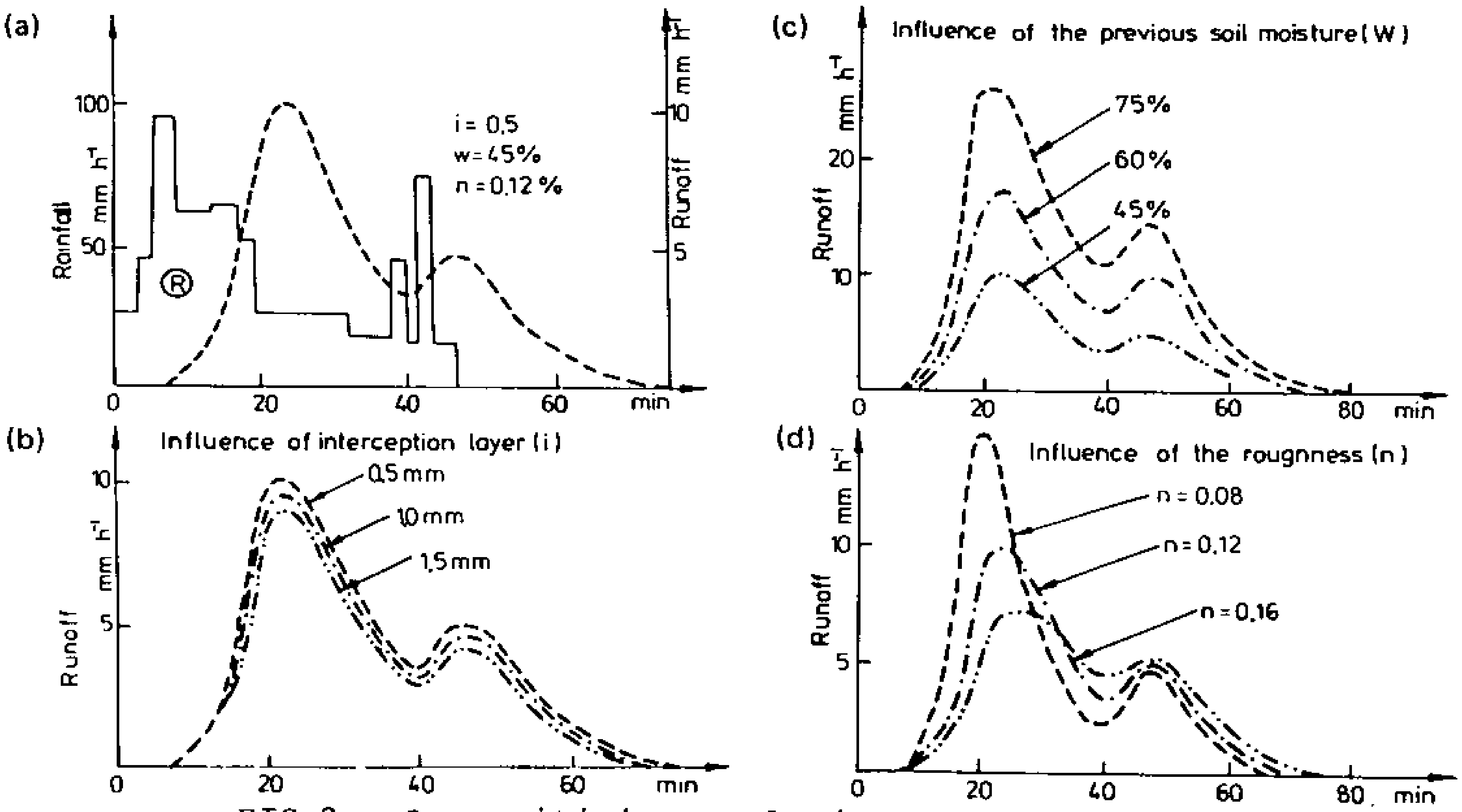

FIG.9 A sensitivity analysis performed by using various input parameters.

Figure 9 shows the computed hydrograph for a given rainfall R using the parameters: interception (i) = 0.5 mm, soil moisture (W) = 45% (of saturation), roughness coefficient (n) = 0.12.

Fig.9(b), (c), (d) show the variation of the computed hydrographs for the same rainfall (R) after various values were assigned to each of the input parameters (i,w,n), keeping the remaining ones constant. The model was tested for surface basins ranging from 300 m^2 to 10-12 km^2. Figure 10 presents the recorded and computed hydrographs for the basins of 300 m^2, 600 m^2 and 900 m^2. The results were rewarding and showed that the model may be applied to drainage surfaces with an unsteady flow regime. Once the basin surface is larger and the flow regime is steady, the model yields satisfactory results only after certain subroutines for groundwater flow and routing (Blidaru *et al.*, 1982) are added.

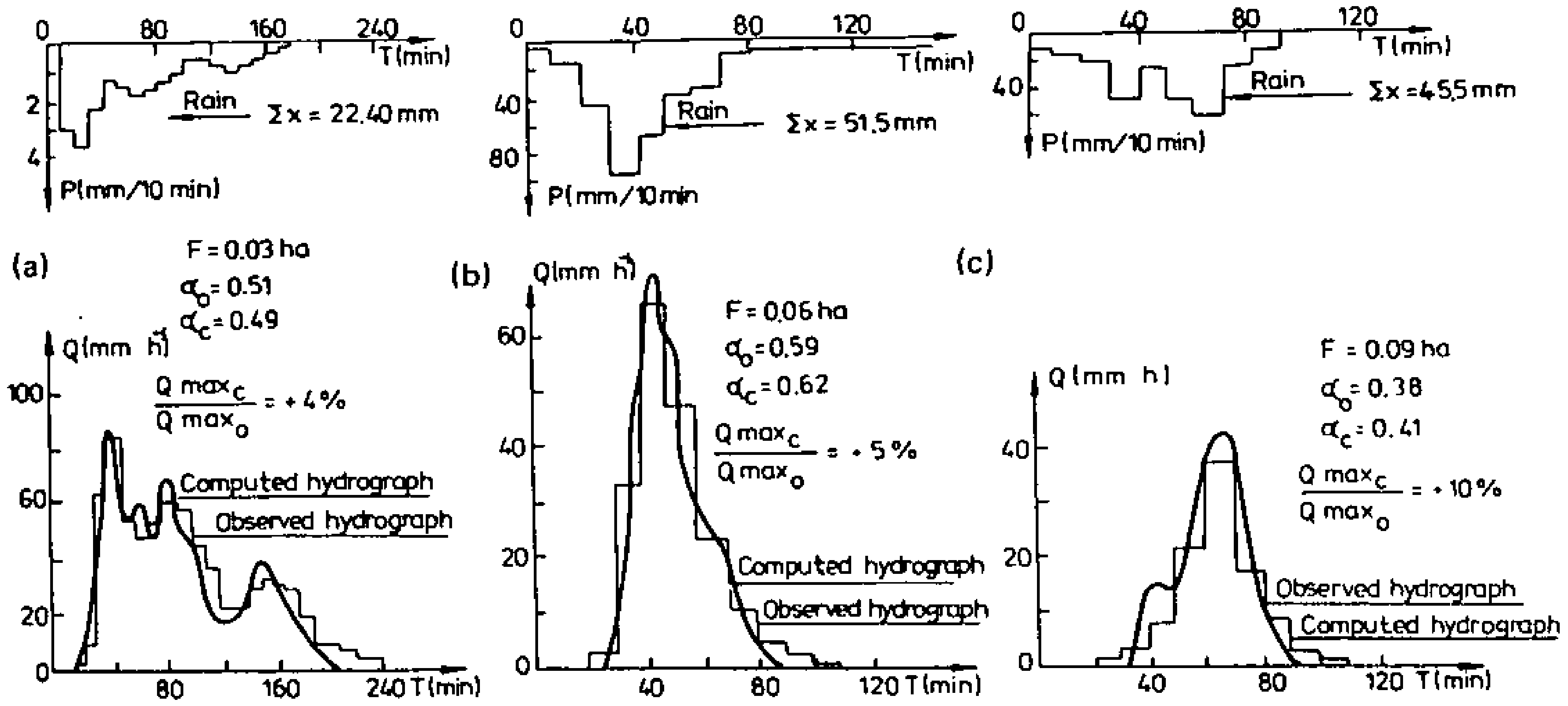

FIG.10 A comparison between computed and recorded hydrographs for three basins.

Nevertheless the model proved a useful means for the analysis of links between land reclamation methods and the elements of the hydrological regime.

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