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RESPONSE OF BADLAND SURFACES IN SOUTH EAST SPAIN TO SIMULATED RAINFALL

A. CALVO-CASES (1); A. M. HARVEY (2); J. PAYA-SERRANO (1) & R. W. ALEXANDER (3)

(1) Departamento de Geografía, Universidad de Valencia
(2) Department of Geography, University of Liverpool
(3) Department of Geography, Chester College

Abstract. Field experiments using a sprinkler type rainfall simulator have been carried out on a variety of badland surfaces in SE Spain in order to establish their response patterns. Nine sites were selected between Valencia and Almería to represent the badland prone lithologies of this region. The hydrological response shows rapid runoff creating four main types of hydrograph. The major factors controlling infiltration and runoff and therefore hydrograph form relate to surface properties such as the presence of particular lichens and the cracking/swelling properties of the material. The erosional response demonstrates the overwhelming importance of cover by lichen plants or stones in reducing erosion rates. On sites with less than 20% cover erosion rates reflect material properties; high rates occur where the regolith is thin and with fine cracks that close rapidly when wetted.

Key words: geomorphology, badland processes, field experimentation

Resumen. Con el uso de un simulador de lluvia a aspersión se han realizado experimentos de campo sobre una amplia variedad de superficies de badlands del SE español, con el fin de establecer las características de su respuesta. Como muestra de las distintas litologias sobre las que se desarrollan badlands en la zona comprendida entre Valencia y Almería se han seleccionado nueve lugares. La respuesta hidrológica muestra una rápida generación de escorrentía y da lugar a cuatro tipos principales de hidrogramas. Los principales factores que controlan infiltración y escorrentía, y por tanto, la forma del hidrograma, se relacionan con propiedades de la superficie tales como la presencia de especies concretas de líquenes y las propiedades expansivas del material. La respuesta erosiva demuestra la importancia primordial de la cubierta de líquenes, plantas o piedras, en la reducción de las tasas de erosión. En lugares con una cubierta inferior al 20% las tasas de erosión reflejan las propiedades del material. Las tasas más elevadas se producen en lugares con una cubierta delgada de regolita asociada a grietas de reducidas dimensiones, las cuales cierran rápidamente con el humedecimiento.

Palabras clave: Geomorfología, procesos en badlands, experimentación de campo.

1. Introduction

Badlands are important in the geomorphology of SE Spain. They are developed on a variety of materials and exhibit a wide range of erosional morphology (Harvey & Calvo, 1989; López Bermudez &

Romero-Díaz, 1989; Calvo *et al.*, 1991). Despite numerous studies of erosion processes and erosion rates at individual badland sites (Romero Díaz *et al.*, 1988; Imeson & Verstraten, 1988; Gerits *et al*, 1987) we know of no attempt to identify the range of erosional behaviour occurring on badlands in SE Spain, nor to identify the factors causing variations in erosion rates and styles.

The aim of this paper is to identify the hydrological and erosional response of the different types of badland surface characteristic of SE Spain. This has been done through rainfall simulation experiments applied to a variety of plots on different badland surfaces.

Previous field experiments using simulated rainfall on badland surfaces have been carried out by several authors (Scoging & Thornes, 1980; Salmon & Schick, 1980; Bork & Bork, 1981; Hodges & Bryan, 1982; Imeson *et al*, 1982; Scoging, 1982; Imeson, 1983; Yair & Lavee, 1985; Gerits, 1986; Gerits *et al*, 1986; Gerits *et al*, 1987; Imeson & Verstraten, 1988; Sanroque *et al* , 1988; Bowyer-Bower & Burt, 1988; Scoging, 1989; Cervera *et al*, 1991). Most of these studies were based on individual sites or drainage basins and focused on the relationships between local surface properties and hydrological and erosional response.

Fig. 1. Location map of the sites of study
Mapa de localización de las zonas de estudio

In this study we deal with a range of badland types in a large geographical area extending from Valencia to Almería (Figure 1). Experimental plots were selected on the basis of lithology, morphology and erosional response detected in previous studies (Harvey, 1982; Calvo & Harvey, 1989; Alexander & Calvo, 1990; Harvey & Calvo, 1991; Calvo *et al.*, 1991).

The main lithologies in SE Spain subject to badland development include Triassic gypsiferous marls, Cretaceous to Oligocene marine marls, Upper Miocene marine marls including gypsiferous marls and Plio-Quaternary terrestrial silts (Harvey & Calvo, 1989). Morphology ranges from total badlands, with little or no vegetation cover and little remaining of any previous surface, to partial badlands, where the erosional area is cutting into a previously stable surface, to isolated single gully features. Processes on some badlands are dominated by rilling, but on others by more complex interactions between rilling, piping, swelling and mass movement (Calvo & Harvey, 1989).

Experiments were carried out on 52 plots at 9 sites throughout the region (Figure 1). At Turis (Valencia) six plots were selected in an area of partial badlands developed on Triassic diapiric shales. The plots include partially vegetated slopes, with a high stone cover, and bare surfaces on which rilling is the main process. Regolith cover on the bare plots is of c.10 cm and has a blocky structure in the fine gravel size. The surface has a thin mineral crust.

In Alicante two sites were selected on Cretaceous marls, with ten plots each at Petrer and Monnegre. These sites show a wide range of badland process interactions involving rilling, swelling and piping (see Calvo & Harvey, 1989; Harvey & Calvo, 1991; Calvo *et al.*, 1991). At Petrer plots include North and South facing slopes with differences in vegetation cover, and subject to a range of rilling, swelling and cracking processes. At Monnegre rilling is weaker and the plots have a soft regolith cover with a thin mineral crust.

Two plots have been selected on the badlands developed on the Plio Quaternary silts near Sucina (Murcia), at a site showing very high infiltration capacities (Harvey, 1982).

Five sites were studied in Almería. At Vera ten plots cover a range of surface types including pure badland plots and vegetated plots, including plots with lichens. These badlands are cut in Messinian gypsiferous marls (Harvey, 1982, 1987) and the main processes are rilling, piping, swelling and mass movement. The plots selected range between some with a well developed very soft regolith cover and with a thin fragile mineral crust, and some with a harder surface, less regolith and better development of rills.

At La Herrería six plots, also on Messinian marls show aspect controlled contrasts, lichen cover, but less of a range of morphologies than do those at Vera (Alexander & Calvo, 1990).

Two individual plots were studied in small badlands nearby, one on the hard surface of the Garcia Alta badlands developed on talc-rich Triassic shales and one on badlands developed in the Plio-Quaternary silts of the Sorbas basin.

At Tabernas, six plots on Tortonian mudstones cover a range of surfaces including pure badland surfaces, and slopes covered with lichens and higher plants (see Alexander & Calvo, 1990). Rilling is the main process and surface differences on bare plots depend on the development of a strong and homogeneous mineral crust or on the development of a rough surface that reflects the blocky structure of the material.

2. Experimental design

The instrumentation used for rainfall simulation has been described in Calvo *et al* (1988); it consists of a sprinkler-based rainfall simulator that works over a circular plot of 0.24 m^2 enclosed by a metal ring five centimeters in height that is inserted two centimeters into the ground. Rainfall intensities ranged between 20 and 70 mm h^{-1}, with an average of 42 mm h^{-1}. These differences in intensity occurred due to the losses of water produced by wind or evaporation. The duration of each experiment was 20-25 minutes, using distilled or deionized water, in order to minimize the effect of dissolved salts on infiltration rates.

During each experiment, runoff was collected and measured at intervals between 1/2 and 5 minutes, depending on the runoff rate. Usually three samples were collected, the first when runoff started, the second after 10 to 15 minutes and the last at the end of the simulation. Sediment concentration and salt content have been measured from these samples.

In ten plots the simulations were repeated after different time intervals (between 0.5 and 67 hours), to give information on plot behaviour in wet conditions.

After each rainfall simulation the soil was excavated in order to check the profile properties and the position of the wetting front.

Each plot has been characterized by a series of parameters reflecting morphology and to express antecedent conditions (Table 1):

- Aspect and slope angle, as morphological variables.
- Percentage of plot surface covered by lichen, herbs or higher plants and stones.
- Soil moisture content of the top soil (SM0-3) and at about 5 cm in depth (SM3-6), measured by weight.

The variables used to express response are (Table 2):

- Rain intensity obtained in the experiment (RI) in mm h^{-1}
- Time in minutes to ponding (TP), to runoff start at the plot outlet (RS), and to crack closure (CC).
- Depth (in cm) of the wetting front after the rainfall simulation (WF).
- Runoff rate (RR), total runoff divided by total time (mm h^{-1})
- Runoff coefficient (RC).
- Infiltration rate after 30 minutes (I30), estimated from the infiltration model of Horton(1945)

Table 1. Plot antecedent conditions
Condiciones previas de las parcelas

Plot	Aspect	Slope	Lich. %	Herbs %	Ston. %	Total Cover	SM0-3 %	SM3-6 %
GA1	235	54	0	0	50	50	2.5	4.6
H1	30	18	64	5	10	79	2.1	NA
H2	350	18	16	10	5	31	1.3	NA
H3	25	18	15	10	15	40	1.3	NA
H4	5	22	0	4	2	6	1.5	NA
H5	180	25	0	3	7	10	2.4	NA
H6	160	26	0	1	1	2	2.4	NA
M2	328	30	0	0	0	0	2.0	3.5
M4	338	28	0	0	0	0	1.3	3.4
M5	90	12	0	0	5	5	3.2	4.0
M6	145	16	0	0	0	0	1.4	2.4
M7	138	37	0	0	35	35	1.3	2.7
M8	240	28	60	10	0	70	0.3	1.4
M9	122	15	0	0	10	10	0.7	2.2
M10	130	28	0	0	5	5	0.5	1.8
M11	188	25	0	0	3	3	1.2	3.4
M12	134	20	0	0	5	5	0.9	3.1
P4	52	25	10	15	75	100	1.2	NA
P5	302	40	0	0	0	0	NA	NA
P8	222	24	0	0	80	80	1.5	NA
P10	160	40	0	0	0	0	4.8	4.4
P11	344	32	0	0	5	5	2.8	4.1
P12	150	30	0	0	0	0	2.3	4.5
P13	198	40	0	0	0	0	2.0	6.4
P14	193	50	0	0	0	0	1.2	1.8
P15	339	24	0	0	4	4	1.3	2.3
P16	325	37	0	0	7	7	0.2	0.9
SO1	156	38	0	0	1	1	5.4	12.5
SU1	60	36	0	0	2	2	2.3	7.3
SU2	163	28	0	0	1	1	2.3	7.3
T1	160	25	0	0	1	1	0.6	NA
T2	80	21	90	1	2	93	0.1	NA
T4	170	26	0	0	3	3	0.9	NA
T5	138	34	0	0	0	0	4.0	6.0
T6	156	34	0	0	1	1	6.5	8.7
T7	312	30	4	40	35	79	2.1	3.2
TU2	314	12	0	5	95	100	NA	NA
TU3	334	14	0	5	95	100	4.3	8.8
TU6	350	14	0	0	0	0	1.9	4.0
TU7	26	26	0	0	0	0	1.2	3.4
TU8	243	14	0	0	35	35	1.0	2.5
TU9	125	21	0	0	5	5	1.0	4.6
V2	325	18	57	9	3	69	2.5	NA
V3	50	21	54	5	1	60	1.9	13.9
V4	84	20	64	5	1	70	6.1	13.0
V5	196	34	0	0	4	4	8.5	20.0
V6	200	34	0	0	1	1	9.3	20.8
V7	328	16	55	25	5	85	2.4	7.1
V8	230	20	54	4	8	66	5.7	9.8
V9	204	20	0	0	5	5	10.8	20.1
V10	92	18	0	0	1	1	15.3	19.1
V11	85	40	0	0	1	1	12.0	20.0

(NA = Not available)

Table 2. Plots response. See text for legend.
Respuesta de las parcelas. Leyenda en el texto

Plot	RI mm h^{-1}	TP min	RS min	CC min	WF cm	RR mm h^{-1}	RC	I30 mm h^{-1}	ER g $m^{-2}h^{-1}$	S.C. g l^{-1}	EC. mS
GA1	63	1.30	2.93	----	1.45	22.73	0.36	28.36	489.45	26.22	6770
H1	42	1.57	6.20	5.48	2.25	6.51	0.15	NA	14.31	5.67	NA
H2	50	1.75	6.23	3.00	2.10	11.34	0.23	NA	26.26	6.00	NA
H3	64	2.30	5.65	3.67	1.50	19.92	0.31	NA	36.27	3.95	NA
H4	44	0.58	8.00	2.77	7.00	7.50	0.17	NA	46.02	13.14	NA
H5	60	1.45	6.20	3.05	3.00	17.13	0.29	NA	72.31	12.40	NA
H6	53	1.40	8.80	3.33	3.10	11.04	0.21	NA	82.50	17.19	NA
M2	30	5.32	9.58	20.73	4.13	8.23	0.27	14.62	68.87	12.15	406
M4	33	4.92	6.50	9.43	2.38	14.54	0.44	5.31	330.10	29.60	371
M5	30	4.58	12.97	11.68	2.13	22.85	0.76	10.26	964.06	72.65	484
M6	36	3.13	3.67	3.50	2.00	22.23	0.62	12.22	296.86	15.46	300
M7	24	3.42	4.55	6.58	2.50	16.20	0.69	25.59	431.06	32.11	365
M8	26	4.43	5.22	4.77	5.00	5.63	0.22	14.35	6.53	1.40	298
M9	36	1.42	3.25	4.92	2.50	24.66	0.69	10.44	832.49	40.06	331
M10	44	2.25	3.12	5.50	1.68	29.93	0.69	13.25	984.52	38.23	252
M11	51	3.32	3.93	4.12	1.20	28.95	0.57	9.06	801.72	33.69	233
M12	38	3.22	3.67	6.72	1.55	24.13	0.63	18.06	600.16	29.41	311
P4	54	4.50	7.83	----	NA	4.78	0.09	48.25	6.46	1.80	NA
P5	70	2.00	2.42	6.53	NA	22.22	0.32	42.65	1355.64	65.80	NA
P8	68	2.83	3.43	----	NA	32.03	0.47	19.45	117.50	4.43	NA
P10	34	2.50	4.92	6.18	2.75	13.95	0.41	15.50	623.76	54.65	976
P11	46	4.67	5.35	6.00	2.25	25.40	0.56	12.94	1250.81	62.20	1070
P12	33	5.00	7.00	5.00	1.25	2.37	0.07	23.60	109.85	69.58	1644
P13	26	4.50	5.43	11.83	3.50	2.51	0.09	22.76	91.45	46.21	1300
P14	48	3.77	4.13	NA	2.06	5.48	0.11	40.32	254.82	55.60	913
P15	43	2.57	3.28	20.00	NA	27.45	0.64	6.39	1679.85	70.08	1050
P16	27	11.60	14.38	14.00	2.53	5.69	0.21	18.63	173.94	51.49	630
SO1	36	2.50	5.25	16.00	3.22	6.96	0.19	27.06	288.71	55.87	2925
SU1	63	2.17	9.00	3.50	1.20	5.48	0.09	42.71	76.37	27.89	2480
SU2	48	4.92	7.67	3.25	4.00	3.70	0.08	19.47	24.05	12.81	2370
T1	60	3.42	4.23	3.50	2.10	20.81	0.35	31.05	141.13	8.55	NA
T2	60	0.57	1.58	----	1.40	21.55	0.36	33.61	42.32	2.10	NA
T4	20	5.00	6.58	4.50	2.40	8.17	0.40	1.89	122.00	21.78	NA
T5	50	2.17	2.92	NA	2.08	32.52	0.65	7.94	787.84	27.57	3160
T6	40	1.33	2.00	5.00	3.18	22.55	0.56	5.31	876.98	42.99	3207
T7	28	3.83	7.33	----	5.00	7.58	0.27	17.03	20.53	3.70	2375
TU2	50	5.50	5.50	----	3.75	25.24	0.50	13.95	35.18	2.07	365
TU3	40	7.00	3.10	----	4.10	7.47	0.19	26.78	24.30	3.59	546
TU6	35	3.95	4.50	7.00	8.50	12.54	0.35	9.41	197.99	19.62	572
TU7	38	3.73	5.15	6.50	5.00	22.81	0.60	2.34	414.49	23.64	442
TU8	24	8.33	8.50	5.00	3.43	7.95	0.33	9.19	32.43	5.64	313
TU9	60	5.23	7.00	3.37	3.38	18.04	0.30	30.50	215.86	17.55	283
V2	60	1.00	1.33	----	1.90	18.01	0.30	31.88	62.52	3.70	NA
V3	30	1.00	1.33	3.00	NA	12.81	0.43	7.72	74.56	6.18	817
V4	26	0.83	1.50	----	NA	15.72	0.61	5.80	67.64	4.59	354
V5	37	2.00	2.33	12.00	2.34	11.02	0.30	8.12	610.79	61.89	1618
V6	44	1.30	1.90	8.00	2.35	27.61	0.63	9.68	1375.14	53.55	3254
V7	45	0.58	1.92	6.50	2.94	28.19	0.63	11.52	143.93	5.49	2648
V8	49	1.40	2.18	5.00	2.75	22.14	0.45	22.22	181.03	9.05	2888
V9	46	1.17	2.08	2.58	2.23	25.84	0.56	15.23	767.50	32.75	3850
V10	37	1.20	1.55	8.50	1.45	27.63	0.74	4.17	1900.14	73.42	20587
V11	40	2.33	3.00	9.00	3.75	21.29	0.53	9.07	1156.92	63.39	3303

(NA = Not available)

- Erosion rate (ER) in g m^{-2} h^{-1} and average sediment concentration (SC) in g l^{-1}
- Electrical conductivity of the runoff water (EC) in mS.

3. Results

A Spearman rank correlation analysis was carried out using the 43 plots with complete data. The relationships between previous conditions and response to simulated rainfall are very variable, with poor correlations between variables. Slope, as have been pointed out by Bryan & Yair (1982), has very little influence, and previous moisture content shows only a low positive influence on electrical conductivity of runoff water (rs=.62) and on ponding times (rs=-.54). The only other good correlations (rs > .5) between controlling and response variables are between lichen cover and sediment concentration (rs= -.59) and between higher plant cover and sediment concentration (rs= -.65). These inverse relationships are in fact the expressions of threshold rather than progressive conditions (Alexanser & Calvo, 1990). As is expressed on Figure 2 there is a significant erosion threshold around the 20 % of total cover (the sum of lichens, plants and stones cover): all the plots with less cover have values of sediment concentration higher than 10 g l^{-1} (see below).

Interestingly, variations in rain intensity have no influence; the only other good correlations are between response variables. There are obvious correlations resulting from timing and obvious correlations between runoff, sediment concentration and erosion rate.

Hydrological response

Runoff response normally occurs very fast (1.3-14.4 min) with an average of only five minutes. Analysis of hydrograph shape shows four main groups of curves (Figure 3), according to the time when maximum runoff rate is reached, a variable closely related to crack closure.

The first group (Figure 3A) comprises those plots (GA1, M10, M11, T5, V7, V9, V10) that have a very rapid response to rainfall. Runoff starts always before 4 minutes and rapidly reaches a maximum rate in less than 7 minutes from the beginning of the rain, after which runoff rate is more or less constant. These plots are mostly on steep bare surfaces with rapidly closing cracks. The final runoff rates of this plots are between 25-40 mm h^{-1}.

The second group (Figure 3B) (M6, M7, M9, M12, P5, P11, T1, T2, T4, TU2, TU7, V2, V6, V8) is less homogeneous in composition. Their characteristics can be summarized by two components: (i) those plots that have a high percentage of lichen cover that includes *Squamarina lentigera, Fulgensia fulgens* and *Dipochistes dicapsis*, these are species of some size and which effectively decrease the infiltration capacity (see Alexander & Calvo, 1990). A similar effect is caused by 95 % cover of small gravels in TU2. (ii) bare plots have as common characteristic, the presence on the surface of a thin and smooth mineral crust broken by small cracks. In all cases runoff starts before 7 minutes and rises to a maximum rate (15-35 mm h^{-1}) between 8 and 12 minutes.

The third group of hydrographs (Figure 3C) (P4, P8, P10, P12, P13, P15, SO1, T6, T7, TU9, V4, V11) is comprises of those plots that take about 15 minutes to reach a stable runoff rate. There are two principal kinds of surface: vegetated plots including herbs and lichens with a continuous black porous crust; and bare surfaces they are characterized by a well developed system of cracks that takes a long time in closing.

The fourth group (Figure 3D) is comprises of plots with similar characteristics to those of the pervious group (M2, M4, M5, M8, P14, P16, SU1, SU2, TU3, TU6, TU8, V3, V5), but includes the extreme cases of crack development and plots on materials (Sucina and Turis) that have a very porous blocky structure. It takes more than 20 minutes to reach stable runoff and in some cases this is not reached during the experiment.

For each group a mean hydrograph was derived for runoff at each one minute interval (Figure 3), from which mean infiltration curves were produced by substracting from the mean rain intensities. Horton curves, based on the equation:

$$f_t = f_c + (f_o - f_c)\, e^{-kt}$$

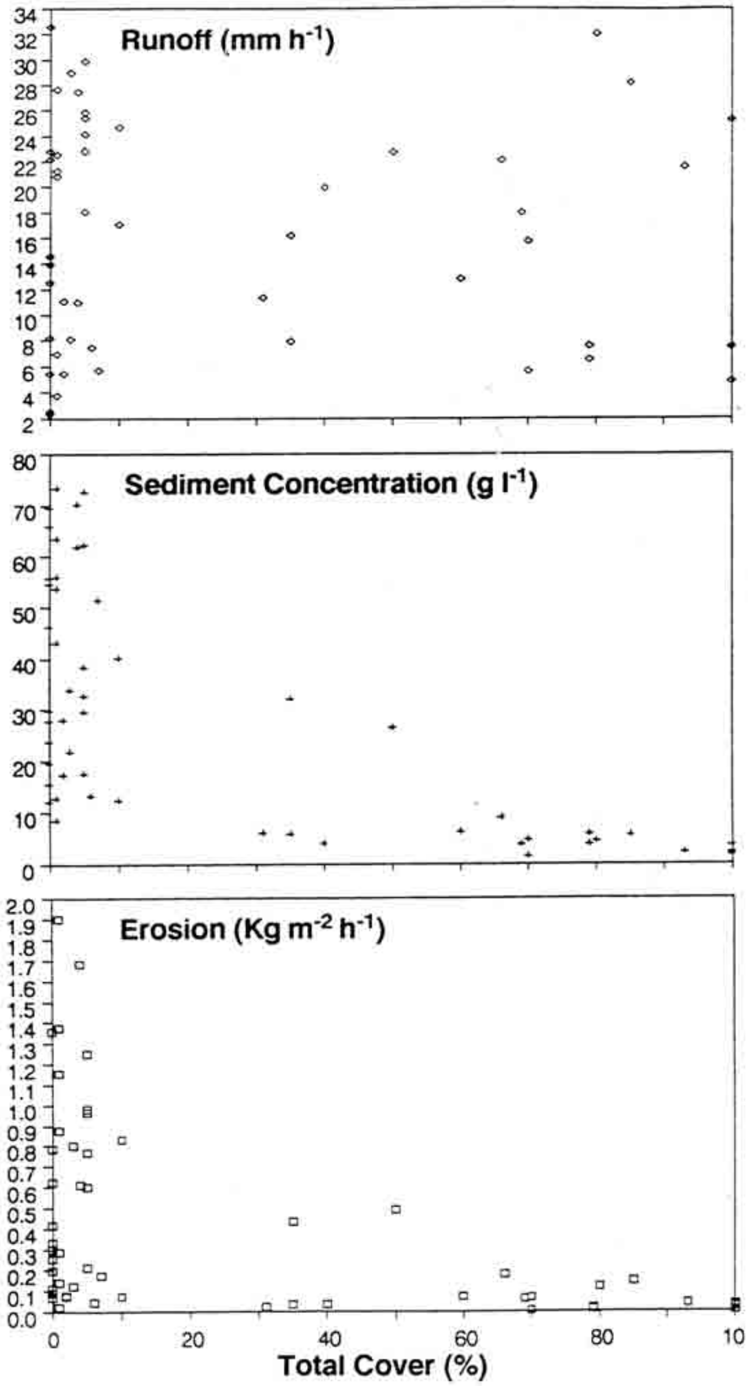

Fig. 2. Relationship between percentage of plot cover and hydrological erosional response
Relación entre el porcentaje de cubierta de las parcelas y la respuesta hidrológica y erosiva.

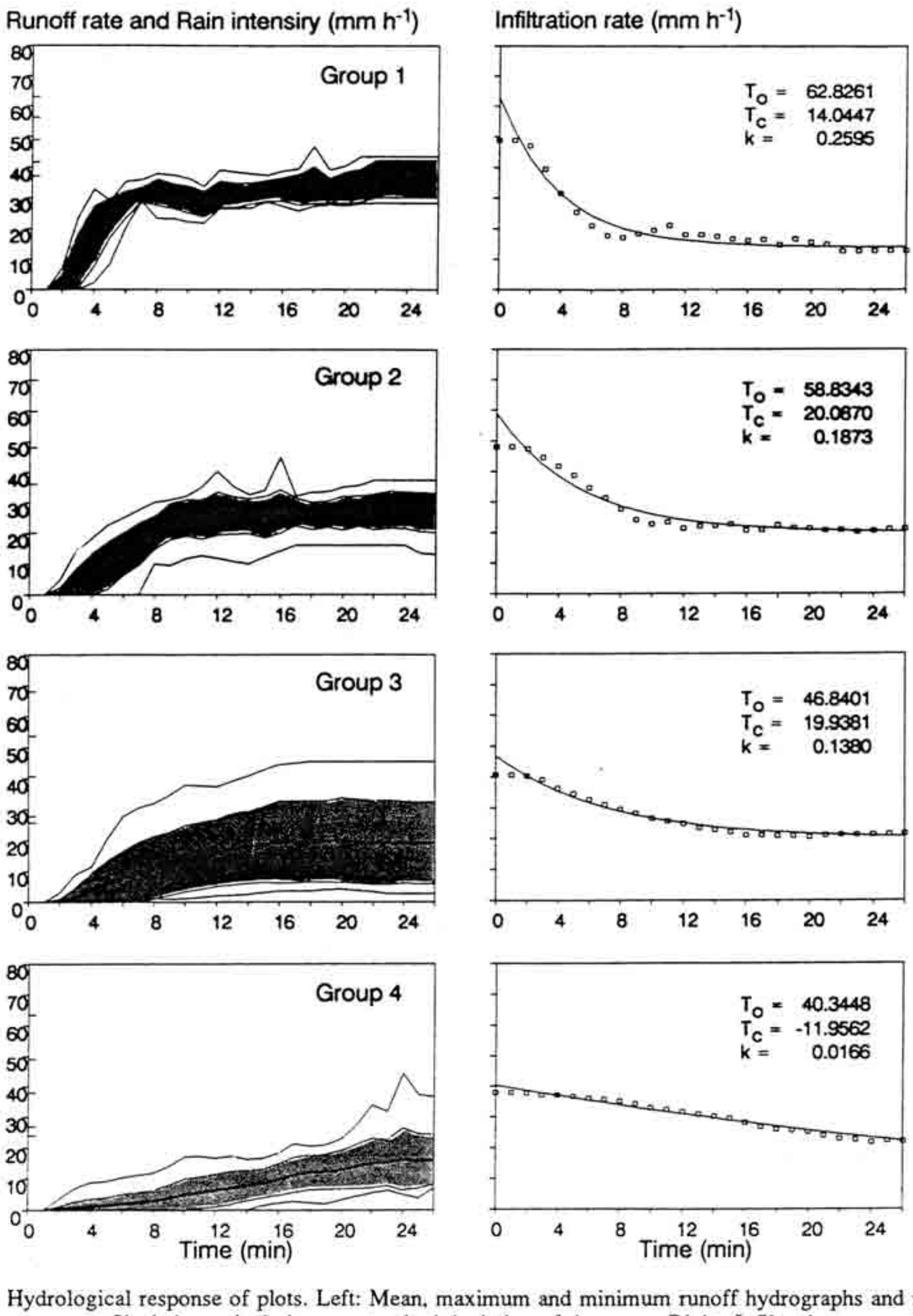

Fig. 3. Hydrological response of plots. Left: Mean, maximum and minimum runoff hydrographs and rainfall values per groups. Shaded area includes one standard deviation of the mean. Right: Infiltration curves fitted to Horton model

Respuesta hidrológica de las parcelas. Izquierda: hidrogramas medios máximos y mínimos y valores de precipitación por grupos. El área sombreada señala ña desviación estandar de la media. Derecha: curvas de infiltración ajustadas al modelo de Horton.

(where ft is infiltration rate at time t, fo is initial infiltration rate , fc is constant infiltration rate)

were fitted to these data and Figure 3 shows the model parameters. Very clearly the rates of change (k) decrease from group 1 to group 4, and predicted values of f_c for groups 1, 2, and 3 of an order that would produce overland flow under natural conditions on these badland surfaces. The very low value of k, for group 4, accounts for the unrealistic value for fc for this group. Infiltration experiments of less than 30 minutes do not achieve constant infiltration on these porous blocky surfaces.

Erosional response

In order to establish categories of erosional response, runoff rates have been plotted against sediment concentration values (figure 4). The plots have been divided into five groups on this figure on the basis of natural gaps in the data, each relating to a range of erosion rates. At the bottom, with very low values of sediment concentration and covering the whole range of runoff, group A includes nearly all the plots with a total cover > 20%, especially of lichens and stones. The estimated rates of erosion based on the three sediment samples from each plot are relatively low in this group (6-181 g m^{-2} h^{-1}). Differences in runoff are positively related to the total cover amount, with some variation due to rainfall intensity. Only one plot in this group has no surface cover (T1) but has a well developed mineral crust which acts in the same way as a lichen crust.

In the context of the bare surfaces four categories of erodibility have been found. Group B, with moderate erosion rates (24-431 g m^{-2} h^{-1}), is composed of plots with high infiltration rates due to well developed crack systems or to the broken nature of the surface crust following disturbances by goats (La Herrería plots). These plots have low erodibility because of their material properties or in the case of M7 because a partial cover by small gravels.

Group C, with higher erosion rates (91-624 g m^{-2} h^{-1}), includes plots that also have well developed crack systems on a deep regolith. Differences in erodibility are due to material properties and, in fact, all plots are from areas where swelling and related mass movements are dominant processes (Petrer, Vera and Sorbas) (see Harvey & Calvo, 1989; Imeson & Verstraten, 1988). It should be made clear that these erosion rates relate only to surface processes: in the long term mass movements on these surfaces would increase erosion rates.

Group D, with high erosion rates (297-985 g m^{-2} h^{-1}), can also be related to material properties, in all cases to poor regolith development with small cracks that close quickly producing high runoff rates and hence high erosion rates.

Group E is representative of extreme erosion rates (964-1900 g m^{-2} h^{-1}) (Petrer north-facing, Vera and Monnegre 5). In all cases materials have high plasticity: crack closure is slow, but when this happens runoff is high and in most cases the crack network becomes a microrill system.

4. Conclusions

The results confirm the complexity of the response of badland surfaces to rainfall events as a consequence of the high spatial and, probably, temporal variability of regolith properties reflected by the detailed morphology.

Runoff response is always fast, but in the in the set of studied plots there are four main kinds of surface, depending on the speed at which maximum runoff rate is reached; five, fifteen and more than twenty minutes are the times that differentiate the four groups.

The most obvious factors controlling erosional response relate to cover, particularly to the existence of a threshold between bare slopes and slopes covered by stones or plants, especially by lichens. Any kind of cover over 20 % produces a considerable decrease in the amount of erosion at any of the rain intensities used.

The most effective cover appears to be a lichen cover. Several types have been recognized on the basis of lichen physiognomy (Alexander & Calvo, 1990), all of which are effective in binding the surface and reducing erosion rates. Some also modify infiltration behaviour, either by increasing ponding or directly by partially sealing the surface. The most complex and effective type, often also with a high cover, is dominated by the crustose lichen, Diploschistes dicapsis.

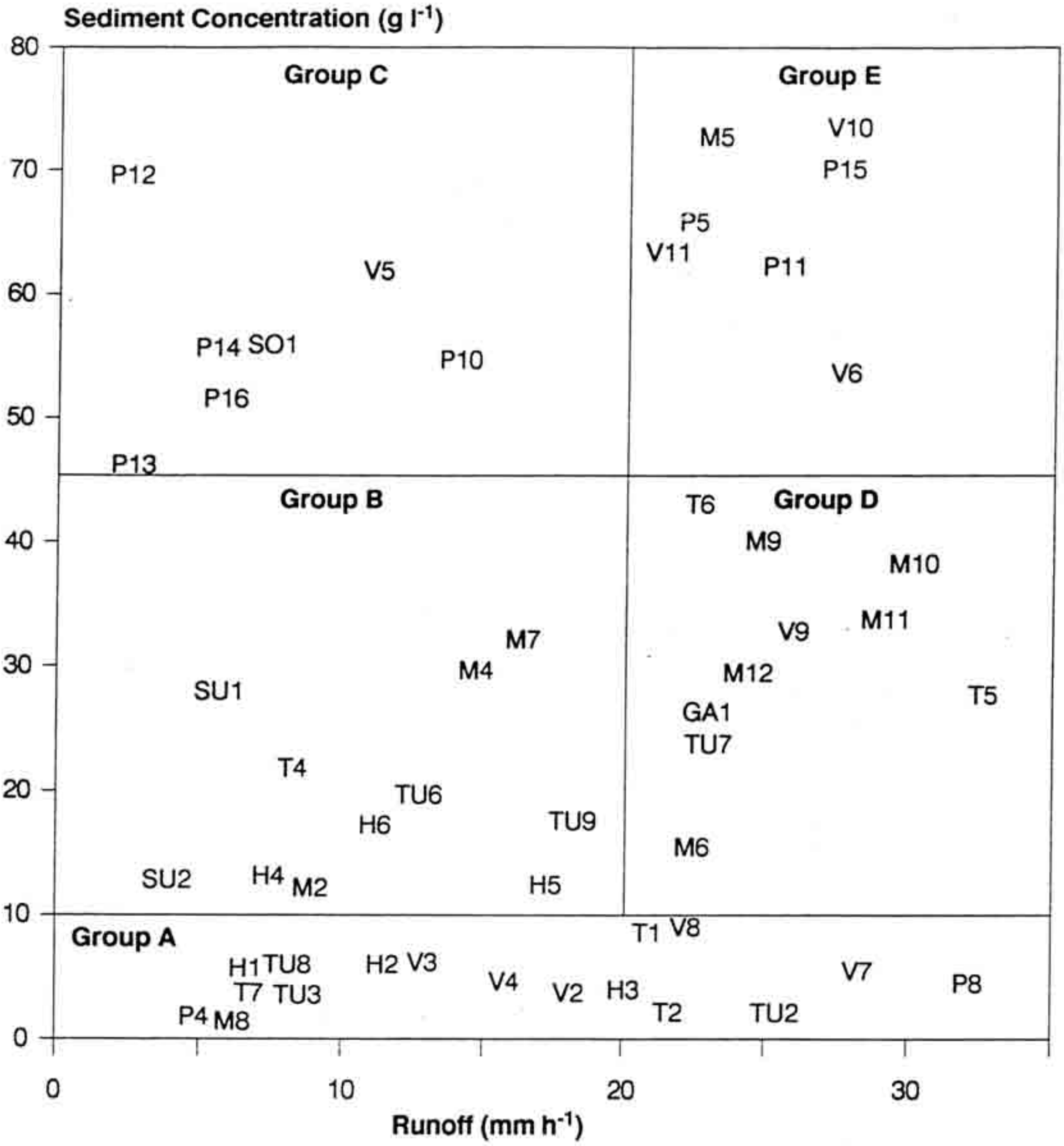

Fig. 4. Relationship between runoff and sediment concentration rates.
Relación entre las tasas de escorrentía y las de concentración de sedimentos.

Higher plants tend to intercept the rainfall, and often occur on surfaces which also have a lichen cover. Individual plants include grasses and annual flowering plants, but the most important are individual clumps of false esparto grass *(Lygeum spartum)* or individual woody shrubs such as *Asparagus spp, Launaea spinosa* and *Fagonia cretica.*

The effect of stones is also important particularly where the stones are related to the remains of an old soil on the surface. Here infiltration is increased and sediment concentration decreased.

In the context of the bare plots, hydrological and erosional response varies with differences in detailed morphology, which reflects the dominant processes, especially weathering, operating prior to the time of the experiments.

The influence of variables such as slope, or previous moisture content of the soil is masked by the noise produced by the detailed morphology and cover properties of the plots.

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