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SOIL EROSION ON FALLOW FIELDS: AN EXAMPLE FROM MURCIA

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SUMMARY

Precipitation, infiltration and soil erosion are examined for four fields which have been left fallow for 1, 2, 5 and 20 years (from November 1985) and for one site which has not been cultivated. Infiltration rates are highest on the sites which have been left fallow for longest. Conversely erosion is lowest on the older sites (due to high infiltration rates) and on the most recently ploughed site (due to the storage effect of the ridges and furrows).

Key words: Murcia, abandoned fields, infiltration, erosion, marls.

EROSION DE SUELOS EN CAMPOS DE BARBECHO: UN EJEMPLO EN MURCIA

RESUMEN

En este trabajo se examina la precipitación, la infiltración y la erosión del suelo en cinco parcelas experimentales. Cuatro de ellas están abandonadas durante 1, 2, 5 y 20 años (hasta noviembre 1985) y otra nunca ha sido cultivada. Los valores de infiltración son altos en las parcelas abandonadas por más tiempo. Por el contrario la erosión es más baja en las parcelas más antiguas (debido a que las tasas de infiltración son más altas), y sobre las parcelas aradas más recientemente (por los efectos de almacenamiento de agua en los caballones y surcos del terreno labrado).

Palabras clave: Murcia, campos abandonados, infiltración, erosión, margas.

Introduction

South east Spain has been suffering from drought since 1978. One of the by products of this in the Province of Murcia is that much of the arable *secano* land is being left fallow as cereal yields have not been economically viable. Vegetation recovery on these fields has been slow due to the lack of moisture and overgrazing so that large areas of bare soil are poorly protected from the agents of soil erosion. This paper presents data from a research programme on the interactions between vegetation recovery and soil erosion on abandoned fields, focusing on the variations of soil erosion and infiltration on fields which have been left fallow for different lengths of time.

Site description

The study area is located about 20 km WNW of Murcia (Province of Murcia, Spain) in the headwaters of the Rambla Cañada Honda (fig. 1). The lithology consists of Andalucian (late Miocene) gypsiferous marls with sandstone layers. The strata have been tilted slightly and in the highest parts of the watershed the sandstone forms the capping rock on escarpments. Away from the interfluves the marl has formed a glacis which is being dissected by the rambla which has cut a box shaped valley with steep, gullied side walls and a flat channel floor. The slopes on the glacis surface around the rambla are low (less than 5°) but increase towards the escarpments. Although flow in the rambla is ephemeral, it is one of the tributaries of the Rio Mula which drains eastwards to the Rio Segura.

Land uses in the area are dominated by *secano* agriculture, but grazing and hunting occur. Most of the land is terraced for tree crops (olive and almond) and cereals (wheat and barley), but many of the arable fields have been left fallow for a number of years due to the drought. Herds of goat and sheep graze the area once or twice a week except during the summer.

Despite the terracing and contour ploughing the area is

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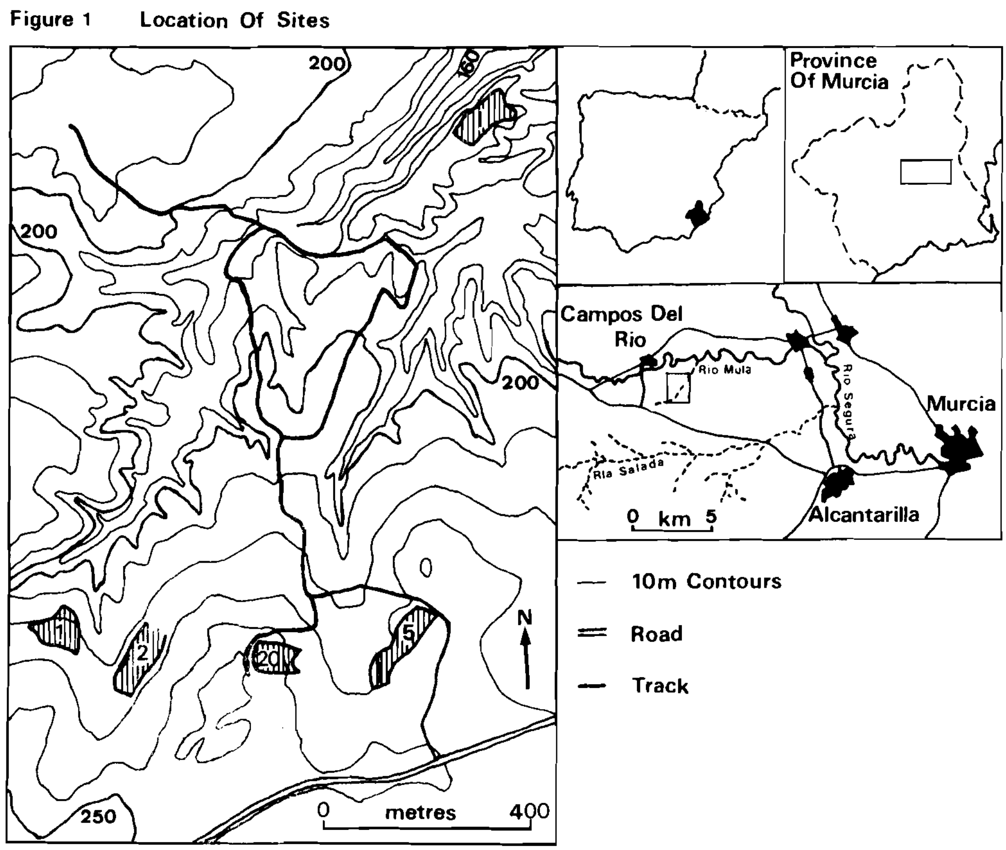

Fig. 1.—Location of sites.

susceptible to soil erosion by various processes. Wash erosion has been observed, rills have developed on both cultivated and uncultivated land, and pipes and gullies are usually found together on the larger earth terrace walss.

Sampling design

Five locations were selected of which four are old fields and the fifth is not thought to have been cultivated (fig. 1). In November 1985 the fields had been left fallow for 1, 2, 5, and approximately 20 years according to local labourers (these are subsequently referred to as sites 1, 2, 5, and 20). Site 5 has a marked spur-hollow-spur topography, whereas the others are almost planar. Slope angles are below 6°. The fifth site is the flat top of an island in the Rambla Cañada Honda which is essentially a remnant of the glacis surface (referred to as site I).

In January 1986 a raingauge was installed on each site. At the same time three run off plots 1 m × 3 m in size and bounded by cement walls plus Gerlach troughs were installed on sites 1, 2, 5 and 20. In the following summer infiltration rates were measured using both a constant head cylinder infiltrometer and a sprinkler in order to examine infiltration rates for dry soils.

The cylinder infiltrometer was based on a standard design (Hills, 1970). Infiltration rates were measured in five locations on each site within an area of 4 m^2 to examine variability within a small area as well as the variability between sites. A surface soil sample was taken before each experiment to measure the «dry» soil moisture value (D), and after each experiment soil samples were taken at the surface (WO) and at 10 cms depth (W10) within the cylinder infiltrometer. The soil moisture values were measured gravimetrically and are expressed as 100×grms/grms. Each experiment was continued for an hour as the majority of storms are less than this in duration.

A sprinkler was used to measure infiltration rates under heavy storm intensities. Water was applied at an average rate of 29l/10 minutes for a 10 minute period over an area of 0.1134 m^2, which represents a high 10 minute intensity for the region (Castillo and Beltran

1979). Unfortunately it was not possible to replicate the energy of raindrops as the sprinkler drop sizes were smaller than under natural conditions and the terminal velocities of the drops were not reached. The duration of the tests was determined by the volumetric capacity of the sprinkler. A metal ring encircling 0.1134 m^2 was used to delimit the trial area and care was taken to minimise losses by wind. The runoff was collected after each experiment and the infiltration rate was calculated by subtracting the volume of run off from the volume of water applied. The 10 minute infiltration rates were multiplied by six to get hourly rates. These figures may over estimate hourly rates because the infiltration rate decreases with time, however previous work has shown that in semi-arid areas the infiltration rate falls rapidly to a constant value (Scoging, 1982), so this was not thought to be a serious error. Six locations were chosen randomly on all sites, including two areas on site 5, namely in the hollow and on the spur. Two tests were undertaken at each location, the second 15 minutes after the first in order to study wet soil conditions. A soil sample was taken at each position to measure the soil moisture content at the time of each experiment.

The relative erodibility of the soil was calculated by measuring the amount of sediment in a 300 ml sample of the runoff and using the sediment: water ratio of the sample to estimate total soil loss (g/m^2). The values obtained give a relative ranking of erodibility rather than estimates of soil erosion because of the difficulty of simulating the energy of the natural raindrops which are important for detaching soil particles.

Precipitation

The nearest meteorological station to the site is 12 km away in Alcantarilla where the mean annual rainfall, based on records between 1945 to 1970, is 289.6 mm, although interannual variation may be 30% (Ministerio De Agricultura 1974). The mean monthly values shown in table 1 indicate a dominance of autumn and spring rainfall with two almost equal maxima per year in April and October. The autumn peak is usually considered to be most effective in terms of erosion as high intensity storms fall onto a soil surface which has already been broken up by mechanical erosion during the summer drought.

The rainfall data for the site show that in 1986 the spring rains occurred late at the end of May (table 1), but more significantly September and October were exceptionally wet months with a total of 241.5 mm falling between 30 September and 13 October. This has had a great impact on soil erosion throughout the Province of Murcia.

Infiltration

Cylinder infiltrometer

Infiltration rates for the cylinder infiltrometer are presented in table 2. The mean values vary between 7.50 cms/hr on site 1 to 19.96 cms/hr on site 20, and the sites are ranked from high to low rates in the following order: site 20, I, 5-spur, 2, 5-hollow, and 1. All the experiments were on bare, unvegetated ground, but despite this uniformity the standard deviations show that within a small area (4m^2) the infiltration rate can vary considerably, especially on site 20. Other authors have also pointed to the variability of infiltration rates (Sharma et al. 1980).

Soil moisture values before and after the infiltration experiments are presented in table 3. The mean soil moisture contents before the tests on sites 1, 2, 5-hollow, 5-spur, 20 and I were 2.09%, 9.49%, 6.95%, 11.54%, 2.51% and 0.96% respectively. Although the infiltration experiments were conducted over a six week period in May and June, the differences in soil moisture between the sites reflect differences in the hydrological properties of these slopes and not the effect of the intervening storm on 29-30 May. To illustrate this point the surface soil moisture content on 14 May on sites 1, 2, 5-hollow, 5-spur, 20 and I were 2.91%, 5.66%, 11.92%, 6.73%, 3.94%, and 1.10%. After the storm the infiltration experiments were continued when the soil had dried out to the pre-storm values.

A soil moisture sample (WO) was taken a few minutes after the cessation of each experiment at the surface within the cylinder infiltrometer when the soil was near saturated. It is assumed that the WO sample represents the percent by weight of the saturated soil moisture content of the soil. The highest mean saturated soil moisture content is 57.15% on site 5-spur and the lowest is 32.16% on site I.

TABLE 1
Precipitation values for the mean monthly precipitation at Alcantarilla (Ministerio de Agricultura, 1974) and for the actual values between January and October 1986

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	24.3	18.4	20.9	47.6	25.6	19.3	1.8	6.2	21.4	46.7	27.0	30.4
Actual	6.4	2.5	39.5	6.5	52.6	6.2	17.7	0.0	69.0	172.5		

TABLE 2

Cylinder infiltration rates (cms/hr)

	SITE 1	SITE 2	SITE 5-H	SITE 5-S	SITE 20	ISLAND
1	13.04	11.96	7.56	15.08	14.75	10.68
2	3.42	3.64	9.49	13.10	35.04	10.30
3	4.53	10.45	8.32	7.69	9.23	19.90
4	7.56	9.83	6.89	7.70	24.34	16.92
5	8.94	16.28	14.00	10.92	16.43	9.62
$\bar{x}$	7.50	10.43	9.25	10.90	19.96	13.48
σ	3.82	4.56	2.82	3.27	10.02	4.63
n	5	5	5	5	5	5

TABLE 3

Soil moisture values for the cylinder infiltrometer experiment (% by weight)

DEPTH	SITE 1	SITE 2	SITE 5-H	SITE 5-S	SITE 20	ISLAND
Dry	1.80	6.97	5.81	11.46	3.13	1.00
WO	39.84	43.70	45.18	50.72	43.83	32.39
W10	23.94	35.97	29.62	38.80	30.72	22.24
Dry	1.95	8.52	6.65	11.99	3.00	1.15
WO	42.17	42.55	47.20	57.43	44.66	32.47
W10	23.84	26.50	34.93	43.00	38.99	24.07
Dry	2.09	10.70	6.39	10.34	2.57	0.85
WO	45.79	45.10	47.50	57.07	40.53	33.63
W10	26.90	32.84	33.79	38.14	28.75	24.63
Dry	2.59	10.06	6.59	11.70	1.75	1.03
WO	39.45	45.43	49.00	55.20	48.99	33.42
W10	28.25	34.47	36.87	45.16	34.53	23.65
Dry	2.00	11.20	9.29	12.20	2.10	0.78
WO	39.56	41.14	50.31	65.33	45.22	28.89
W10	30.12	35.39	39.34	41.73	32.43	20.89
$\bar{x}$ dry	2.09	9.49	6.95	11.54	2.51	0.96
$\bar{x}$ sat.	41.36	43.58	47.84	57.15	44.65	32.16
Bulk D.	1.21	1.08	1.13	0.95	1.17	1.30
Porosity	51.6	56.8	54.8	62.0	53.3	48.0

The bulk density (BD) was measured by taking a known volume of soil in a Kubiena tin (181.94 cm^3) and dividing the dry weight of the soil by the volume. Two samples were taken within 10 cms of the soil surface on all sites. The porosity (P) was estimated by assuming a specific density (SD) of 2.5 (a suitable figure for calcareous soils according to Duchaufour 1975) where $P = ((SD - BD) / SD) \times 100$. The estimates of porosities are high, but they mirror the magnitude of the mean saturated soil moistures so that site 5-spur has the highest values of the saturated soil moisture and porosity, while sites 1 and I have the lowest values of both.

TABLE 4 a)

Sprinkler infiltration rates for the dry experiments (cms/hr)

	SITE 1	SITE 2	SITE 5-H	SITE 5-S	SITE 20	ISLAND
	5.29	5.66	8.62	6.88	6.88	7.41
	6.88	6.61	4.87	6.75	6.61	9.79
	7.94	4.76	7.09	7.41	8.47	6.08
	5.82	4.10	7.83	4.76	7.14	7.41
	7.01	6.75	7.80	6.22	6.75	7.41
	5.82	5.42	7.41	5.29	10.45	6.88
$\bar{x}$	6.46	5.55	7.27	6.22	7.72	7.50
σ	0.99	1.03	1.28	1.01	1.50	1.24
n	6	6	6	6	6	6
Σx	38.76	33.30	43.62	37.31	46.30	44.98

CALCULATIONS FOR ANALYSIS OF VARIANCE		DEGREES OF FREEDOM		F
Total Sum of Squares	= 1721.24 – 1657.44 = 63.80	35		
Between Sum of Squares	= 1678.81 – 1657.44 = 21.37	5	4.27	
Within Sum of Squares	= 42.43	30	1.41	3.03
$F_{5,30}$ at 0.05 = 2.53				

Sprinkler infiltration

The data for the sprinkler infiltration rates for the dry and wet runs are given in table 4. For the dry run the mean values rank from highest to lowest sites 20, I, 5-hollow, 1, 5-spur and 2, but for the wet run the ranking changes slightly to I, 20, 5-hollow, 5-spur, 1, and 2. These two rankings can be compared statistically using Spearman's rank correlation coefficient (r_s) to test whether they are different. The sites are ranked according to the mean infiltration values, the difference (Di) between the ranks is squared (Di^2) and used to calculated r_s where:

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} Di^2}{N(N^2 - 1)}$$

The r_s values can be tested for significance using Student's «t» distribution by

$$t = r_s \sqrt{\frac{N - 2}{1 - r_s^2}} \text{ for N – 1 degrees of freedom.}$$

The test requires a minimum of six observations, and the calculations are as follows:

SITE	DRY RUN RANK	WET RUN RANK	Di	Di^2
1	4	5	1	1
2	6	6	0	0
5-h	3	3	0	0
5-s	5	4	1	1
20	1	2	1	1
I	2	1	1	1
				4

r_s = 1–((6 × 4) / (6(36 – 1))) = 1 –(24 / 210) = +0.886

The r_s value suggests a high positive correlation between the two rankings. This is tested for significance where

$$t = 0.886 \sqrt{(4 / (1 - 0.784))} = 3.82$$

The t value in the distribution for 5 degrees of freedom in a two tailed test for a level of significance of 0.05 is 2.571. As the calculated value for t is 3.82 it is possible to accept that the correlation in rankings between the wet and dry experiments is significant at the 0.05 level.

Mean values of infiltration vary between 7.72 cms/hr on site 20 to 5.55 cms/hr on site 2 for the dry experiments, and between 5.45 cms/hr on site I and 3.61 cms/hr on site 2 for the wet experiments. It is possible to examine firstly the variation in values between sites for

TABLE 4 b)

Sprinkler infiltration rates for the wet experiments (cms/hr)

	SITE 1	SITE 2	SITE 5-H	SITE 5-S	SITE 20	ISLAND
	4.76	4.21	6.35	4.50	4.23	5.56
	3.70	4.10	4.95	5.82	4.63	6.61
	4.76	3.31	5.71	4.63	5.56	5.82
	4.23	3.17	4.21	3.70	5.69	4.89
	5.29	3.44	3.70	5.56	4.89	4.50
	4.37	3.44	5.03	3.84	5.69	5.29
$\bar{x}$	4.52	3.61	4.99	4.68	5.12	5.45
σ	0.55	0.43	0.96	0.87	0.62	0.74
n	6	6	6	6	6	6
Σx	27.11	21.67	29.95	28.05	30.69	32.67

CALCULATIONS FOR ANALYSIS OF VARIANCE		DEGREES OF FREEDOM		F
Total Sum of Squares	= 831.77 − 804.10 = 27.67	35		
Between Sum of Squares	= 816.26 − 804.10 = 12.16	5	2.43	
Within Sum of Squares	= 15.51	30	0.52	4.67

$F_{5,30}$ at 0.05 = 2.53

(For discussion of the analysis of variance test see Blalock, 1972)

Mean soil moisture values during the sprinkler infiltration experiments

SITE 1	SITE 2	SITE 5-HOLLOW	SITE 5-SPUR	SITE 20	ISLAND
1.61%	6.56%	4.08%	7.18%	7.24%	0.98%

the dry and wet cases and secondly to compare between the dry and wet experiments.

A one-way analysis of variance was used to test whether infiltration rates varied significantly between the sites. (This could not be done for the cylinder infiltrometer data because the test locations were not chosen randomly.) For the sprinkler example the null hypothesis is that there is no difference in the population means, for both the dry and wet cases. The calculations are presented in table 4a for the dry case and 4b for the wet case. The result is tested at the 0.05 significance level, and published tables show that the F value for 5 and 30 degrees of freedom ($F_{5,30}$) is 2.53. In the dry and wet cases the calculated F value is 3.03 and 4.67 respectively, so that the null hypothesis can be rejected, that is for 95% of occasions there are significant variations in infiltration rates between the sites.

On each site a comparison of dry and wet runs shows that the mean infiltration rates are between 25% to 35% lower for the wet run, reflecting the decrease of available storage as the soils become wetter and the infiltration rate falls towards a constant value determined by the conductivity of the soil.

Erodibility test

Table 5 presents the quantity of sediment eroded (g/m^2) during each sprinkler test. Three factors stand out. Firstly, for a given soil moisture condition (ie wet or dry) there is a large difference in soil erosion between the highest values (eg 128.9 g/m^2 on site 1 – dry case) and the lowest values (16.9 g/m^2 on site I – dry case). Secondly, the sediment loss is greater for the wet run than for the dry run, but the difference varies (48.4 g/m^2 on site 5-spur to 0.60 g/m^2 on site 20). Thirdly, the variability of the soil loss is high for sites 1 and 2, and low for sites 20 and I.

For the dry experiments the ranking of sites for sediment loss from high to low values is site 1, 5-spur, 2,

TABLE 5 a)
Sediment loss for dry run sprinkler experiments (g/m^2)

	SITE 1	SITE 2	SITE 5-H	SITE 5-S	SITE 20	ISLAND
	252.2	23.2	27.8	50.3	30.1	22.3
	51.6	74.5	34.9	120.5	53.5	13.2
	154.8	39.7	22.0	97.7	21.2	18.1
	125.7	55.0	20.6	88.8	20.9	15.4
	101.1	164.7	74.1	80.2	19.0	14.1
	87.9	135.8	74.5	135.2	13.7	18.5
$\bar{x}$	128.9	82.2	42.3	95.5	26.4	16.9
σ	69.7	56.2	25.3	30.1	14.3	3.4
n	6	6	6	6	6	6
Σx	773.3	492.9	253.9	572.7	158.4	101.6

CALCULATIONS FOR ANALYSIS OF VARIANCE USING THE LOG VALUES FOR THE DATA		DEGREES OF FREEDOM		F
Total Sum of Squares	= 104.81 – 100.03 = 4.78	35		
Between Sum of Squares	= 103.34 – 100.03 = 3.31	5	0.662	
Within Sum of Squares	= 1.47	30	0.049	13.51

$F_{5,30}$ at = 0.001 = 5.53

TABLE 5 b)
Sediment loss for wet run sprinkler experiments (g/m^2)

	SITE 1	SITE 2	SITE 5-H	SITE 5-S	SITE 20	ISLAND
	418.9	32.3	36.2	112.9	44.5	19.6
	44.1	55.8	28.2	280.9	45.4	17.6
	98.8	42.8	25.0	105.8	27.6	24.7
	119.9	40.4	34.9	97.0	20.3	18.3
	102.9	129.9	290.4	66.1	14.6	12.9
	77.2	359.8	49.4	200.6	9.5	20.7
$\bar{x}$	143.6	110.2	77.4	143.9	27.0	19.0
σ	137.3	127.4	104.7	80.8	15.2	3.9
n	6	6	6	6	6	6
Σx	861.8	661.0	464.1	863.3	161.9	113.8

CALCULATIONS FOR ANALYSIS OF VARIANCE USING THE LOG VALUES FOR THE DATA		DEGREES OF FREEDOM		F
Total Sum of Squares	= 112.97 – 106.61 = 6.36	35		
Between Sum of Squares	= 110.20 – 106.61 = 3.59	5	0.718	
Within Sum of Squares	= 2.77	30	0.092	7.80

$F_{5,30}$ at = 0.001 = 5.53

TABLE 6
Average sediment loss per storm (g/m²)

DATE	PRECIPITATION mm	SITE 1	SITE 2	SITE 5	SITE 20
8/3/86	35.4 [1]	1.72	43.52	23.48	20.98
29-30/5/86	52.2 [1]	3.64	21.22	17.26	16.68 [2]
30/9/86	64.8	5.27	21.00	20.97	17.72
3-4-5/10/86	108.8	128.79	197.47	170.70	102.74
6-7/10/86	14.7	3.06	1.02	1.51	0.51
10-11/10/86	47.9	38.19	33.71	36.69	19.26

1 These are underestimates for the precipitation due to a faulty raingauge.
2 This average is based on two samples only, all the others are based on three samples.

5-hollow, 20 and I, and for the wet experiments the only change is that sites 1 and 5-spur are transposed.

Between site variability is again tested using analysis of variance, however as this test can not be used where sample variances differ considerably, the sediment data were converted to logs to reduced the sample variances (Blalock 1972). Thus in table 5 the actual sediment loss is given together with the calculations for analysis of variance using the logged data. In both the dry and wet cases the null hypothesis states that there is no difference in the population means, and this is tested for a significance level of 0.001 where $F_{5,30}$ is 5.53. For the dry run F equals 13.51 and in the wet run F is 7.80, so that in both cases the null hypothesis is rejected. Thus in 99% of the cases there is a significant difference in soil loss between the sites.

Soil erosion

Between January and October 1986, six storms have caused soil erosion by wash. The mean soil loss values for the three runoff plots on each site are presented in table 6, together with the total precipitation values. For the first three storms soil erosion is very low on site 1 in relation to the other three sites where erosion is greatest on site 2 and less for sites 5 and 20. During the storm on 3-4-5 October the amount of soil erosion was much higher on site 1 than on previous occasions, and was relatively larger on 10-11 October with respect to the other sites. This might be due to the breaching of the ridges as the plough lines are still well marked and offer a lot of storage area in the furrows. Apart from this the pattern of soil loss follows that predicted by the erodibility test namely that soil erosion will be less on the fields which have been left fallow longer.

Discussion and conclusions

The infiltration rates (for all methods used) were lower on the sites which were most recently abandoned. Conversely, soil erosion was higher on the more recently ploughed slopes. These two factors are interelated as if infiltration rates are higher there is less water available for surface wash and hence lower rates of erosion are probable. Other factors are involved, for example with time the surface characteristics of the soil may change to impede soil erosion as fine material is washed away in the early stages. Also vegetation recovery may serve to increase infiltration and protect the soil surface from the destructive impact of raindrops. Nevertheless infiltration seems to have an important influence on rates of erosion on abandoned fields.

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Bibliography

BLALOCK, H. M. (1972): *Social Statistics*. McGraw-Hill Kogakusha, 583 pp.

CASTILLO, F. E. and BELTRAN, L. F. (1979): Precipitaciones máximas en España. Instituto Nacional para la Conservación de la Naturaleza. Monografía 21, 555 pp.

DUCHAUFOUR, P. (1975): *Manual de Edafología*. Toray-Masson, 476 pp.

HILLS, R. C. (1970): The determination of the infiltration capacity of field soils using the cylinder infiltrometer. BGRG Technical Bulletin, 3, 25 pp.

MINISTERIO DE AGRICULTURA (1974): Caracterización agroclimática de la provincia de Murcia. Dirección General de la Producción Agraria.

SCOGING, H. M. (1982): Spatial variations in infiltration, runoff and erosion on hillslopes in semi arid Spain. Ch 5, in ***Badland Geomorphology and Piping***, Eds., Bryan, R. B., and Yair, A., GeoBooks.

SHARMA, M. L., GANDER, G. A. and HUNT, C. G. (1980): Spatial variability of infiltration in a watershed. Journal of Hydrology, 45, pp. 101-122.