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The Rambla Honda Field Site: Interactions of Soil and Vegetation Along a Catena in Semi-arid Southeast Spain

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7.1 INTRODUCTION

Desertification and land degradation in the Mediterranean Basin show two contrasting trends (Le Houérou, 1991). In the southern part, continuous population growth increases the susceptibility of the landscape to degradation by enlarging the cultivated area and by increasing the grazing pressure on rangelands. In the northern part, with the social and technological changes that took place in the 1950s, traditional rural life disintegrated. Some areas support increasing intensification and immigration, while others suffer from loss of population and abandonment of land.

The interruption of the activity of man in the landscape raises some intriguing questions. It is known that man has been a very significant factor in shaping the Mediterranean landscape (Puigdefábregas, 1992). Therefore the cessation of human activity does not lead to any ideal or primeval condition, because such a condition has never existed without man. Vegetation is recovering in many places, but very little is known about the long-term response of the landscape. There are local increases in erosion

Mediterranean Desertification and Land Use. Edited by C. Jane Brandt and John B. Thornes.
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and wild fires, and the destruction of man-made structures which controlled runoff and soil loss is common feature. These facts suggest that the interruption of man's activities is not a guarantee for long-term recovery of the landscape and that greater risks of instability of the landscape may be faced, especially if climate fluctuates.

The main goal of the Almeria group in the MEDALUS project is to provide information about the evolution of the semi-arid Mediterranean landscape and its sensitivity to climate once the activity of man has been interrupted. A typical catena with different land uses and elapsed times since abandonment was selected and a research programme was set up with the following objectives.

1. To find relationships between land use, soil, vegetation and organic matter along a catena representative of a semi-arid environment.
2. To provide information about the response of the elements of the catena, in terms of runoff, sediment outputs, leaf area index (LAI) and net primary productivity, to rainfall events and to seasonal and annual variations in climate.
3. To describe the physiological strategies of the main building species and the micro-environmental variations created by their patchy distribution. To use this information to improve existing water-balance models.

The Almeria research programme is designed to provide both comparable data for the core MEDALUS project and information specific to the objectives of the Almeria group. In the following, the geographical setting and the experimental design are described, as are preliminary results from the first year's research.

7.2 GEOGRAPHICAL SETTING

7.2.1 The field site

The Almeria field site (Figure 7.1) is located in the contact zone between the south versant of the Filabres range, a core of Pre-Cambrian to Triassic metamorphic rocks (from the Nevado–Filabride complex), and the Neogene depression of Sorbas–Tabernas, in the eastern part of the Betic Cordillera. The area is covered by extensive alluvial fan systems which have developed since the Late Pliocene. It may be considered as a key area to study slope–fan relations in total sediment outputs and their significance at a regional scale (Harvey, 1987).

In the lower sector of the Rambla Honda (30S-WG-5509 UTM coordinates), an ephemeral river (rambla) draining a basin of 30.6 km^2 in the southern versant of the Filabres range, a study area was selected. It is 300 m wide by 600 m long, from 630 m altitude at the rambla bed, to 800 m on the divide (Figure 7.1).

This sloping area consists of a catena of soils and vegetation (Figure 7.2), going from the upper sector with soils on micaschist bedrock and *Stipa tenacissima* L. tussocks, to soils on sedimentary deposits with *Anthyllis cytisoides* L. shrubs in the upper part of the alluvial fans and *Retama sphaerocarpa* (L.) Boiss. on the lower part of the fans and on drainage channels.

Although the agricultural land has been abandoned, the area is still grazed by sheep flocks and, in rainy winters, plots on alluvial fans and riverbeds may be cultivated.

The study area comprises two separate sampling sites, coded by the initials SP and MA:

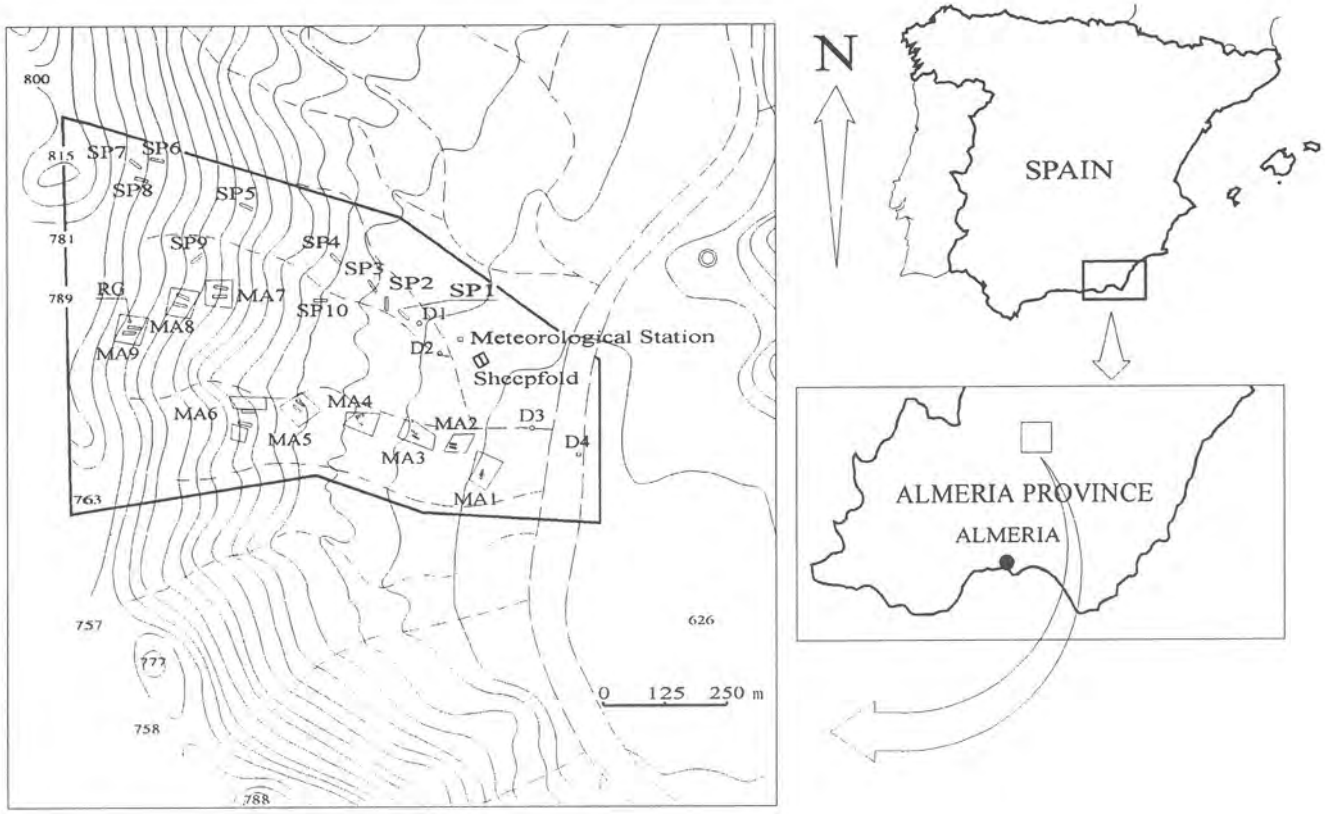


FIGURE 7.1 Location of Rambla Honda field site. SP = runoff plot in sampling site 1; MA = measurement area in sampling site 2; RG = rainfall gauge; D = bore hole; — — — = drainage line.

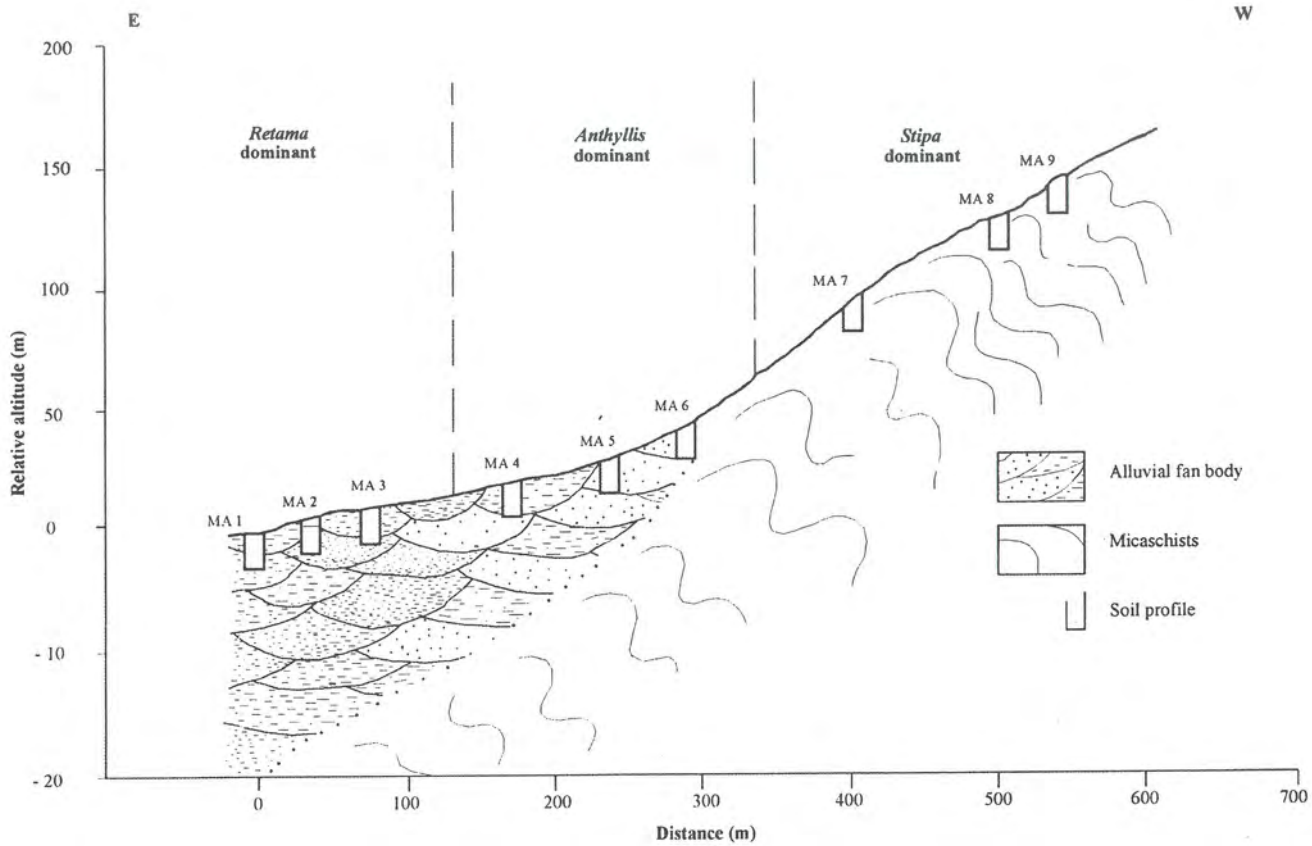


FIGURE 7.2 Diagram of the catena in the Rambla Honda showing the bedrock, the distribution of the vegetation and the positions of measurement areas (MA) and soil profiles

SP This includes 10 runoff plots (SP1 to 10), 8×2 m, on abandoned fields on alluvial fans and slope colluvia. They were set up in November 1990 with the objective of collecting information about the role of old fields with low perennial plant cover and different gradients as potential sources of runoff and sediments. The characteristics of the plots are presented in Table 7.1.

MA This site was set up in September 1991, and includes nine measurement areas (MA1 to 9) arranged in a line along the catena: three in *Retama sphaerocarpa*, three in *Anthyllis cytisoides* and three in *Stipa tenacissima* dominated areas (Figure 7.2). In each MA, two closed runoff plots, 10×2 m, were built, one with relatively dense and one with sparse perennial plant cover. In addition, each MA has been provided with three types of plots for sampling soil moisture, litterfall and non-destructive vegetation sampling. The main characteristics of the MAs are shown in Table 7.2.

Grazing was excluded from the whole study area from 1 September 1991 onwards through arrangements with the owners.

7.2.2 Climate

The climate is semi-arid with long hot summers. Geographical interpolations among nearby weather stations with long series (Lazaro and Rey, 1991) provide estimates of 300 to 350 mm annual rainfall, mainly in the cold season, and mean annual temperatures of 15.5 to 16.5°C. The nearby Tabernas meteorological station provides the most complete climatic record in the area (Figure 7.3). The 3-year data-set from the automatic weather station in Rambla Honda (installed in 1990), confirms the high annual and seasonal variability of rainfall (Figure 7.4).

Prevailing winds mostly come from N, NW and SE (Figure 7.5), following the alignment of the Rambla Honda valley. The wind speed is greater than $5\,m\,s^{-1}$ for only 1% of the year (Figure 7.6).

Global solar radiation (Figure 7.7) reaches a maximum of $1000\,W\,m^{-2}$ in summer and around $500\,W\,m^{-2}$ in winter, indicating that the minimum atmospheric extinction is

TABLE 7.1 Characteristics of the runoff plots (SP) in sampling site 1

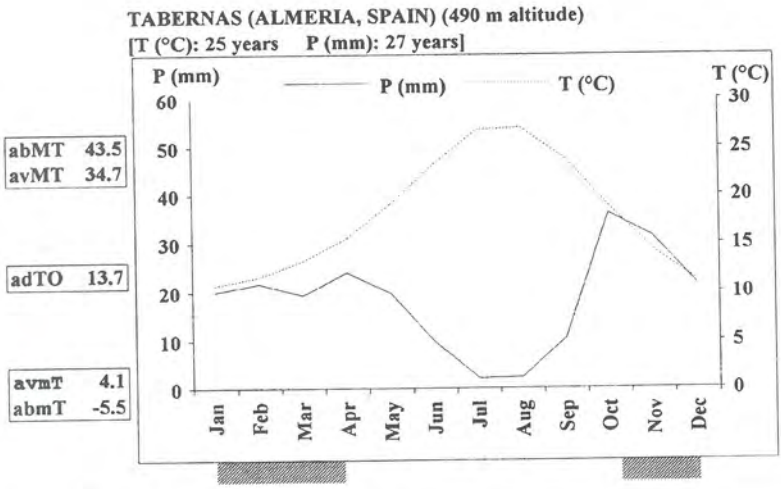
Runoff plot	Relief	Grass cover (%)	Shrub cover (%)	Altitude (m)	Slope gradient (°)
1	AF	40	5	650	12
2	AF	65	5	648	21
3	AF	20	15	655	27
4	COL	40	15	690	29
5	COL	70	5	725	33
6	COL	70	5	770	28
7	COL	90	10	773	41
8	COL	75	10	769	23
9	COL	80	10	740	35
10	COL	80	25	695	45

AF = alluvial fan; COL = colluvium.

TABLE 7.2 Characteristics of the measurement areas (MA) in sampling site 2

							Runoff plots			
							Dense perennial plant cover		Sparse perennial plant cover	
	Relief	Plant cover (%)	Surface (m^2)	Altitude (m)	Slope gradient (°)	Vegetation	Slope gradient (°)	Plant cover (%)	Slope gradient (°)	Plant cover (%)
MA 1	FD (ST)	8	1682	628	3	*Retama*	2	26	2	0
MA 2	AF (CV)	19	1009	632	4	*Retama*	4	55	5	6
MA 3	AF (CV)	15	1253	637	5	*Retama*	5	43	5	4
MA 4	AF (CV)	29	778	648	7	*Anthyllis*	7	48	9	24
MA 5	AF (CV)	32	644	662	12	*Anthyllis*	12	36	12	22
MA 6	COL (ST)	25	324	681	20	*Anthyllis*	20	48	22	15
MA 7	MO (CV)	34	611	720	25	*Stipa*	24	40	23	23
MA 8	MO (CC)	39	466	730	17	*Stipa*	21	44	18	30
MA 9	MO (CV)	31	437	752	27	*Stipa*	21	32	23	29

FD = fluvial deposit; AF = alluvial fan; COL = colluvium; MO = micaschists.
ST = straight; CV = convex; CC = concave.



abMT Absolute maximum temperature (°C)
avMT Average maximum temperatures from hottest month (°C)
adTO Average of daily temperature oscillations (°C)
avmT Average minimum temperatures from coldest month (°C)
abmT Absolute minimum temperature (°C)
▒ Months with potential absolute minimum temperatures < 0 (°C)

17.9°C - average yearly temperature
218.3mm - average annual rainfall

FIGURE 7.3 Climatic diagram of the Tabernas weather station, according to Walter (1973)

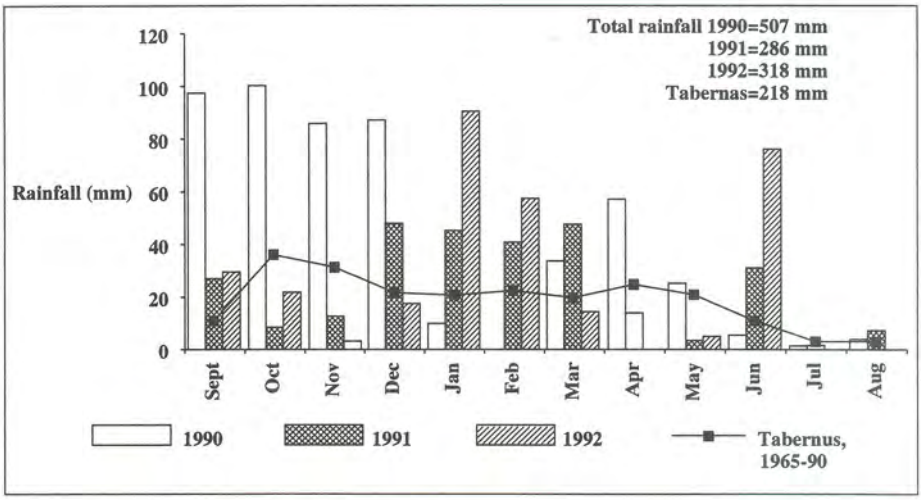


FIGURE 7.4 Monthly distribution of rainfall in Rambla Honda (630 m altitude) since the installation of the weather station. Annual periods start 1 September 1990 and finish 31 August 1992

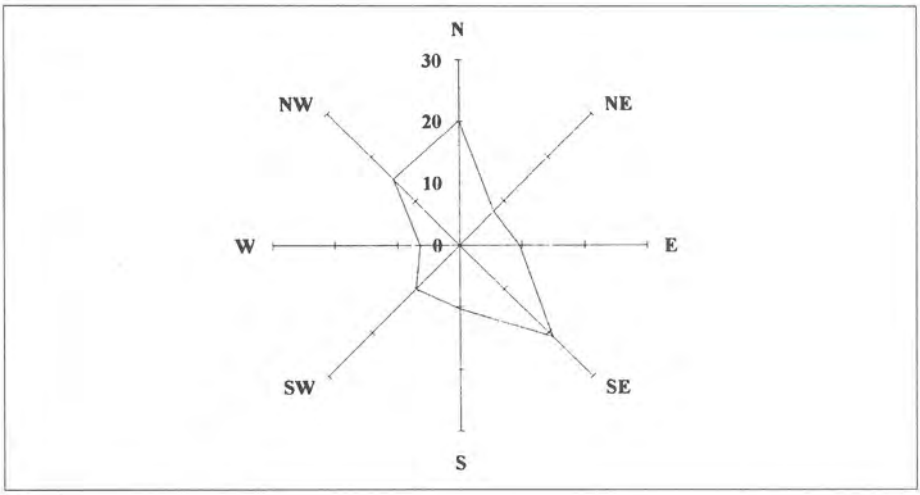


FIGURE 7.5 Main directions of wind in the Rambla Honda during the period 1991–92

around 21 and 27% respectively (for extraterrestrial radiation of 1273 W m^{-2} in summer and 689 W m^{-2} in winter, at this latitude).

7.2.3 Geology and hydrogeology

The bedrock of the area is highly convoluted and fractured, dark grey, fine-grained, Devonian–Carboniferous slaty micaschists with graphite and garnets, crossed by abundant

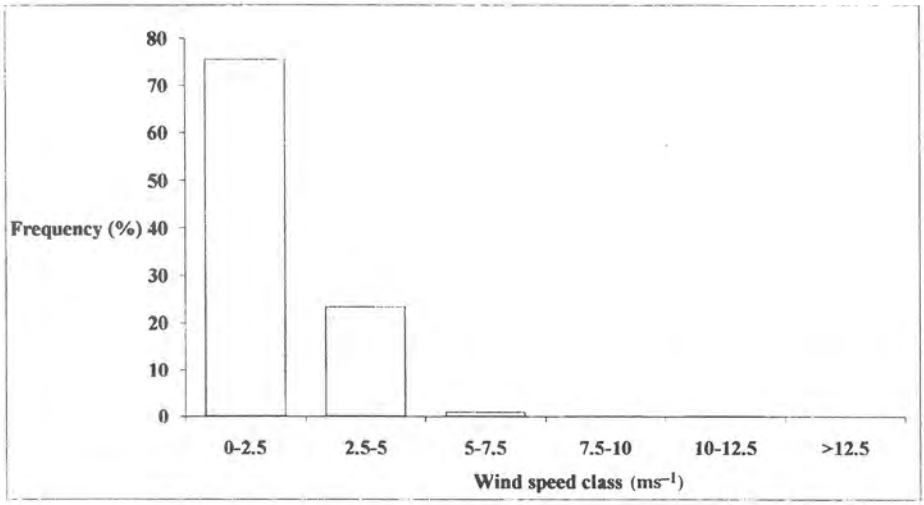


FIGURE 7.6 Frequency distribution of wind speed ($m\,s^{-1}$) in the Rambla Honda during the period 1991–92

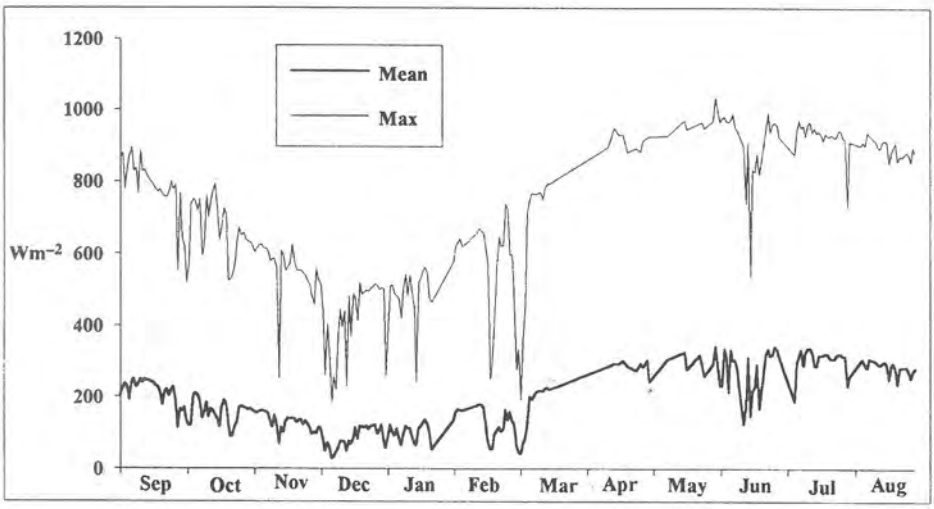


FIGURE 7.7 Solar radiation (335–2200 nm) at the Rambla Honda weather station during the study period showing daily maxima and daily average (including night period) values

quartz veins alternating with thin phyllite layers. Its degree of weathering is related to the layering pattern and to the proportions of garnets and quartz. When the latter is high, spurs or shoulders are formed by differential erosion and colluvial debris is accumulated upslope behind them. In the middle to low part of the catena, the slope colluvia gradate to an alluvial fan formation which connects with the large Rambla Honda fan system.

Four bore holes were drilled along an altitudinal transect, from the root of the alluvial fan to the rambla floor in order to investigate the sedimentary characteristics of the alluvia and colluvia and to monitor the phreatic level. The bore holes reached the underlying micaschist basal rock. The thickness of the sediment (18, 8, 16, 28 m) and hence the altitude above sea-level of the basal rock (627, 632, 609, 597 m) show the existence of a rather pronounced palaeo-relief, antecedent to the deposition of sediment. The sedimentary columns contain alternating beds of coarse and fine material. Gravels and sands, with a planar geometry, prevail in the upper section, whereas red loams with small sandy intercalations predominate in the lower section. The intermediate section shows transitional characteristics.

In bore hole 4, a permeability test (constant head, Lefranc type) was performed in dry conditions. The estimates of permeability range from 8.61×10^{-3} cm s^{-1} for the total column to 1.9×10^{-2} cm s^{-1} for the gravel beds. Owing to the inaccuracies of this test, these figures should be treated with caution, but they suggest a moderate total permeability which almost doubles in the coarser layers.

7.2.4 Soils

The soils from Rambla Honda are essentially colluvial and alluvial in origin. Those on the slopes have developed directly from micashists and quite shallow slope deposits. Steepness of slope and variability in hardness of bedrock influence soil thickness: where slates with abundant quartz veins dominate, soils are usually shallow (up to 15 cm); where phyllite strata dominate, soils are thicker (up to 60 cm). Those on alluvial fans have developed from bedded colluvia which have originated from the erosion and sedimentation of material from the slopes above them.

All soils are mostly channery loamy sands and channery fine sandy loams (with low proportions of silt + clay). Coarse fragments (larger than 2 mm in diameter) within the soil mass range from 12.75% in the lower part of the alluvial fan to 67% in the higher part of the catena, with 2–8 mm fragments being the most abundant size (Table 7.3). Surface stoniness also increases up the catena (Table 7.4, Figure 7.8). The dominant stone type, either quartz or micaschist, is quite variable and depends on proximity to large quartz outcrops (veins of variable thickness, from a few millimetres to more than 1 m).

The soils of the whole area show little development of pedogenic horizons and may be arranged in two main groups (Tables 7.5 and 7.6): (a) the soils on the lower part of alluvial fans, classified as Eutric Fluvisols and Eutric Regosols, which exhibit a clear stratification and an irregular distribution of organic matter down the profile, and (b) the soils on the upper part of alluvial fans and hillslopes, classified as Eutric Leptosols, which are texturally somewhat finer. Both groups of soils have some common attributes: (1) pH ranges from slightly acid (6.5) to moderately alkaline (8); (2) electrical conductivity is very low, from 0.003 to 0.022 S m^{-1}; (3) cation exchange capacity is also very low, less than 10 cmol kg^{-1}, as a consequence of the low relative content of both clay and organic matter. But also they show some differences: the soils on the alluvial fans contain relatively less clay, less organic matter and less coarse fragments than the slope soils.

The organic matter content of surface horizons in all soils is quite variable (Table 7.6) being largely dependent on the vegetation type and cover: under bushes the proportion can

TABLE 7.3 Particle size distribution and bulk density of soils from the Rambla Honda catena. Bulk density was measured on samples from two depths: 0–7 cm and 20–27 cm

	Particle size distribution								
			Fine earth fraction (%)						
MA	Horizon (cm)	>2 mm (%)	c.sand	f.sand	c. silt	f. silt	clay	Horizon (cm)	Bulk density ($kg\,l^{-1}$)
	0–4	12.75	24.4	51.1	9.8	10.9	3.8	0–7	1.51
	4–11	32.21	41.5	42.6	4.9	8.3	2.9		
1	11–42	31.46	50.9	36.2	3.7	6.9	2.4	20–27	1.67
	42–73	0.74	n.a.	n.a.	n.a.	n.a.	n.a.		
	73–96	30.45	47.4	38.4	4.3	7.6	2.4		
	0–3	22.71	42.0	40.0	5.0	9.6	3.5	0–7	1.59
2	3–34	38.64	48.5	36.6	4.0	8.3	2.7	20–27	1.65
	34–60	54.71	n.a.	n.a.	n.a.	n.a.	n.a.		
	0–6	40.68	53.9	29.7	4.6	8.8	3.1	0–7	1.52
3	6–21	36.40	51.1	33.8	4.2	8.4	2.5		
	21–38	29.39	50.7	37.0	3.0	7.3	2.0	20–27	1.57
	38–70	25.50	42.1	43.3	4.1	8.2	2.3		
	0–4	40.06	40.6	36.3	5.9	12.0	5.1	0–7	1.53
4	4–20	35.96	34.6	38.5	6.0	16.9	4.0		
	20–50	45.31	31.7	38.5	5.9	17.0	6.9	20–27	1.55
	0–3	40.63	31.7	47.5	6.1	10.2	4.5	0–7	1.45
5	3–20	34.30	35.8	41.9	5.8	11.7	4.7		
	20–60	44.70	33.7	39.9	6.3	15.9	4.1	20–27	1.59
	0–5	60.12	38.4	35.2	7.7	14.5	4.3	0–7	1.45
6	5–16	40.90	32.8	39.2	7.1	16.7	4.2		
	>16	62.01	21.4	26.6	12.0	31.1	8.9	20–27	1.68
	0–5	55.83	30.0	37.8	8.9	15.9	7.5	0–7	1.34
7	5–30	58.47	29.8	36.2	6.9	18.7	8.5	20–27	1.34
	30–60	30.49	25.9	30.7	8.6	24.2	10.6		
	0–3	47.05	26.6	41.4	8.4	15.9	7.7	0–7	1.34
8	3–15	67.02	27.0	33.2	7.5	22.1	10.2		
	>15	54.06	26.1	24.0	9.6	29.9	10.4	20–27	1.21
9	0–6	55.19	37.0	38.2	6.7	15.3	2.8	0–7	1.27
	6–60	28.56	21.6	33.9	11.3	26.6	6.6	20–27	1.5

n.a. = not available. c. = coarse; f. = fine.

almost be twice that between bushes; areas with *Retama* have the lowest organic matter content (1.38 to 1.57%) while areas with *Stipa* have the highest (from 3.8 to 5.2%).

Soils from the lower part of alluvial fans have a 20 to 40 mm thick, surface layer, exclusively formed by very fine gravels (Figure 7.9). Under this gravely layer there is an horizon with a much finer texture, 2 to 10 mm thick, fine to very fine sandy, quite compacted and only crossed by vertical or sub-vertical cracks. Under these two surface layers, an undifferentiated, coarse-textured mass, containing randomly

TABLE 7.4 Surface stoniness and roughness from runoff plots in the sampling site 2. Plots A have a denser plant cover than plots B. Roughness coefficients are the average standard deviation of relative altitudes of 41 horizontal transects per plot

Plot	Surface stoniness (average ± SE) (%)	Surface roughness (cm)
1A	14.44 ± 3.92	
1B	16.11 ± 3.72	
2A	53.33 ± 5.42	1.15
2B	32.22 ± 6.74	1.13
3A	46.67 ± 7.24	
3B	63.61 ± 9.46	
4A	75.55 ± 7.77	
4B	76.67 ± 7.72	
5A	67.78 ± 6.88	3.11
5B	56.11 ± 7.42	2.64
6A	67.78 ± 7.73	
6B	75.89 ± 7.74	
7A	75.83 ± 7.66	
7B	73.89 ± 7.74	
8A	55.55 ± 6.87	3.45
8B	57.41 ± 6.78	3.07
9A	69.17 ± 7.52	
9B	73.15 ± 7.47	

FIGURE 7.8 Surface stoniness in the lower part of the alluvial fan (MA 1). Observe how rock fragments are on the soil surface and not embedded within the surface. A 50×50 cm frame with a 10×10 cm grid was used to evaluate the surface stoniness

TABLE 7.5 Soil morphology and classification (FAO, 1985) of the soils in the Rambla Honda catena

Soils	Horizons (cm)	Horizon type	Soil classification (FAO, 1990)	Solum thickness	Structure type	Structure grade	Consistency	Pores
	0–4	A			platy very thick	low	loose	many
1	4–11	2C	Eutric Fluvisol	>3 m	medium crumb	low	loose	common
	11–42	3C			medium crumb	low	loose	common
	0–3	A11			fine subang. blocky	low	loose	common
2	3–34	A12	Eutric Regosol	>3 m	medium crumb	low	loose	common
	21–38	2C			medium crumb	low	loose	common
	0–6	A11			med. subang. blocky	low	loose	few
3	6–21	A12	Eutric Regosol	>3 m	fine subang. blocky	low	loose	few
	21–38	AC			fine subang. blocky	low	loose	few
	0–4	A11			fine subang. blocky	low	soft	common
4	4–20	A12	Eutric Regosol	>1 m	med. subang. blocky	low	soft	common
	20–50	2C			med. subang. blocky	moderate	slight. hard	common
	0–3	A11			medium platy	low	soft	common
5	3–20	A12	Eutric Regosol	>1 m	med. subang. blocky	low	soft	common
	20–60	2Bca			fine prismatic	moderate	soft	common
	0–5	A11			med. subang. blocky	low	soft	many
6	5–16	A12	Eutric Leptosol	0.25 m	no structure	—	loose	many
	>16	AC			fine prismatic	moderate	slight. hard	few
	0–5	A11			med. subang. blocky	low	soft	common
7	5–30	A12	Eutric Leptosol	0.6 m	medium prismatic	low	soft	common
	30–60	C			medium prismatic	low	soft	common
	0–3	A11			med. subang. blocky	low	soft	few
8	3–15	A12	Eutric Leptosol	0.2 m	medium prismatic	low	soft	few
	>15	C			medium prismatic	low	soft	few
9	0–6	A	Eutric Leptosol	0.6 m	thick platy	low	soft	common
	6–60	AC			fine subang. blocky	low	soft	common

med. = medium; subang. = subangular.

TABLE 7.6 Chemical properties of the soils in the Rambla Honda catena

MA	Horizon (cm)	OM (%)	Total N (%)	pH (H_2O)	EC ($S\,m^{-1}$)	$CaCO_3$ (%)	CEC	Ca	Mg	Na	K
							(cmol kg^{-1})				
1	0–4	1.57	0.18	7.3	0.016	1.7	2.85	7.06	0.69	0.25	0.28
	4–11	1.16	0.17	7.7	0.009	0.84	2.90	5.29	0.48	0.23	0.08
	11–42	0.77	0.14	7.8	n.a.	0.75	2.32	6.42	0.61	0.17	0.06
	42–73	n.a.	0.12	8.0	0.006	n.a.	2.25	4.33	0.54	0.23	0.06
	73–96	0.96	0.20	7.8	0.006	0.49	3.40	n.a.	n.a.	n.a.	n.a.
2	0–6	1.38	0.18	6.9	0.008	0.99	6.64	2.86	0.59	0.17	0.23
	3–34	0.68	0.11	7.0	0.003	0.42	2.52	1.65	0.39	0.17	0.06
	34–60	0.75	0.10	7.3	0.004	0.44	2.65	n.a.	n.a.	n.a.	n.a.
3	0–6	1.38	0.14	7.0	0.014	0.99	3.00	2.29	0.57	0.47	0.18
	6–21	0.93	0.14	7.6	0.005	0.48	n.a.	1.79	0.37	0.18	0.08
	21–38	0.71	0.11	7.6	0.004	0.61	2.50	1.52	3.35	0.15	0.05
	38–70	0.76	0.10	7.4	0.003	0.44	3.39	1.56	0.37	0.23	0.04
4	0–4	1.83	0.22	7.5	0.022	1.46	3.57	7.27	0.90	0.18	0.18
	4–20	0.76	0.10	7.2	0.004	0.47	4.12	3.90	0.49	0.26	0.05
	20–50	0.92	0.09	7.2	0.003	0.76	3.65	3.88	0.50	0.21	0.05
5	0–3	2.57	0.32	7.3	0.019	1.13	4.29	7.00	0.79	0.35	0.29
	3–20	1.35	0.15	7.3	0.007	0.42	2.92	4.48	0.46	0.18	0.08
	20–60	1.08	0.13	7.7	0.007	3.75	2.62	15.64	0.71	0.16	0.03
6	0–5	1.82	0.24	7.3	0.018	2.9	3.69	11.13	0.67	0.15	0.24
	5–16	1.28	0.16	7.8	0.010	3.02	3.04	12.40	0.51	0.15	0.08
	>16	1.42	0.20	7.6	0.016	9.85	4.39	17.59	0.52	0.17	0.04
7	0–5	5.2	0.33	6.9	0.004	2.01	9.45	12.96	1.45	0.37	0.51
	5–30	1.91	0.19	6.8	0.005	0.97	5.19	5.92	0.81	0.19	0.15
	30–60	1.89	0.17	6.5	0.004	1.12	7.30	5.29	0.97	0.18	0.06
8	0–3	4.8	0.34	6.9	0.016	1.9	4.74	9.77	1.32	0.19	0.51
	3–15	2.41	0.19	6.9	0.005	0.64	4.69	4.98	0.76	0.17	0.21
	>15	2.54	0.28	7.3	0.006	0.99	4.69	6.16	1.18	0.28	0.08
9	0–6	3.82	0.28	7.1	0.010	1.29	4.82	7.75	1.00	0.16	0.40
	6–60	1.67	0.17	7.2	0.004	0.86	4.35	5.14	0.88	0.27	0.05

n.a. = not available.
OM = organic matter; Total N = total nitrogen; EC = electrical conductivity; CEC = cation exchange capacity.

distributed and unoriented gravels, constitutes the whole soil. Soil structure, when present, is fine to medium crumby, very weakly developed and it arises only around and among roots. Bioturbation is not observed, so that sedimentary structures are well preserved.

Soils from the slope deposits also show a surface layer <10 mm thick of pure fine gravels; under the gravels a loamy layer of about 5 mm may have an origin similar to the one observed in alluvial fan soils. Under these two layers, a much less delineated layering, with alternate layers of coarse and fine textures, constitutes the whole soil mass. Bioturbation is present but rare.

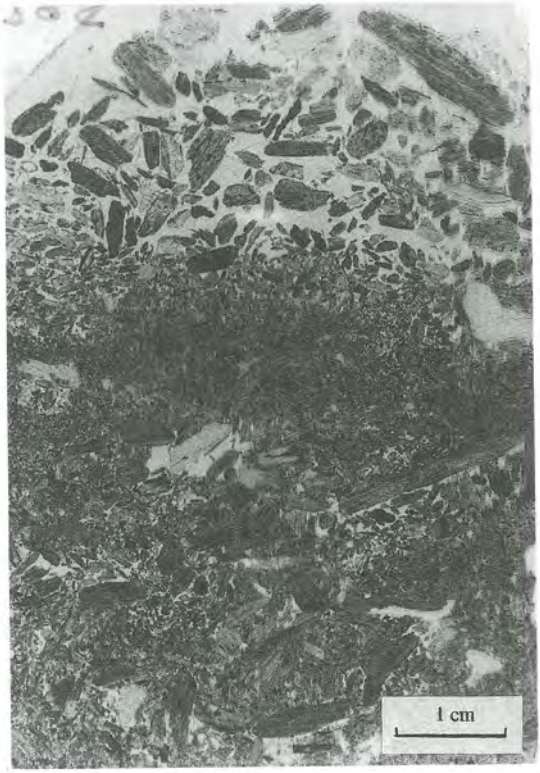


FIGURE 7.9 Thin section of the upper 7 cm of soil from MA 3, showing a washed fine gravel surface horizon overlying a loamy accumulation horizon

In general, in spite of sandiness, the water released from 0.01 to 1.53 MPa is relatively high, between 33 and 60%, of soil volume in surface horizons (Figure 7.10), as can be calculated from the moisture retention curves (Figure 7.11).

Infiltration, which was determined by simulating rainfall at 50 mm h^{-1} (Calvo et al., 1988), is high in the lower part of the alluvial fan, in *Retama* areas (24 to 41 mm h^{-1}), intermediate in the upper part of the alluvial fan, in *Anthyllis* areas (9 to 25 mm h^{-1}), and quite low in higher slopes, in *Stipa* areas (3.7 to 6.4 mm h^{-1}). Infiltration values under bushes are generally lower than under bare soil (Figure 7.12). These data are in agreement with the particular morphology of these soils.

There is a large variation in hydraulic conductivity (K), which is a consequence of local heterogeneity due to layering. The highest values appear in *Retama* soils, averaging from 1 to 2 m day^{-1}, and the lowest in the apex of the alluvial fan (MA 5), from less than 0.1 to 0.4 m day^{-1}. Under *Stipa* soils, K ranges from 0.3 to 1 m day^{-1}. In all cases, K is slightly higher in soils under or close to bushes than away from them. Figure 7.13 shows typical draw-down curves for the three main soils.

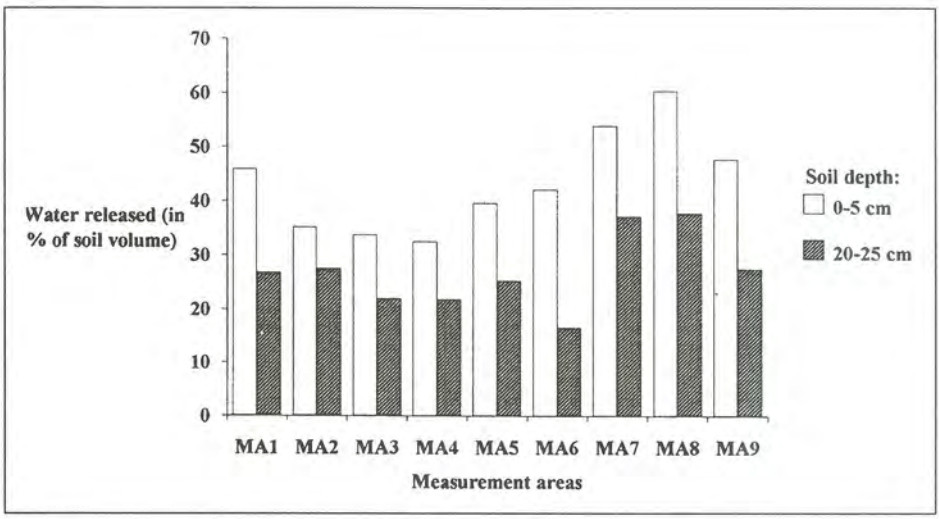


FIGURE 7.10 Water released between 0.01 and 1.5 MPa in soil profiles from the different MAs

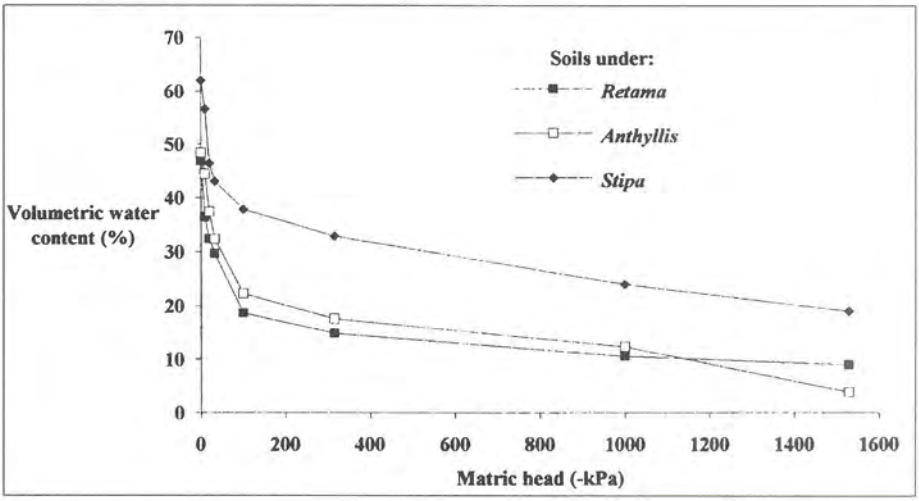


FIGURE 7.11 Water retention curves for the first mineral horizon (0–7 cm, excluding surface gravels) from representative soils in open areas with different vegetation types

7.2.5 Vegetation and land use

The natural vegetation includes bushes and thorny shrubs of the series *Rhamno lycioidi–Querceto cocciferae* sigmetum betic facies with *Ephedra fragilis* (Rivas-Martínez, 1987) but the remnants of this primeval matorral (*Rhamnus lycioides*, *Pistacia lentiscus*, etc.) are restricted to very small patches. A large part of the area is covered with alfa grass, *Stipa tenacissima*, with variable proportions of *Anthyllis cytisoides*.

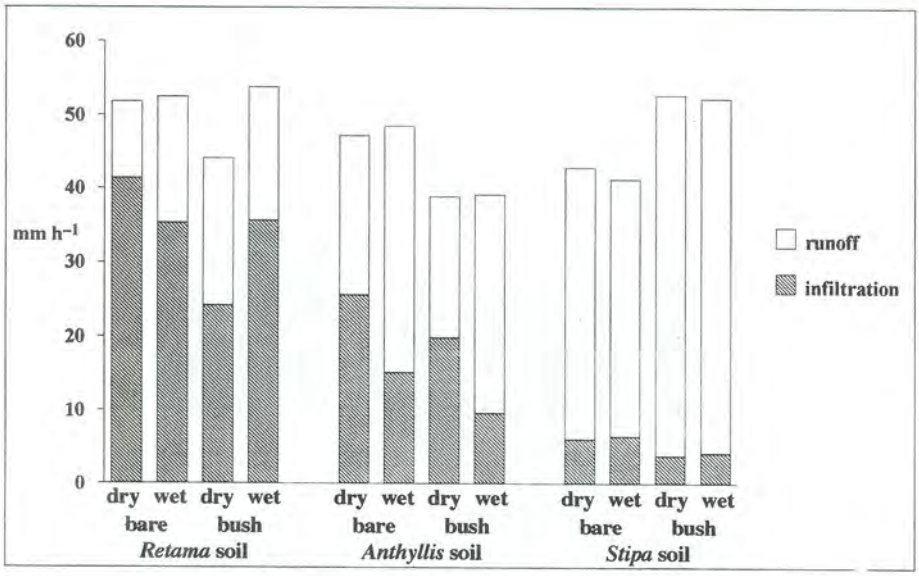


FIGURE 7.12 Runoff and infiltration rates after 30 minutes of rainfall simulation over circular plots on wet and dry soils both in open areas and above three vegetation types

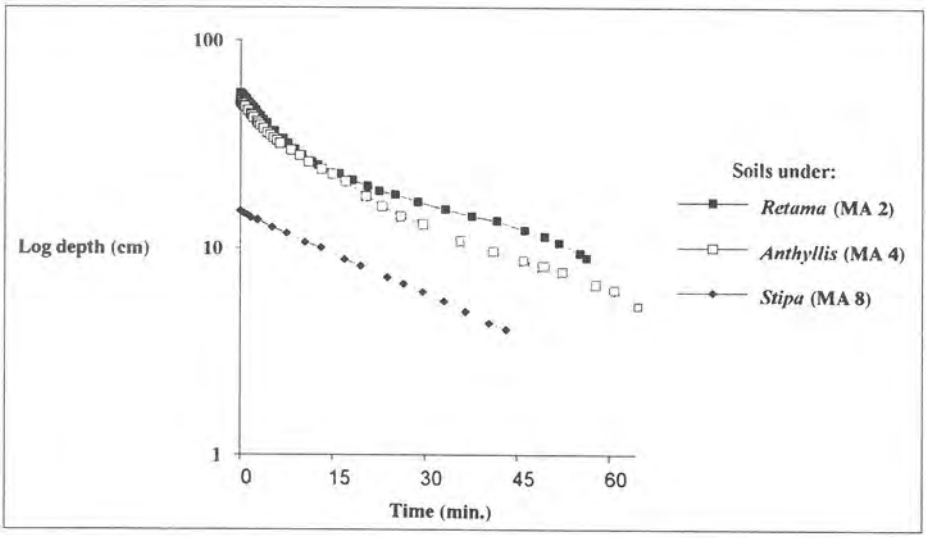


FIGURE 7.13 Draw-down curves for representative soils in open areas within the three vegetation types. These data were used to calculate saturated hydraulic conductivity

The lower sector of the catchment, where the field site is located, has an area of 5.28 km^2. Until the 1960s, three farms, with nine families, were exploiting the area. The total number of sheep and goats owned by the farmers was around 600. The mean grazing pressure may be estimated at around 1.13 sheep per ha. The alfa grass was harvested for

cellulose and the rest of the area was cultivated for grain. Alfa grass and livestock accounted for more than 90% of the cash income in the traditional economy. Three types of fields have been identified: terraced plots on the slopes; fields without specific structures on the alluvial fans and along the drainage ways; and fields enclosed with stone walls, which were irrigated by flooding. In the first two, the main crop was barley, and in the third type, wheat and maize were often grown. The uncultivated floor of the rambla was covered with bushes of *Retama sphaerocarpa* which were cut for fire wood.

This traditional agricultural system was abandoned some 30 years ago. The steppe of *Stipa tenacissima* is encroaching with its own unharvested litter. The terraces and upper sectors of alluvial fans are being invaded by dense populations of *Anthyllis cytisoides*. The lower sectors, still occasionally cultivated in rainy years, are covered with scattered populations of *Retama sphaerocarpa* which sprout from root systems that remain in the fields after ploughing.

7.3 EXPERIMENTAL LAYOUT

7.3.1 Data acquisition system

A new low-speed digital radio network (LAN) field facility has been developed for this project. It consists of several remote microprocessor stations (based on Motorola MC68HC05/11 microcomputer families) and a central unit connected to an IBM AT computer, which has real-time overall control, monitoring, housekeeping, calibration and logging functions. The radio frequency link is bi-directional (half duplex), operating in the upper part of the VHF band, with a modified X.25 protocol, at 7200 baud with PCM-NRZI-BPSK modulation format. Multiple access has been implemented with a CSMA/CD (Carrier Sense Multiple Access Collision Detect) algorithm. For long-distance links or to avoid areas of radio shadow, the remote stations can also be programmed as zone relay stations (digipeaters) which have their own associated address group.

Each station which has a unique address according with zone–subzone–function topology, is polled cyclically by the host computer, as requested by the software, e.g. the Rambla Honda weather station has a polling period of 20 seconds. The host averages and stores data on hard disk in ASCII format at 10-minute intervals (5 minute for rainfall data). The data file can be accessed by other computers connected to the EEZA ETHERNET LAN for DBASE/EXCEL transformations and streamer backup.

Each station has telemetry and telecontrol functions and can be controlled through the network or locally by an RS-232 interface, using similar dialogue language for both paths. The system is actually managing the meteorological sensors but it is easily expandable to manage further instruments.

7.3.2 Weather data

An automatic weather station was installed in the Rambla Honda, at 640 m altitude. It is integrated in the EEZA radio network data acquisition system and it is provided with the following sensors listed in Table 7.7. One of two rainfall intensity gauges is located at the base of the slope, within the weather station, and the other, near the divide, at 750 m altitude. In addition, each runoff plot has been provided with a rain gauge for measuring total precipitation per event.

TABLE 7.7 Sensors in automatic weather station

Variable	Sensor model	Range	Resolution
Temperature	National Semicond. LM35CZ	−20 to +80°C	8 bits
Relative humidity	EE Electronik HC500	0 to 100%	8 bits
Wind speed	Health	0 to 25.5 m s^{-1}	8 bits
Wind direction	Health	360°	4 bits
Solar radiation	Kipp & Zonen CM6B	0 to 1200 W m^{-2}	8 bits
Rainfall (2 units)	Health	—	0.23 mm

7.3.3 Water and sediment yield

Surface runoff and sediment yield are estimated on the closed runoff plots described in Section 7.2.1. Each plot is provided with two collector tanks of 200 litres. When the first overflows, it conveys to the second 1/10 of the flow through a slot divisor. Readings are made after each rain event and samples are taken for the determination of coarse sediment (>2 mm) and fine sediment (<2 mm) bulked with total solutes by drying.

7.3.4 Vegetation

In the core field programme, biomass, above ground net primary productivity (AGNPP), leaf area (LAI), cover and litterfall are measured throughout the year in the nine MAs in sampling site 2. Plant cover, by functional types, and plant height are measured in 180 permanent quadrats (50×50 cm); observations, which started in October 1991, are made at 3-monthly intervals. Surface litter was sampled in November 1991 from 165 quadrats (50×50 cm). Litterfall is collected at monthly intervals from 105 traps installed in November 1991. In *Anthyllis*, five funnel traps for individual plants were installed per each MA. The distribution of traps and quadrats is at random within the main plant cover types.

Biomass and GNPP of shrubs are estimated through allometric relations based on branch dimensions which were established by field sampling in each MA during the winter of 1991/92. Later periodic sampling of twigs with leaves through the year provides estimates of seasonal variations of leaf and twig dry weight, leaf area, flower, fruit and standing dead dry weight.

In the case of *Stipa tenacissima*, biomass was estimated by allometric methods using the tussock dimensions as predictors. Litterfall, leaf mortality and AGNPP are estimated by measuring leaf numbers and length in samples of previously marked tillers. This operation, which started in November 1991, involves a total of 195 marked tillers in tussocks of different size and vigour.

Coarse root biomass was estimated through allometric relations based on root diameter. Fine root biomass (diameter <5 mm) was estimated in cubes of soil (10 cm^3), taken at each 10 cm in two columns per MA from the soil surface to the basal rock or up to a depth of 100 cm. Samples were collected in August 1991 and processed by means of dispersing agents (hexametaphosphate), by floatation and decantation.

The cellulolytic activity in the soil was estimated by the cotton strip assay (Sagar, 1988) as an index for soil biological activity. Six situations have been considered: *Retama*, *Anthyllis* and *Stipa* vegetation types and in each of them, under the canopy and in open

areas. In each situation, five quadrats were installed and six cotton strips were exposed per quadrat, three in the ectoorganic horizon (soil surface in open areas) and three in the uppermost mineral horizon. The strips were exposed for 30 days and three runs have been completed: spring (17 March to 14 April 1992), summer (24 June to 22 July 1992), and autumn (21 October to 21 November 1992). After exposure, the strips are sent to the University of Bristol for the tensile strength determinations.

7.3.5 Plant ecophysiology

A total of five sets of measurements were completed and they were timed for the periods of minimum temperature (February 1992), maximum growth (May 1992), onset of drought (June 1992) and maximum drought (August and October 1992). From uniform stands of each of the three species characterizing the catena (*Retama sphaerocarpa*, *Anthyllis cytisoides*, *Stipa tenacissima*) eight randomly selected plants were chosen per species per set. One species was sampled per day, hence a set took 3 days. Measurements were carried out before dawn, a few minutes after sunrise, two hours after sunrise, at solar noon, midway between solar noon and sunset, and before dusk. For each measurement, a leaf, shoot or cladode was taken from each of the four cardinal positions on a plant. For relative water content (RWC), all leaves or cladodes per plant sampled at each time of the day were bulked. For water potential, the four leaves, cladodes or shoots per plant sampled at each time of the day were measured separately with a pressure chamber (Skye Instruments, UK). An infra-red gas analyser (LCA3, ADC, UK) in combination with a narrow leaf chamber (PCL-N, ADC, UK) measured stomatal conductance and net photosynthetic rate. Four leaves per shoot were measured simultaneously in the cuvette. The same sets of leaves were measured throughout the day. Leaf areas were measured from images obtained with a grey level scanner (Scanman, Logitek, USA). Fluorescence ratio rather than absolute fluorescence was measured with a fluorimeter (PEA, Hansatech, UK). Hourly meteorological data were obtained over the whole period from the weather station approximately 0.5 km from the sites of the *Retama* and *Stipa* stands. For sets two to four there was an on-site station recording 10-minute averages of micrometeorological variables.

7.4 HYDROLOGICAL RESPONSE TO RAINFALL EVENTS

7.4.1 Weather features in the period September 1991–August 1992

Total rainfall in the 1-year study period was 318 mm (Figure 7.4) and average temperature was 15.5°C. Both values are close to the average estimates in the area (see Section 7.2.2). Monthly maximum and minimum average temperatures range from 33°C in August to 3°C in January (Figure 7.14). Rainfall shows a large annual variability, both in its total amount and in its monthly distribution (Figure 7.4). Within the general trend of rainfall concentration in the cold season, the study period is characterized by a dry autumn, and a very dry spring, with only late and abnormal rains in June.

Average monthly values of vapour pressure deficit (VPD) are small, around 0.5 kPa, in winter, but in March they start to grow and, in August, they reach average values of 2.5 kPa and monthly averages of daily maxima of 5.5 kPa (Figure 7.15). This trend is only interrupted in the humid period which was recorded in June. The annual radiation curve (Figure 7.7) shows that during rainy periods (winter and June) there are both troughs and

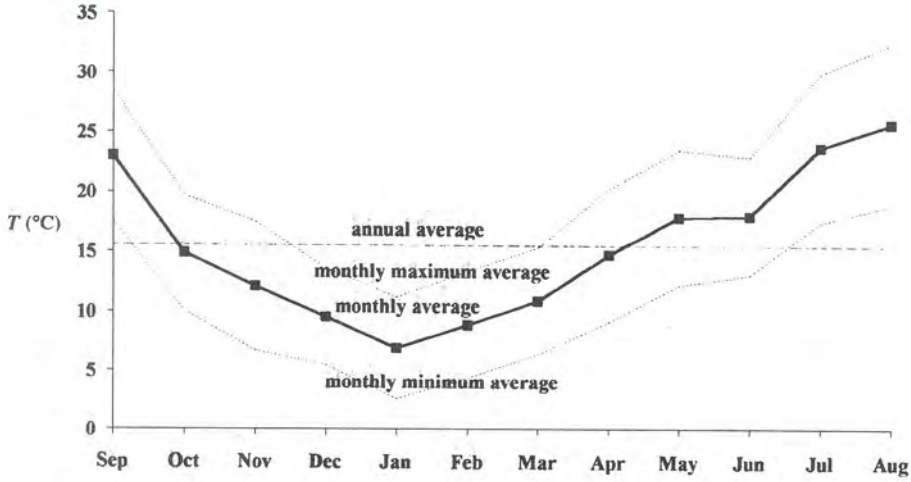


FIGURE 7.14 Distribution of monthly average temperatures (average, maxima and minima of daily values) at the Rambla Honda

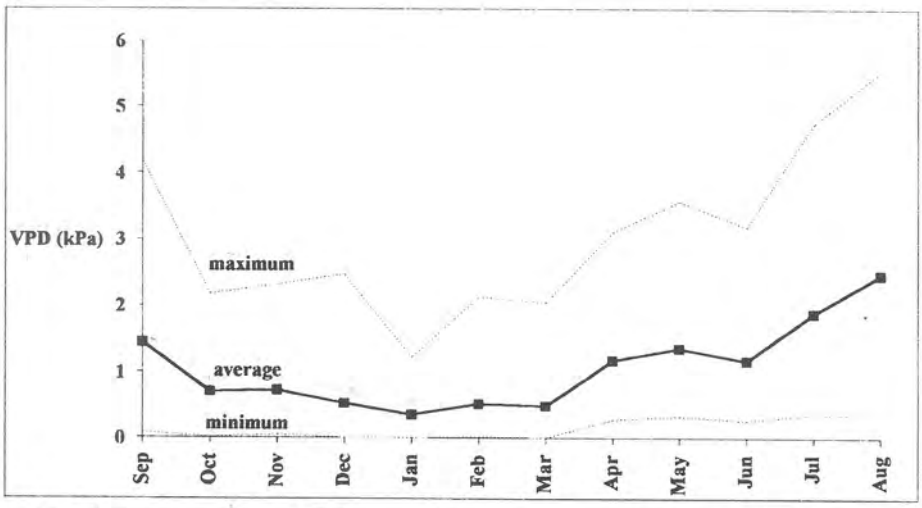


FIGURE 7.15 Distribution of monthly averages of vapour pressure deficits (VPD) (average, maxima and minima of daily values) at the Rambla Honda

peaks; the latter are probably due to cloud reflectance that may increase irradiance by up to 10% above the main cloudless trend.

7.4.2 Soil–water relationships

As a consequence of the origin of the parent material, layering as well as particle sorting across the slope are the main features in Rambla Honda soils that explain their morphological differences. When studied at a very detailed scale, they exhibit enough

variations to account for their different hydrological behaviour. These differences refer to their surface morphology as well as to their horizon layering. Stones on and within the surface are much larger in slope soils than in fan soils. As a consequence the surface roughness coefficient is much higher over slopes than over the fan surface (Table 7.4). Surface roughness may influence surface runoff and infiltration at the slope scale.

It is also noticeable that most rock fragments larger than 100 mm are embedded in the soil surface; smaller sizes are usually found on the surface, and very seldom are they embedded. As slope soils contain larger rock fragments which are mostly embedded, and fan soils contain smaller rock fragments just on the top of the surface, the findings of several authors (Abrahams and Parsons, 1991; Poesen and Ingelmo-Sánchez, 1992) suggest that higher infiltration in fans and higher runoff in slopes could be expected. Runoff and infiltration in Rambla Honda confirm these expectations.

The surface gravel layer which characterizes the lower part of the alluvial fan, has a total porosity of 40% (calculated from bulk density measurements), which can be completely assigned to macroporosity, enabling the soil to drain internally. The layers just below the gravels, however, have macroporosities always less than 40% and as low as 20%. This means that in some cases (when rainfall intensities exceed a given threshold), subsurface flow (on the top of this lower macroporous layer) may be important in these soils. In fact, runoff data from sampling site 2 (after 39 rain events) show a significant and positive correlation between runoff and the percentage of gravel at the surface (Puigdefábregas et al., 1992). The latter may be interpreted as an indicator of a layered structure of contrasting macroporosity.

As infiltration (measured from a simulated rainfall of 50 mm h^{-1}) and saturated hydraulic conductivity are lower under *Stipa* soils than under *Anthyllis* and *Retama* soils

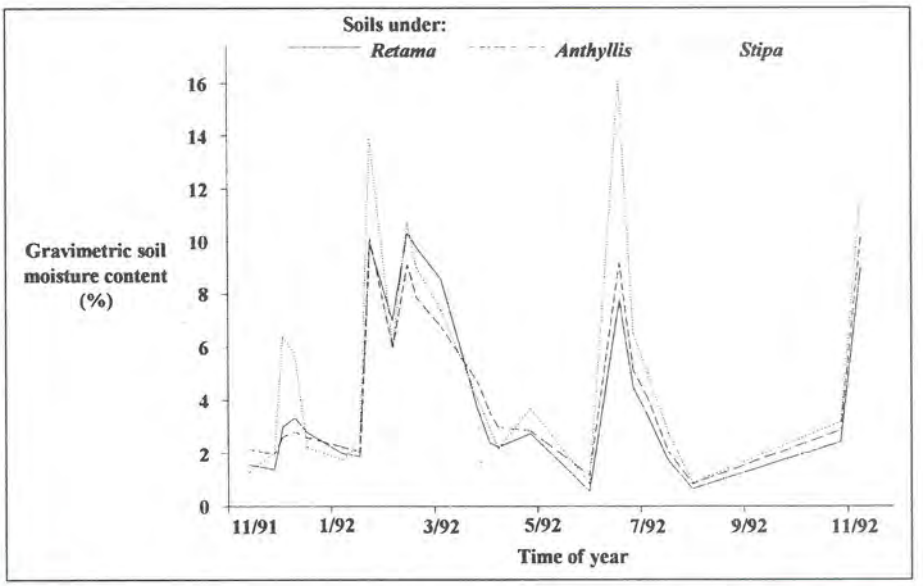


FIGURE 7.16 The average gravimetric soil moisture content at 15–20 cm depth in the Rambla Honda (mean values of the three MAs of each vegetation type in the catena) over a 12-month period

(Figure 7.13), it may be thought that the former soils get less water. This may be true, but in the first case, water is stored by the soil and, in the second, water is lost by internal drainage. The changes in soil moisture content during a 12-month period (Figure 7.16) confirm this.

A physical consequence of the observed dissimilarities in the different soils is that the water released between 0.01 and 1.53 MPa (Figure 7.10) in slope soils is higher than in fan soils (from 40% to 60% of the volume of the fine earth in slope soils; 33% to 40% in fan soils).

At soil water potentials of -1.5 MPa, the volumetric soil water content is still 0.1 LL^{-1} under *Retama* soils and 0.2 LL^{-1} under *Stipa* soils (Figure 7.11). But in desert ecosystems, water released between 0.01 and 1.5 MPa should not be considered as the only available water for plants. During the summer the soil water content is well below 0.07 LL^{-1} (1% gravimetric) (Figure 7.16), and measured leaf water potentials with psychrometric techniques during this season vary from -2 MPa in *Retama* to -5 MPa in *Stipa* (see 5.3.) (Pugnaire et al., 1996). This suggests that some water might still be available for plants at bulk soil water potentials lower than -1.5 MPa.

7.4.3 Water and sediment yield

The 10 runoff plots in sampling site 1 have provided data for runoff and sediment yield for a period of 2 years (1 December 1990 to 1 December 1992) in which 39 rainfall events took place. Results show a large variation between years (Table 7.8). Despite the fact that 1992 was drier than 1991, outputs in terms of runoff and sediment were two and three times higher respectively.

Significant runoff and sediment yield only occurs when total rainfall per event is larger than 20 mm (Figures 7.17 and 7.18). Beyond this threshold, the outputs are very variable because they are controlled both by the rainfall patterns and by the site characteristics, mainly the physical properties of the uppermost soil layer (Puigdefábregas et al., 1992).

The 18 runoff plots in sampling site 2, during the period 1 September 1991 to 1 December 1992, recorded 19 rainfall events but only four of them were significant in terms of runoff and sediment yield (>0.5 mm and $>0.5\ g\,m^{-2}$). Three events which occurred in the cold season (November to March) produced 90% of the total runoff and sediment output during the period.

No permanent groundwater flux has been found in the Rambla Honda bore holes. Ephemeral groundwater has been recorded only on two occasions, in spring and autumn 1992, both in bore hole 2, which is drilled in a channel that trenches the sediment fill and

TABLE 7.8 Average runoff and erosion from the 10 runoff plots in sampling site 1

	Rainfall (mm)		Runoff ($l\,m^{-2}$)		Runoff coeff. (%)		Erosion ($g\,m^{-2}$)	
	Annual total	SE	Annual total	SE	Annual total	SE	Annual total	SE
1991	265.43	1.26	14.02	1.59	5.27	0.59	15.77	3.55
1992	215.00	16.00	27.23	2.67	12.88	1.25	39.59	11.23

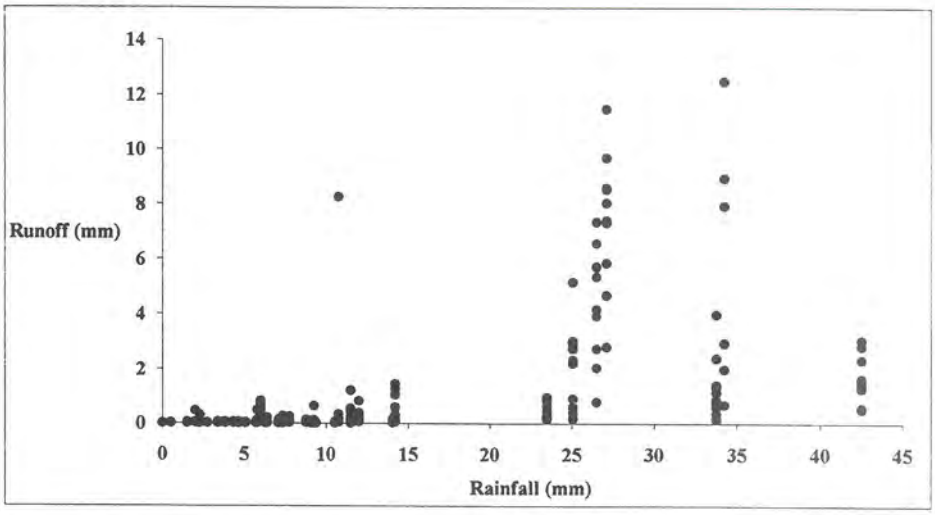


FIGURE 7.17 The relationship between runoff and total rainfall per event (1991/92) in the runoff plots of sampling site 1

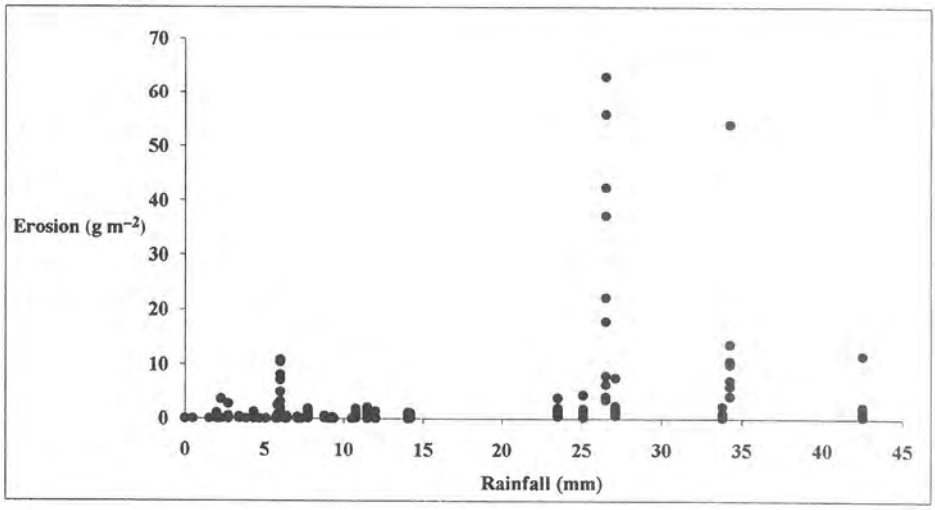


FIGURE 7.18 The relationship between erosion and total rainfall per event (1991/92) in the runoff plots of sampling site 1

drains a slope sector of about 0.06 ha. Both occasions were preceded by a succession of rain events, the time lag of the response was 1 to 4 days, and the maximum water level above the micaschist basal rock was between 40 and 70 cm. These facts suggest that water is provided by the top layers of the sedimentary body. These layers are more gravely and

may be connected in some way with the drainage net. The river channel (rambla) lacks a permanent saturated zone and the slope runoff produces only local and ephemeral perched water-tables at the outlets of gullies that become lost within the main sedimentary formation.

Available data are still too scarce to establish definitive comparisons between plots along the catena, because they do not allow the separation between effects of site and rainfall. Nevertheless, preliminary results (Table 7.9) show that in terms of runoff, the values from *Retama* plots (MA 1 to 3) are almost three times lower than those of *Anthyllis* (MA 4 to 6) and *Stipa* plots (MA 7 to 9). Densely vegetated plots tend to produce less runoff than the sparsely vegetated ones, particularly in *Retama* plots.

In terms of sediment yield, *Retama* plots produced four times less than those of *Anthyllis* and five times less than those of *Stipa*. The effect of plant cover density is conspicuous in the case of *Stipa*, where densely covered plots double the sediment yield of sparse ones. In the rest of vegetation types, the effect of plant cover is not apparent. On the whole, sediment yields (6–50 $g\,m^{-2}\,yr^{-1}$) are moderate in comparison with data from a similar climate (Romero Díaz et al., 1988).

Concerning the slope–fan relationships for sediment yield, the former (*Stipa* covered) have values two to five times greater than the latter (*Anthyllis* and *Retama* covered) (Table 7.9). This may be explained by a greater availability of fine sediment on the slopes, which is enhanced by higher weathering rates of the fresh micaschists compared to the more resistant residual gravels of the alluvial fans. In those rapidly weathering slopes, the tussocks of *Stipa tenacissima* are very effective in promoting spatial heterogeneity in the distribution of runoff which increases the storage of sediment, mainly of fine size classes. As this storage is related to the growth and decay patterns of the tussocks (Sánchez and Puigdefábregas, 1994), it is highly dynamic and, hence, the sediment yields remain high. Apart from the linear erosion by trenching of the alluvial fans, micaschist slopes show greater runoff, sediment yield and probably weathering rates, than the sedimentary bodies.

TABLE 7.9 Runoff and erosion in the three vegetation types of the Rambla Honda sampling site 2 in the study period (1 September 1991 to 31 August 1992)

	Runoff (mm)		Runoff coeff. (%)		Erosion ($g\,m^{-2}$)	
Vegetation type	Average	SE	Average	SE	Average	SE
Retama dense ($n=3$)	3.84	2.58	1.33	0.91	6.25	1.60
Retama sparse ($n=3$)	7.99	5.98	2.78	2.10	5.91	1.29
Retama average ($n=6$)	5.91	4.42	2.06	1.55	6.08	1.30
Anthyllis dense ($n=3$)	13.73	4.95	4.50	1.86	17.95	0.12
Anthyllis sparse ($n=3$)	18.02	4.68	5.30	1.58	19.62	17.39
Anthyllis average ($n=6$)	15.88	4.62	5.76	1.65	22.38	12.90
Stipa dense ($n=3$)	13.13	3.80	4.94	1.40	48.02	16.55
Stipa sparse ($n=3$)	16.99	4.61	6.34	1.56	20.80	0.91
Stipa average ($n=6$)	15.06	4.06	5.64	1.43	34.41	14.87

coeff. = coefficient; SE = standard error.
Dense/sparse values are averages of the three runoff plots per vegetation type.
Data for vegetation type are average values of six runoff plots.

It is notable that plots from sampling site 1 (8 m long) produced higher runoff and sediment yield than longer runoff plots from sampling site 2 (10 m long). This fact may be interpreted as a result of re-infiltration along the slope which reduces overland flow as the length of the plot increases.

7.5 VEGETATION STRUCTURE AND DYNAMICS

7.5.1 Biomass, productivity and litterfall

The summary of the available results pools the data from the three MAs of each vegetation type (Table 7.10). The above-ground living biomass (AGB) of the *Stipa* stands (356 g m^{-2}) is between two and three times greater than that of the shrub stands, and its standing dead biomass is also greatest and about six times its AGB. Below-ground biomass (BGB) is very large in *Retama* stands and is 23 times greater than the AGB, whereas this ratio varies between three and five in the other vegetation types.

TABLE 7.10 Biomass, net primary productivity, litterfall and leaf area in the three vegetation types of the Rambla Honda catena

Plant community attribute	Plant community attribute	*Retama* MA ($n=3$)		*Anthyllis* MA ($n=3$)		*Stipa* MA ($n=3$)	
		Average	SE	Average	SE	Average	SE
Canopy cover (%)	Perennial plants	14.03	3.29	28.89	2.00	34.91	2.33
AGB (g m^{-2})	Living	117.23	9.87	133.25	15.60	356.31	44.22
	Dead	44.42	1.42	119.28	29.08	2343.41	234.91
BGB (g m^{-2})	Stump	90.78	14.71	16.05	4.59		
	Coarse roots	2168.53	769.57	176.03	33.77		
	Fine roots	403.85	94.74	541.64	20.46	1143.62	40.12
	Total	2663.16	719.97	733.71	58.30	1143.62	40.12
LPOOL (g m^{-2} yr^{-1})		202.70	7.49	212.77	33.56	2343.11	234.91
AGNPP (g m^{-2} yr^{-1})	Wood/bark	33.41	4.10	16.32	3.32		
	Curr. twig & leaf	75.54	6.82	174.53	3.30	316.75	20.32
	Annual plants	79.33	7.96	47.89	4.05	9.54	2.23
	Total	188.28	14.47	238.74	9.36	326.29	18.12
LFALL (g m^{-2} yr^{-1})	Leaf (peren. + ann.)	134.76	9.46	107.31	2.26		
	Wood	5.88	1.10	1.23	0.12		
	Total	140.64	8.36	108.54	2.35	396.86	38.52
LAI MAX (m^2 m^{-2})	Perennials	0.16	0.01	0.44	0.01	0.98	0.08
LDW MAX (m^2 m^{-2})	Peren. + ann. plants	150.37	12.88	93.52	2.95	364.67	40.66

AGB = above-ground biomass in winter.
BGB = below-ground biomass.
LPOOL = litterpool on the soil surface.
AGNPP = above-ground net primary productivity.
LFALL = litterfall.
LAI MAX = maximum leaf area index in the growing period.
LDW MAX = maximum leaf dry weight in the growing period.
curr. = current year.
peren. = perennial.
ann. = annual.

Above-ground net primary productivity (AGNPP) is of the same order as AGB if annuals are included in the latter. Annual biomass increments (AGNPP–Litterfall) range from 131 $g\,m^{-2}$ for *Anthyllis* to $-70\,g\,m^{-2}$ for *Stipa*, although these figures should be considered with caution because of the short study period and the probable annual variability of the standing dead compartment.

The above-ground biomass distribution along the catena (Table 7.10) shows the contrast between the more stable *Stipa* community on the upper slope sector and the unstable formations of *Anthyllis* and *Retama* in the alluvial fan sector. The former seems to be near a steady state; it shows slightly negative biomass increments and large pools of dead debris. The *Anthyllis* and *Retama* communities are growing after the cessation of cropping; they show positive biomass increments, similar to those reported for other Mediterranean ecosystems (Specht, 1969; Schlesinger, 1980; Black, 1987). Biomass increments are particularly high in *Anthyllis*, probably due to the suppression of sheep grazing during the study period. Annual plants seem to suffer strong competition from perennials, since their biomass is inversely proportional to the cover of perennial plants (Table 7.10).

The two independent estimates of leaf dry weight (Table 7.10), the allometric one (LDW MAX) and the litterfall one (leaf LFALL), provide coherent figures, with differences that vary between 11 and 18%.

The huge below-ground biomass of *Retama* is explained by two facts: first, ploughing removed branches, but roots and root crowns able to sprout remained in the soil; second, the branches of *Retama* were cut for fire wood. Therefore, the root system of *Retama* is often much older than the aerial part. The higher fine-root biomass of the *Stipa* stands may be related to the finer textures of their soils, to their higher water-holding capacity and to the genetic adaptation of *Stipa* to use water from small rains at all times of the year.

Litter pool versus litterfall ratios (LPOOL/LFALL from Table 7.10) provide provisional figures of the litter turnover time: 1.44 years for *Retama*, 1.96 years for *Anthyllis* and 5.90 years for *Stipa* stands.

The longer turnover time of *Stipa* litter may be more related to the characteristics of its leaves, higher C/N ratios (Table 7.6) and richness in recalcitrant compounds, than to limiting soil moisture.

The cotton rotting rates (CRR) in Table 7.11, show that the largest differences among vegetation types occur in early summer, below canopies and in the mineral soil. These CRR rates seem to express well the decomposition rate of the litter, as they show a negative trend with LPOOL/LFALL ratios (Figure 7.19).

7.5.2 Phenology

The phenological stages through the year for the main species (Figure 7.20) show that vegetative growth is concentrated in autumn, winter and early spring, while in summer the reproductive stages and leaf fall prevail. The effects of the unusual rainfall recorded in June 1992 are shown by the rise of soil moisture content (Figure 7.16) and by the regrowth of the vegetation. This regrowth emphasizes the significance of the spring rains in this semi-arid environment. If they come early, they set up the soil moisture storage that has to support the larger part of the annual productivity. If they come too late, they produce short-lived extra growths that in general are useless to the plant.

TABLE 7.11 Cellulolytic activity of soils in the different vegetation types of the Rambla Honda catena. Values are expressed as cotton rotting rates (CRR per year)

			Time of year			
			18 Mar. to 15 Apr. 1992		22 Jan. to 24 Jan. 1992	
			Average $n=5$	SE	Average $n=5$	SE
Retama	Shade	Ectoorganic	6.496	1.792	8.052	1.354
		Mineral	18.454	1.137	31.41	4.405
	Open	Ectoorganic	6.855	0.624	6.006	0.635
		Mineral	12.94	2.075	15.91	2.084
Anthyllis	Shade	Ectoorganic	7.194	0.831	8.861	1.068
		Mineral	13.12	1.027	23.14	4.298
	Open	Ectoorganic	6.303	1.429	5.237	0.693
		Mineral	10.902	0.931	11.197	1.390
Stipa	Shade	Ectoorganic	8.54	1.802	7.778	0.411
		Mineral	14.09	2.545	15.85	3.600
	Open	Ectoorganic	8.873	1.206	6.064	0.647
		Mineral	8.886	2.384	8.697	1.132

Shade = below shrubs or tussocks.
Open = in open areas among shrubs.

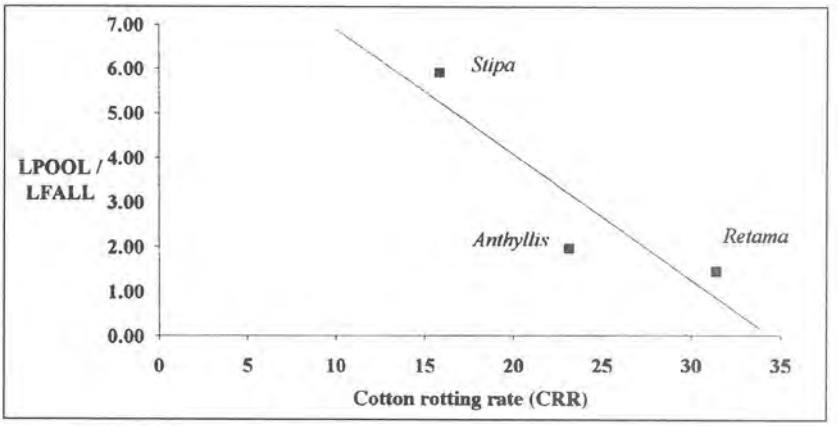


FIGURE 7.19 Cotton rotting rates (CRR) versus litter pool/litterfall ratio in the three vegetation types of the Rambla Honda catena

7.5.3 Ecophysiology

There were significant differences between species, times of the day and some plants in all sets for all attributes except orientation. In the case of total water potential of leaf or shoot (ψ_1), *Retama* had the highest (least negative) and *Stipa* the lowest values. These differences increased from February to September. There were no consistent trends between sets because of irregular weather conditions. For the relative water content (RWC) *Anthyllis*

always had the lowest values. Diurnal differences in each run were small. There were significant differences between runs for *Stipa* and *Anthyllis* and some consistent trends over all runs for each species. For example *Anthyllis* had values of 0.6 to 0.8, which are lower than those for *Stipa* and *Retama*, 0.7 to 0.95. The relationship between ψ_1 and RWC differed significantly between species (Figure 7.21a). Stomatal conductances (g_s) in *Stipa* were the most uniform during the day, with the lowest g_s, whereas *Anthyllis* and *Retama* had high g_s at the start of the day which decreased rapidly as the day progressed (Figure 7.21b). In the case of net photosynthetic rate (P_n), *Retama* had the highest rates under most conditions. *Stipa* and *Anthyllis* had approximately similar and low rates. Fluorescence (F_v/F_m) ratio showed some significant diurnal and seasonal differences between and within species, with *Retama* the most uniform (Figure 7.21c).

It may be pointed out that the absence of any significant difference between orientations in the canopy suggests that diurnal changing factors nullify their effect. The significant difference in water relations ψ_1 between some replicate plants suggests a genetic and/or a soil moisture heterogeneity at the scale of the plants' root systems. The significant diurnal changes in ψ_1 are to be expected in a semi-arid environment. In the driest conditions there were measurable changes in water status during the day, suggesting that any summer dormancy state was partial. The failure of any species to regain full turgor by dawn suggests high plant and/or soil resistance to water movement in the rooting zone. The significant diurnal differences between the species is probably partly due to differences in the soil moisture regimes experienced. However, ψ_1 changes in *Stipa* more rapidly under all conditions, indicating a genetic difference. There were some consistent differences between species, notably the low potential of *Stipa* compared with *Retama*, and the increase in this difference as the season progressed. This divergence was probably due first,

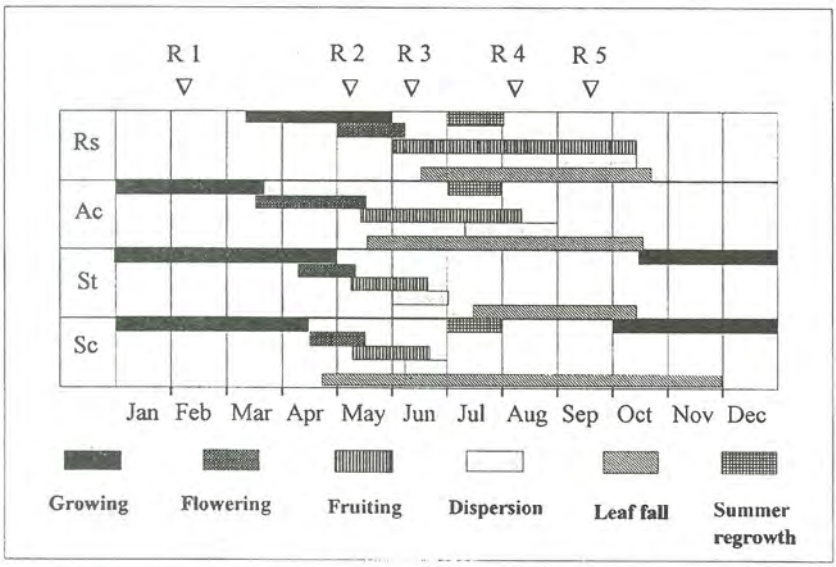


FIGURE 7.20 Plant phenology events in Rambla Honda during 1992. Rs = *Retama sphaerocarpa*, Ac = *Anthyllis cytisoides*, St = *Stipa tenacissima*, Sc = *Stipa capensis* (as a representative of winter annual plants). R1 to R5 show when ecophysiological measurements were carried out

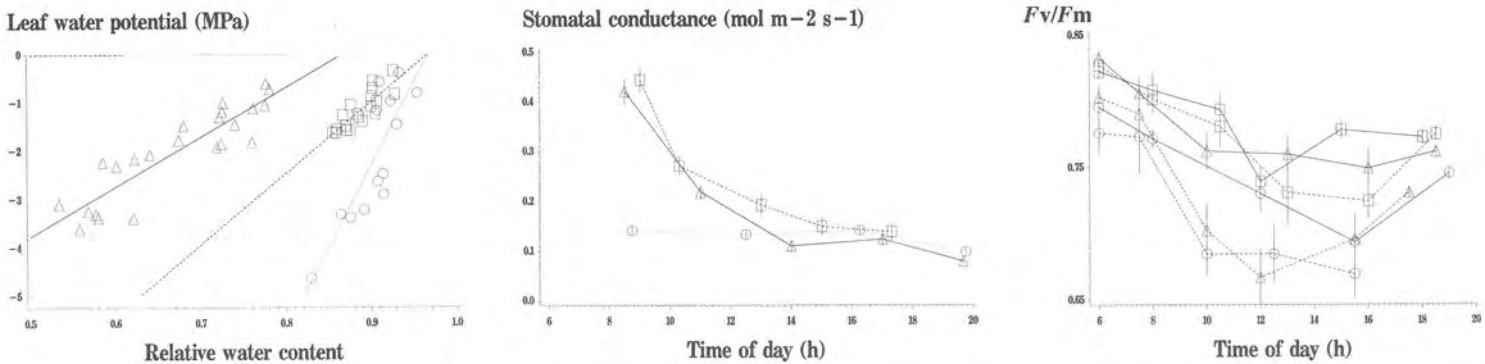


FIGURE 7.21 Some ecophysiological characteristics of the three species studied in Rambla Honda and their diurnal changes. (a) The relationship between leaf water potential and relative water content for *Retama* (□), *Anthyllis* (△) and *Stipa* (○) using data from sets 1 to 4. Lines show fitted linear regression lines. (b) Diurnal changes in stomatal conductances for *Retama* (□), *Anthyllis* (△) and *Stipa* (○) in June 1992; error bars represent SE. (c) Fluorescence ratio for *Retama* (□), *Anthyllis* (△) and *Stipa* (○) for set 3, well watered plants (- - - - -) and set

to the *Retama* community's higher and more constant soil moisture content and second, to *Stipa*'s more rapid and greater response to changes in soil moisture content.

Retama differed least seasonally in relative water content. It maintained the highest RWC because *Retama* has an extensive root system that can effectively exploit soil water. RWC for *Anthyllis* varied significantly between runs, reflecting perhaps greater dependence on current precipitation than on stored water, because of its smaller root system. *Stipa* maintained a high and constant RWC, not because of access to readily available water but because of its low transpiration rate. In species with a high dry matter content, changes in absolute and not relative water contents may be more important physiologically. Thus a small decrease in RWC and hence in water content from *Stipa*'s near-constant 0.8–0.9 RWC throughout the year, although unimportant in its effect on water relations, could reduce the number of viable cells present and adversely affect protein functioning.

The relationships between ψ_1 and RWC (Figure 7.21a) suggest that *Stipa*'s cells have a higher bulk modulus of elasticity than *Anthyllis*'s and *Retama*'s. This could explain the more rapid diurnal changes in ψ_1 and RWC in *Stipa*.

Maximum stomatal conductances for *Retama* and *Anthyllis* were high (0.5 mol m^{-2} s^{-1}), but for *Stipa* (0.1 mol m^{-2} s^{-1}) were typical for species from similar habitats elsewhere. Stomata of *Retama* and *Anthyllis* responded rapidly to diurnal increases in vapour pressure deficit (VPD) bringing their g_s down to values more usually expected for this environment. *Stipa*'s response to VPD was not noticeable perhaps because folding of its leaves gave a long pathway for water vapour from inside the leaf to the leaf surface.

Rates of carbon assimilation in *Retama* were similar to those of other C3 plants (11–25 mmol m^{-2} s^{-1}). Rates were lower, around 10 mmol m^{-2} s^{-1}, in *Stipa* and *Anthyllis*. The values for *Anthyllis* may be atypically low as they were obtained when ψ_1 was low and when some of the leaves may have been in the initial stages of senescence.

A preliminary interpretation indicates that fluorescence is correlated with diurnal and seasonal changes in the other attributes and that it reveals marked differences between species regarding departures from optimum conditions for photosynthesis.

7.6 CONCLUSIONS

1. The slope–fan system on micaschists in Rambla Honda shows two contrasting types of soils. Slope soils are richer in fines and organic matter and show a lower saturated hydraulic conductivity, but higher water-holding capacity and sediment availability. Therefore, they produce higher outputs of runoff and sediments. The fan soils offer better opportunities to deep-rooting plants, but their water-holding capacities are less. They show a surface layer of washed gravel upon a thin very fine sandy layer of much lower macroporosity. This structure enhances subsurface runoff with light rainfalls and overland flow in large events. In the fan system, the internal drainage is high and no permanent saturated layer has been found. The phreatic levels are local and ephemeral and probably connected with the upper sector of the sedimentary body which shows a higher permeability.
2. The *Stipa* stands on the slopes are near a steady state in terms of biomass accumulation (300–400 g m^2) and LAI (0.9–1.0), but the storage in standing dead biomass is six times living biomass because of the cessation of harvesting 25 years ago.

The *Anthyllis* and *Retama* stands are unstable. They are growing and occupying the area after cessation of cropping. The turnover time of their litter is three to four times lower than for *Stipa*. *Anthyllis* and *Retama* stands show very high root/shoot ratios, especially *Retama* (20–25) in which the root system is much older than the shoots due to the traditional management.

3. *Retama* is least affected adversely by high temperatures and high VPDs. It closes its stomata rapidly in response to VPD and its narrow-diameter cladodes and open canopy facilitate loss of heat. Due to the large volume of soil exploited (the main roots can extend >15 m), high root/shoot ratios ($<16:1$), and the presence of relatively moist bands of soil in the rooting zone, water stress is least severe in *Retama* and its water relations are not closely related to current rainfall events. *Retama* is a drought avoider by habitat and a high-temperature avoider by morphology. *Anthyllis* is sensitive to VPD, resulting in high early morning photosynthetic rates but a short assimilating period over the day. Its summer deciduousness confers drought and heat avoidance. *Stipa* is a drought and high-temperature endurer, having low rates of photosynthesis and water loss due to low gas conductance. It can lower its leaf water potential substantially without appreciable loss of water and it keeps a high biomass of fine roots in the upper soil horizons. In all three species, root growth and arrangement are related opportunistically to the temporal and spatial distribution of soil water. Each species has a different adaptive syndrome for the same climate but a similar strategy for the different soil water regimes.
4. The variability of rainfall in terms of events, seasons and years has a strong hydrological and ecological significance. One or two events may account for 80–90% of the total annual runoff and sediment yields. Two years with similar total rainfall but different time distribution, may show very different amounts of runoff. The timing and amount of the spring rainfall set up the water storage for sustaining the largest part of the annual plant growth.

7.7 ACKNOWLEDGEMENTS

Miguel Angel Domene, Domingo Fernández, Juan Paris and Montse Guerrero are thanked for analysing soils, water and plants; Alfredo Durán, for indispensable technical assistance in field instrumentation; and the owners of field sites, J.J. Sánchez and R. Coca, for permission to carry out research and to exclude animals.

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MEDITERRANEAN DESERTIFICATION AND LAND USE

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ESTACION EXPERIMENTAL DE ZONAS ARIDAS
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Library of Congress Cataloging in Publication Data

Mediterranean desertification and land use / [edited by] C. Jane Brandt
and John B. Thornes.
p. cm.
Includes bibliographical references and index.
ISBN 0-471-94250-2
1. Desertification—Mediterranean Region. I. Brandt, C. Jane.
II. Thornes, John B.
GB618.68.M43M43 1996
333.73'6'091822—dc20 95-26001
CIP

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0-471-94250-2

Typeset in 10/12pt Times by Dobbie Typesetting Limited, Tavistock, Devon
Printed and bound in Great Britain by Bookcraft (Bath) Ltd
This book is printed on acid-free paper responsibly manufactured from sustainable forestation, for which at least two trees are planted for each one used for paper production.