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Cerdà, A.

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Seasonal variability of infiltration rates under contrasting slope conditions in southeast Spain

A. Cerdà¹

Fysisch Geografisch Bodemkundig Laboratorium, Faculteit der Ruimtelijke Wetenschappen, Universiteit van Amsterdam, Nieuwe Prinsengracht, 130, 1018 VZ Amsterdam, The Netherlands

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Abstract

Infiltration is the key process in the rainfall–runoff relationship. Little is known, however, about the seasonal and spatial variability, which is important for the behaviour of the slope surface geomorphological processes.

The infiltration rates for contrasting slopes in southeast Spain have been measured by means of simulated rainfall and ponding. A north- and a south-facing slope were selected to analyze effects of aspect. The results show that aspect as well as slope position and vegetation cover determine the steady state infiltration rates.

Moreover, seasonal changes play an important role in the soil hydrology. During summer the infiltration rates are high, no runoff is observed on vegetation covered soils. On the bare surfaces, runoff was only 10% of the rainfall. During the wet season, especially in autumn, the infiltration rates are lower, and runoff coefficients equal to 0.3. For the vegetated surfaces, runoff is negligible.

Infiltration measurements by means of ponding and simulated rainfall are both suitable to study the infiltration process. In the present study, the infiltration rates measured by cylinder infiltrometer were 8 times greater than by rainfall simulation at 55 mm h⁻¹.

1. Introduction

Infiltration is the process of water entry into the soil through the soil surface. The maximum rate at which water soaks into or is absorbed by the soil is termed infiltration capacity (Ward and Robinson, 1990). This process is one of the most important in the hydrological cycle as it controls the partitioning of the runoff upon a catchment area (Dunne and Leopold, 1978). The relationship between rainfall intensity and duration with the infiltration capacity determines the amount of surface runoff, subsurface runoff, ground-water recharge and soil moisture (Gregory and Walling, 1973).

¹ Present address: Departament de Geografia, Universitat de Valencia, Ap. 22060, 46080 Valencia, Spain.

The first studies related to the infiltration capacity of soil were done by Horton (1933). Since these were performed in semi-arid areas, the rainfall intensity was often greater than the infiltration rate, which results in severe ponding and overland flow. Nevertheless, this model proved not to be useful for temperate climates, where overland flow is uncommon (Hewlett, 1961; Betson, 1964; Dunne, 1978). Although, recent works have proved that Hortonian overland flow exists at patch scale in semi-arid environments, at slope and basin scale other models must be used to explain the runoff discharge (Yair and Lavee, 1985; Cerdà, 1995). To understand the rainfall–runoff relationship, measurements of the spatial distribution and temporal changes of the infiltration rates measurements are necessary.

The infiltration rate decreases rapidly over time as a result of pore saturation by water or clogging by sediments, crust formation, and swelling of the clays (Römken et al., 1990). Within the wide range of factors that control infiltration, the most important are located at soil surface such as vegetation (Dunne et al., 1991), crust (Bradford et al., 1987), and stone cover (Poesen and Ingelmo-Sánchez, 1992), although the soil profile characteristics also affect the process (Blackburn, 1975). Under saturated conditions, the soil can reach steady-state infiltration rate, which is related to the soil texture and structure, and is equivalent to the saturated hydraulic conductivity (Dunin, 1976). Most of the improvements in the knowledge of the infiltration process came from soil physics researchers (Green and Ampt, 1911; Philip, 1957, 1991; Fok, 1988; Van der Berg and Ullersma, 1995).

In climates with contrasting seasons the infiltration rate will vary in time due to the influence of the antecedent soil moisture on infiltration, although there is still little knowledge about this topic (Thornes, 1994). The Mediterranean environments are subject to seasonal climatic fluctuations, which modify the soil conditions and as a consequence hydrological processes, such as runoff volume, runoff sources and water redistribution within a year.

Knowledge of the spatial and seasonal variability of infiltration, which is the objective of this paper, will supply information about all the above mentioned topics, and will improve knowledge on soil, slope, and basin hydrology.

2. Material and methods

2.1. Location

In Mediterranean latitudes, the basins located on soft material present different landscapes due to the influence of aspect, topography and/or land-use. To investigate the seasonal changes of infiltration rates on north- and south-facing slopes, a small E–W oriented watershed (7500 m²) was selected in the Province of Valencia, southeast Spain (Figs. 1 and 2). The climate is Mediterranean, characterized by a dry-hot summer and wet-warm spring, autumn, and winter. The annual average precipitation is 577 mm, which falls mainly in October–November and in spring, although winter is also wet. The medium monthly temperature is 23.9°C for the hottest month (August) and 7.5°C for the coldest month (February). Frost events are unusual.

Depending on aspect, large differences exist between the north- and the south-facing slopes, for vegetation as well as for slope morphology. On the medium and foot slopes of

Fig. 1. Location map.

Fig. 2. View of the study area in autumn 1990. At the beginning of the 1970s the upper slope parts was afforested with *Pinus halepensis*.

the north-facing slope, the density of vegetation cover is high (70–75%), while on the south-facing slope, it is only 15%. The dominant vegetation species are *Thymus longiflorus*, *Brachypodium retusum*, *Sedum sediforme* and *Anthyllis cystisoides*. The upper part of both slopes was afforested 20 years before the first set of experiments and the vegetation is (90%) dominated by trees (*Pinus halepensis*).

The main stream shows an important incision due to the uplift of the area (IGME, 1980, 1981), which is the typical situation of the Keuper clay sediments in the Iberian mountainous system. The slope morphology is determined by the incision of the thalweg, and the erosion of the footslopes resulting in convex–straight–convex slope profile (Cerdà, 1993a).

2.2. Methods

The infiltration rates were measured by means of rainfall simulation (Meyer, 1988) and ponding (cylinder infiltrometer) (Hills, 1970) experiments. The sites for rainfall simulation

Fig. 3. Rainfall simulator. (a) View of the apparatus and the pumps; (b) view of the apparatus with the wind protector; and (c) detail of the nozzle and nozzle connexions.

experiments and sampling were selected at lower, middle, and upper slope positions. The surface and soil characteristics were taken into account by selecting representative surfaces of each slope position.

For the rainfall simulation experiments, a sprinkling rainfall simulator described by Cerdà (1995) was used (Fig. 3). The rain was produced at an intensity of 55 mm h^{-1} over a 1 m^2 area. Runoff was measured from a 0.25 m^2 plot within the target area. The duration of the experiments was at least one hour in order to achieve the steady-state infiltration rate (Cerdà, 1993a, b). Distilled water was used in order to avoid differences between seasons and because semi-arid soils are influenced by the chemical composition of the rain as other authors demonstrate (Imeson and Verstraten, 1988; Shainberg et al., 1981; Agassi et al., 1994). Runoff was measured every minute.

Several authors have studied the frequency and duration of natural rainfall events in southeast Spain and they have demonstrated that storms similar to the one simulated (one

Fig. 4. Cross-section of the slope. Morphology and location of the plots. Plots 1 and 7 are located on an area affected by afforestation at the beginning of the 1960s (*Pinus halepensis* with cover of herbs, *Brachypodium retusum*, are the main features). Plots 5 and 6 are located on the north-facing slope on a vegetated environment (*Thymus longiflorus*, *Brachypodium retusum*, *Anthyllis cystisoides*, etc). And plots 2, 3 and 4 are located on the south-facing slopes where badland surfaces are the dominant features.

hour with 55 mm h^{-1}) has a return period of 4–5 years (García Bartual, 1986). The 10 year return period rainfall event with one hour duration in the North of Betic Mountains, southeast Spain, ranges between 80 and 110 mm (Elías and Ruiz, 1977).

Seven experimental plots were selected (Fig. 4) for the simulated rainfall experiments. All of them were set up in the field, and measurements were done every season (4 seasons $\times$ 7 plots = 28 experiments).

South slope:

AN1: Upper slope position. Afforested with *Pinus halepensis*.

AN2: Medium slope position. Contact surface between the afforested area and the badland surface.

AN3: Medium slope position. Badland surface. Gypsum thick crust formation

AN4: Down slope position. Badland surface. Thin crust formation

North slope:

AN5: Down slope position. Shrub cover, *Thymus longiflorus*

AN6: Medium slope position. Herb cover, *Brachypodium retusum*

AN7: Upper slope position. Afforested with *Pinus halepensis*

For the rainfall simulated experiment results, the infiltration curve was drawn by subtracting the runoff rate from the rainfall intensity. Real infiltration values were fitted to the Horton infiltration equation (Horton, 1940), as for the cylinder infiltrometer as for the simulated rainfall data (Cerdà, 1993a, b, 1995):

$$f = fc + (f_0 - fc) e^{-\alpha t}$$

$$F = fct - (f_0 - fc) / \alpha (e^{-\alpha t} - 1)$$

where f is the instantaneous infiltration rate, F is the cumulative infiltration rate, fc is the steady state infiltration rate, f_0 is the initial infiltration rate ($t=0$), and α is an empirical constant (infiltration curve form).

At the same surface types where rainfall simulation experiments were done, measurements of infiltration rates were carried out the same day by means of cylinder infiltrometer ponding (4 season $\times$ 7 plots = 28 measurements). The apparatus is a 15 cm high cylinder

with a diameter of 7 cm. Measurements of the infiltrated water were done at time steps of 1, 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 minutes. Steady-state infiltration rates were always reached.

Cylinder infiltrometer and rainfall simulation measurements were done for each of the seven surface types. Every season a new site was chosen to install the cylinder, but the rainfall simulation plots were permanent.

Soil samples to determine the moisture content were taken before the experiments at the surface (0–2 cm) and at 4–6 cm depth. The soil water content was measured gravimetrically. The organic matter content (Walkley–Black method), particle-size distribution (USDA classification), and calcium carbonate content (Bernard calcimetry) for all plots were measured during the summer of 1990. A representative sample was taken at each plot. Only surface samples (0–6 cm) were taken because under semi-arid conditions the first soil layer determines the infiltration process (Berndtsson et al., 1985; Römkens et al., 1990; Dunne et al., 1991; Cerdà, 1995). Profile and surface descriptions were done during four years (1989–1993) in order to know the seasonal changes of the cracks, crusts, litter, plants, etc. (Cerdà, 1993a).

3. Results

3.1. Soil characteristics

The soil surfaces have different characteristics depending on aspect and slope position (Tables 1 and 2). On the upper slopes (plots AN1 and AN2), the soils are covered by pine needles, grass (*Brachypodium retusum*), and litter. The rock fragment cover is small and soil depth is greater than at other slope positions. On the medium and bottom of the north-facing slope, vegetation cover is high (plots AN5 and AN6). On the medium and lower parts of the south-facing slope (plots AN2, AN3 and AN4), the soils are eroded by surface wash. Rock fragment cover and crust development are greater than in other locations.

Table 1
Soil surface characteristics

Plot	As (deg)	Sl (deg)	Li (%)	Mo (%)	Pl (%)	Tv (%)	Vh (cm)	Lc (%)	Sd (cm)	Rf (%)
<i>South-facing slope</i>										
AN1	164	7	0	0	35	35	10	100	15	5
AN2	185	20	0	0	15	15	5	30	9	15
AN3	180	30	0	0	10	10	3	0	6	20
AN4	178	24	0	0	7	7	1	0	2	8
<i>North-facing slope</i>										
AN5	350	22	0	90	75	165	15	5	15	0
AN6	340	20	0	10	100	110	19	10	25	10
AN7	320	25	0	0	80	80	15	100	23	0

As: aspect, Sl: plot angle slope, Li: lichens, Mo: mosses, Pl: plant cover, Tv: total vegetation cover, Vh: vegetation height, Lc: litter cover, Sd: soil depth, and Rf: rock fragment cover.

Table 2

Organic matter (OM), particle size distribution (sand, silt and clay), calcium carbonate and Bulk density (Bd) at surface (0–2 cm) and below the surface (4–6 cm)

Plot	OM (%)	Sand (%)	Silt (%)	Clay (%)	CaCO ₃ (%)	Bd (g cm ⁻³)
<i>Depth (0–2 cm)</i>						
AN1	2.3	10.1	36.6	53.4	9.0	0.99
AN2	0.6	7.7	28.5	63.7	7.5	1.11
AN3	0.6	6.9	40.4	52.7	3.2	1.15
AN4	0.3	8.4	32.2	58.2	3.3	1.18
AN5	3.2	9.5	30.3	59.3	3.3	0.99
AN6	4.3	20.9	28.5	50.7	9.8	0.90
AN7	3.7	16.0	31.2	50.9	5.6	0.97
<i>Depth (4–6 cm)</i>						
AN1	2.0	20.3	37.1	42.6	9.7	0.97
AN2	0.2	14.2	23.7	62.6	7.9	1.05
AN3	0.5	4.7	36.9	38.4	5.9	1.11
AN4	0.1	14.7	23.0	62.3	1.8	1.13
AN5	1.9	15.4	16.9	67.7	41.6	1.00
AN6	2.1	5.1	30.3	61.6	2.6	0.94
AN7	1.4	16.4	29.2	56.4	2.1	0.99

Vegetation and litter cover are low, and the shallow and short plants on a cracked crust surface are dominant features.

Other soil characteristics dominated by the physiographic location are organic matter and bulk density. Organic matter in the first two centimetres of the soil profile has the highest values in the north-facing slope (3.2–4.3%), intermediate values on the upper part of the south-facing slope (2.3%), and the lowest values in the medium and lower parts of the south-facing slope (0.6–0.3%). At the 4–6 cm depth, organic matter also shows differences between plots, but the values are lower than at the surface (see Table 2).

Directly related to the organic matter, the bulk density shows similar trends. On the north-facing and on the upper part of the south-facing slope, the bulk density is $< 1 \text{ g cm}^{-3}$. On the south-facing slope, at the surface as well as at 4–6 cm depth, values of bulk density are $> 1 \text{ g cm}^{-3}$, and even $> 1.1 \text{ g cm}^{-3}$.

At the medium and lower parts of the south slope, bulk density at the surface (0–2 cm) is greater than at 4–6 cm depth, which reflects the crust development as a consequence of the direct drop impact. In contrast, the north-facing slope and the upper part of both slopes, the soil density increases with depth, showing positive effects of vegetation in the reduction of bulk density.

The calcium carbonate content is always below 10%, and the spatial distribution appears random, which probably depend on the genesis of the clays. Also the soil texture does not show any clear difference between slope locations or vegetation content.

The soils have been classified as Regosols (FAO-UNESCO, 1988), but the variability at the slope and basin scale is very large. On the south slope it is possible to distinguish between different levels of regolith development. The soil profiles are different at each slope location (Fig. 5).

Fig. 5. Soil profiles. (Left) Medium and lower part of the south-facing slope, with low vegetation and litter cover and with surficial crust and cracks. (Middle) Upper parts of both slopes, vegetated by *Pinus halepensis* and *Brachypodium retusum*, with a high cover of pine needles. (Right) Medium and lower north-facing slope (vegetated mainly by herbs, *Brachypodium retusum*, and shrubs, *Thymus longiflorus*).

The seasonal profile and surface description shows that large seasonal variability exists in bare areas on the cracks formation. On the one hand, the surface cracks are shallow (2–4 cm) and wide (4–5 mm) in summer, on the other hand, cracks are smaller and shallower, and the polygon network is less developed in the wet periods. On the upper part of both slopes and the lower and medium part of the north-facing slope, cracks appear only in summer, being deeper (20 cm) and wider (1–2 cm) than in the bare soils. During the wet periods of winter, spring and autumn the soil moisture was constant, and no cracks were observed.

3.2. Soil moisture seasonal changes

Fig. 6 shows the soil moisture contents at each soil plot and on average depending on season at 0–6 cm depth. Soil moisture content is low in summer and high in other seasons, especially in autumn. Only on the south-facing slope gravimetric soil moisture content was low during the wet season, especially at plot AN3, where the hard crust produces less clear seasonal changes. For average values, the soil surface moisture content is 25% of the summer season of that of the wet periods. For the 4–6 cm layer soil moisture is slightly more than twice for the wet periods.

Fig. 6. Gravimetric soil moisture content at 0–6 cm depth. On average and for each plot.

Table 3

Steady-state infiltration rates measured by means of cylinder infiltrometer at different season for the seven plots studied and in average

Plot	Winter mm h ⁻¹	Spring mm h ⁻¹	Summer mm h ⁻¹	Autumn mm h ⁻¹
<i>South-facing slope</i>				
AN1	488	494	371	150
AN2	187	73	65	155
AN3	385	50	123	155
AN4	429	219	188	274
<i>North-facing slope</i>				
AN5	634	515	617	155
AN6	571	638	749	770
AN7	583	303	406	135
Average	468	328	360	256

In the vegetated soils, water content is high during all the seasons, except for the summer. In the bare soils the drying process is very fast after rain due to the direct radiation. At the surface (0–2 cm), soil moisture contents below 5% are common, even in the wet season.

Among the seasons, autumn is the wettest. This is related to important thunderstorms in October, the wettest month at the study area. The greater amount of water is specially important below the surface (4–6 cm layer) where in the north-facing slope reach the maximum values (30%).

3.3. Direct measurements of the infiltration rates by ponding

Infiltration measured by ponding give us information about the soil maximum or potential infiltration rate. Values of steady-state infiltration rate are very high on average: 353 mm h⁻¹. Nevertheless, the values range from 50 mm h⁻¹ in a bare surface to 770 mm h⁻¹ in a vegetated surface (Table 3). The distribution of the infiltration rates show a clear pattern along both slopes. The north-facing slope displays high infiltration rates (581 mm h⁻¹ in average), while the south-facing slope has low infiltration rates in average: 172 mm h⁻¹. The afforested upper slope parts show quite high values, 365 mm h⁻¹. Although, the seasonal changes and the intrinsic spatial distribution at each slope also favour a large variability, a clear spatial distribution in the slopes can be observed (Fig. 7).

The temporal changes of the infiltration rates show a large variability. No significant trends can be observed (Fig. 8). A slight decrease from winter to autumn 1990, however, can be noted. The steady-state infiltration rate in summer is 360 mm h⁻¹, compared to the annual average rate of 353 mm h⁻¹. This difference is smaller than the differences between winter (468 mm h⁻¹) and autumn (256 mm h⁻¹). In fact, the small differences between seasons are not significant. The reduced surface measured with the cylinder infiltrometer results in high spatial variability which is as important as the seasonal fluctuations (Table 3, Fig. 8).

Fig. 7. Spatial distribution of the steady state infiltration rate (mm h^{-1}) measured by ponding (*ifc*) during different seasons at each plot (see Fig. 5). South-facing slope (plots 2, 3 and 4) have the lower *ifc* values. The vegetated soil located at the north-facing slope (plots 5 and 6) have the highest values, and the upper slope parts affected by afforestation (plots 1 and 7) the intermediate ones.

Fig. 8. Seasonal changes of the steady state infiltration rates (mm h^{-1}) on average and for each plot. Measurements performed by means of simulated rainfall (*fc*).

3.4. Seasonal changes of the infiltration rates under simulated rainfall

Higher infiltration rates were found in summer, while in winter, spring, and especially in autumn the infiltration rates were lower (Fig. 9). Average values of infiltration rates were high. No or negligible runoff was observed on the vegetated soils. The bare soils produced medium runoff rates (30 mm h^{-1}).

The seasonal variability of infiltration is small within the vegetated plots, where 90–100% of the simulated rainfall infiltrated. On the contrary, the bare soils of the south-facing slope had runoff coefficients ranging from 0.45 to 0.85 and always generated surface runoff.

The slope position influences the vegetation cover and erosion processes and as a consequence the infiltration process. On the bare south-facing slope infiltration rates are $15\text{--}20 \text{ mm h}^{-1}$ smaller than in the forested upper slope parts and in the north-facing slope, where the soil infiltration capacity is very large. The seasonal trend for vegetated soils is characterized by an increase in infiltration rate from 46 mm h^{-1} in autumn to 55 mm h^{-1} in summer. In spring (55 mm h^{-1}) and in winter (52 mm h^{-1}) the infiltration rates are also

Fig. 9. Seasonal changes of the steady-state infiltration rates (mm h^{-1}) measured by means of simulated rainfall (f_c) for the three soil types: vegetated in the north-facing slope, badland in the south-facing slope and afforested in the upper part of both slopes, and on average.

very high. A similar seasonal trend and magnitudes have been found in the upper part of both slopes, where afforestation took place 20 years prior to the experiments.

On the south-facing slope, where badland surfaces have been developed, the infiltration is small than on the north-facing slope, but the seasonal trend is similar: lower infiltration rates in winter, spring, and especially autumn (33 , 32 , and 28 mm h^{-1} , respectively) and higher infiltration rates in summer (41 mm h^{-1}).

The relationship between measured steady-state infiltration rate in summer and in other seasons are positive (Fig. 10), which explains the large spatial dependence of the seasonal changes. The winter and spring values show a similar trend, but autumn has lower infiltration rates, which is related to higher soil moisture content.

Fig. 10. Relationship between the steady-state infiltration rate (mm h^{-1}) in summer and the wet season (winter, spring and autumn). Measurements done by means of simulated rainfall (f_c).

Fig. 11. Relationship between the steady-state infiltration rate (mm h^{-1}) measured by means of ponding (ifc) and simulated rainfall rate (fc). Group a consists of the bare soils and group b consists of the vegetated soils.

3.5. Relationship between measurements by ponding (ifc) and simulated rainfall (fc)

The relationship between the steady-state infiltration rates measured by means of ponding and simulated rain is positive, although the variability is large (Fig. 11). Generally, two groups of samples can be distinguished. Group a consists of samples taken at the south-facing slope with no or little vegetation. They show infiltration rates lower than the second group (b), both for ponding as well as for simulated rain. Group b consists of samples taken at the vegetated soils, where fc and ifc are very high. In group b, 90% of the cases have ifc values lower than 200 mm h^{-1} and the fc values are always lower than 50 mm h^{-1} .

On average, ifc is 8 times higher than fc . The ratio (ifc/fc) is different for each soil type: 5.7 times for the bare soils and 9.3 times for the vegetated ones.

4. Discussion

The steady-state infiltration rates measured at the Keuper clay soils are high for both ponding and simulated rainfall. From the point of view of runoff generation, the water discharge is small. Infiltration rate is always more than 60% of the rainfall rate. Runoff does not occur on the north-facing slope during the dry season, and is negligible during the wet seasons. Also, the upper part of both slopes, afforested by *Pinus halepensis*, has negligible runoff. Direct surface runoff (Hortonian overland flow) is not important for thunderstorms with a return period of up to 10 years, except for the bare surfaces located on the south slope.

On the south-facing slope, the medium and lower parts are affected by accelerated erosion, and badland morphologies have developed. Infiltration is smaller than in the vegetated soils, but in comparison to measurements by other researchers in similar landscapes the rates of infiltration are greater (Bryan and Yair, 1982; Campbell, 1987; Payà and Cerdà, 1992; Cerdà, 1995).

Fig. 12. Seasonal changes through the year of the steady state infiltration rate distinguishing between bare and vegetated soils.

Similar influence of vegetation, aspect and slope position has been found when the process is measured by ponding. The cylinder method seems to be appropriate, but the amount of measurements must be larger due to the large spatial variability of the infiltration process (Berndtsson and Larson, 1987). This is why the results for the seasonal changes of infiltration are slightly different when measured by ponding compared to rainfall simulator.

The seasonal changes show that larger infiltration occurs in summer, for all soil types and slope locations. The autumn displays the lowest infiltration capacity. During autumn, winter, and spring, the infiltration process has a similar behaviour due to the large moisture amount. On average, winter and spring infiltration is 10% lower than in summer. In autumn it is 25% lower. Similar work done in forested soils by Johnston and Beschta (1981) using a rainfall simulator (Meewing, 1969) and a plot of 0.3 m², found 50% less infiltration in autumn compared to summer. The higher rainfall intensity used by Johnston and Beschta (1980, 1981) explains the higher differences in western Oregon compared to southeast Spain. Climate and soils also are different.

Other authors have found similar trends: summer is the season with greater infiltration rates both in natural semi-arid soils and in agricultural fields (Beutner et al., 1940; Borst et al., 1945; Horner and Lloyd, 1940). Normally, the highest infiltration rates were found during the dry and hot season or at the end of the spring (Gifford, 1972), increasing from spring to summer and decreasing from summer to autumn (Bertoni et al., 1958), reaching the maximum in late summer. Some authors found that land management practices (Gifford, 1972) control the seasonal changes of infiltration rates due to the addition of organic matter to the soil, plant growth, and the activity of soil fauna and flora.

In this study, the soil moisture regime was shown to be the most important factor. Although plants, and especially herbs, reduce the spatial aerial biomass due to the summer drought and the microbial biomass decrease in summer in the Mediterranean environment (García Álvarez and Ibáñez, 1994; A. García Álvarez, pers. commun., 1995). The reduction of soil moisture allows the rain to be stored easily, and the cracks favour a deeper infiltration.

To summarize, the Mediterranean landscapes with contrasting aspects and Keuper clays present seasonal changes of the infiltration rate throughout the year as shown in Fig. 12. The highest infiltration rates occur during summer and the lowest during the wet seasons,

especially in autumn. The lowest rates were found in the bare soils on the south-facing location, which have the highest variabilities throughout the year. During the wet season, drying cycles are more active in the bare soils, which implies that cracking of the surface can occur, thus increasing the infiltration rates.

5. Conclusions

Except for aspect and slope position, seasonal changes play an important role for infiltration rates in the semi-arid environment. During summer, the infiltration rates are high, no runoff could be observed for the vegetated soils, and the runoff rates were only 10% of the rain on the bare surfaces located in the south-facing slope. During the wet season, especially in autumn, the infiltration rates reduced, and the runoff increased to 30% of the rain on the bare surfaces. In the vegetated surfaces, runoff was still negligible.

Measurements by means of both ponding as well as simulated rainfall are suitable to study the infiltration process. The first one, due to the small observation area needs more replications to measure seasonal changes. For spatial variability in a basin, however, this method is appropriate. The second method is suitable to study seasonal changes and the spatial variability due to the larger covered surface, and the same plot can be used during different seasons.

From the simulated rainfall measurements a model of seasonal changes of soil infiltration rates was established. For the vegetated soils, infiltration is constant throughout the year, runoff does not exist in summer and it is negligible in winter, spring and autumn. For the bare soils, located on the south slope, infiltration is high in summer, while in the wet seasons it is slightly lower and characterized by fluctuations depending on the climate. Autumn is the season with smaller steady state infiltration rates due to the higher soil moisture contents. The spatial variability of the infiltration rates at basin scale are different at each season, being greater in summer compared to spring, autumn and winter.

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